Improving collaboration with Raketeer

Development of a serious game with multi-touch interaction for teaching children with PDD-NOS collaboration

- Master Thesis -

Master Human Machine Interaction
Department of Artificial Intelligence

Maarten van Veen
mvanveen@ai.rug.nl

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Internal advisors:
dr. F. Cnossen
Artificial Intelligence
University of Groningen

External advisors:
A. de Vries MSc
TNO Information and Communication Technology
Groningen

Abstract

In 2005 a set of educational renewals were introduced in The Netherlands under the common name “new learning”. These renewals advocated problem-driven education where students solve problems in project groups with little assistance of a teacher, using peer consulting and collaboration.
Children with an autism spectrum disorder (ASD) and specifically children with pervasive developmental disorder- not otherwise specified (PDD-NOS) have great problems with the educational renewals. These children have difficulty with working in groups, collaboration and taking initiative, which are the prerequisites to “new learning”. As a result, a lot of children who formerly attended a regular school now have to go to a school for special education because they no longer fit in.
To allow these children to have a chance at transferring to a regular school it is very important they learn how to work in groups. Learning to collaborate is also important for their furthermore education as well as for their future working life.
To teach children with PDD-NOS how to collaborate, a serious game with multi-touch interaction was developed. The use of multi-touch technology allows for two (or more) children to work on the same computer and screen at the same time. It also provides a fun and intuitive way of interacting.
The game that was built consists of six levels with different mathematical problems designed to learn specific basic parts of collaboration. Two players start out at level 1 with each their own part of the screen and their own equations. Playing through the game they have to collaborate increasingly with each other. The theme of the game is about building a rocket and the math problems are in that context. The players have to collect rocket parts, collect inventory, mix fuel and protect their rocket until it can be launched successfully.
For four weeks the game was tested at an elementary school for special education. Observations and game data showed that children improved considerable during play and teacher ratings showed improvements of their collaborative skills in the classroom. However, the teacher interviews showed no or little transfer of skills to the classroom.
Teachers may have judged the children more on their overall social skills whereas the teacher ratings were about more specific skills.
To provide more conclusive evidence on the use of a serious game with multi-touch interaction for teaching children collaboration a larger study is necessary. Furthermore, a longer period of use is probably necessary to accomplish a transfer to the classroom and more in general: to real life.

Contents

Introduction 9

Autism 9

PDD-NOS 9

Dutch economy and educational system 11

Thesis overview 12

Teaching collaboration 13

Collaboration 13

Teaching social interaction 13

Central Coherence Theory 14

Theory of Mind 14

Social skills intervention 16

Social training programs 17

Teaching social interaction summary 18

Serious games 18

Game theory 19

Serious game definition 19

Designing serious games 19

Examples of serious games 21

Serious games summary 24

Multi-touch 24

Collaborative multi-touch serious game 26

Research question 27

Preliminary survey 28

Collaborative skills 28

Educational requirements 28

Game design 30

Game story 30

Level 1 – collecting rocket parts 31

Level 2 – collecting rocket parts together 31

Level 3 – counting passengers 32

Level 4 – collecting rocket inventory 33

Level 5 – mixing fuel 34

Level 6 – defending the rocket 34

Implementation 36

Hardware 36

Software 37

Tracker 37

TNO WPF multi-touch framework 37

Raketeer 37

Testing Raketeer 38

Setup 38

Participants 38

Procedure 38

Method 39

Child experiences 39

Behaviour during play 39

Transfer to the classroom 40

Results 41

Observation about playing 41

During play 42

Play time and progress 42

Math points 43

Buddy bonus 45

Observations 47

Teacher interviews 48

Transfer to classroom 49

Teacher ratings 49

Teacher interviews 53

Child experiences 54

Math games card-sorting task 54

Children interviews 54

Raketeer levels card-sorting task 55

Teacher experiences 56

Discussion **58**

References **61**

Appendix A **64**

Appendix B **65**

Appendix C **67**

Appendix D **69**

Appendix E **71**

I

Introduction

1.1. Autism

Autism is a neurological developmental disorder characterised by problems with social interaction, communication and imagination. The consequences are a limited and repetitive pattern of interests and activities (American Psychiatric Association, 2000).

Autism is a heterogeneous disorder with symptoms of varying severity. The term autism spectrum emphasises that symptoms range from singular developmental disorders such as ADHD (Attention Deficit Hyperactivity Disorder), ADD (Attention Deficit Disorder), specific disorders such as Rett's syndrome, CDD (Childhood Disintegrative Disorder) and Asperger's syndrome to very severe (multiple) developmental disorders such as the autistic disorder also known as classic autism.

Autism usually starts in the first three years of life, although social deficits may not be obvious until a child becomes more mobile or when surrounding typically developing children become more socially sophisticated (Lord, Cook, Leventhal & Amaral, 2000). While some social abilities may be intact, deficits can occur in the most basic areas of social development such as a child who can recite the alphabet but does not react to the calling of his name.

Most people with autism only rarely form ordinary, reciprocal friendships. In their adult life very few people with autism can function in a normal job and most depend on supported work programs.

1.2. PDD-NOS

Right in the middle of the range of the autism spectrum is a group of disorders without clear borders known as PDD-NOS (Pervasive Developmental Disorder – Not Otherwise Specified). Field trials performed by Volkmar, Klin, Siegel, & Szatmari (1994) found PDD-NOS is the most common disorder of the autistic continuum.

The DSM-IV-TR (American Psychiatric Association, 2000) describes PDD-NOS as follows: "This category should be used when there is a severe and pervasive impairment in the development of reciprocal social interaction associated with impairment in either verbal and non-verbal communication skills, or with the presence of stereotyped behaviour, interests, and activities, but the criteria are not met for a specific Pervasive Developmental Disorder, Schizophrenia, Schizotypal Personality Disorder, or Avoidant Personality Disorder."

As the description from the DSM-IV-TR and the last part of the name suggests, PDD-NOS is a leftover group. Children with PDD-NOS do not fully meet the criteria of any of the disorders from the autism spectrum, but do have problems with social interaction and communication and have stereotypical behavioural patterns and interests. Children with PDD-NOS actually have the same disabilities as any of the other disorders but some of the symptoms are less intense or are not present. A child can be diagnosed with PDD-NOS when it has impairments in two of the three autism domains as described by the DSM-IV-TR: social interaction, communication and stereotypical behaviour.

The problems with social interaction of children with PDD-NOS are not about the quantity, but about the quality of the interactions (Vermeulen, 2002). Especially the reciprocity of interaction is a problem. The criteria for impairments in the social interaction as described by the DSM-IV-TR include: (1) marked impairment in multiple non-verbal behaviour such as eye-to-eye gaze, facial expressions, body postures, and gestures to regulate social interaction; (2) failure to develop age-appropriate peer relations; (3) lack of spontaneous seeking to share enjoyment, interests, or achievements; and/or (4) lack of social or emotional reciprocity (American Psychiatric Association, 2000). To diagnose a child with, for instance Asperger’s syndrome, two of these criteria have to be met. However for PDD-NOS there are no guidelines on the number of criteria necessary for a classification. Also a child can be diagnosed with PDD-NOS even when he/she only has impairments in the two other domains: impaired communication and stereotyped behaviours.

Buitelaar, Van der Gaag & Klin (1999) used data from the DSM-IV field trial to come up with more specific guidelines for the diagnosis of PDD-NOS. For this field trial, extensively described by Volkmar et al. (1994), clinicians assessed 977 children with either an autistic disorder or another disorder that would reasonably include autism in the differential diagnosis. The study was designed to collect data on individuals with autism that would represent the range of syndrome expression of the condition, that is, from pre-school to young adulthood and with intellectual levels from the profound range of mental retardation to normal IQ.

Through a series of 2 x 2 contingency table analysis was examined which criteria from the DSM-IV-TR (American Psychiatric Association, 2000) and the ICD-10 (World Health Organisation, 1992) significantly discriminated between the diagnostic groups: Autism, PDD-NOS and non-PDD.

The analysis showed that a total of three or more items from the social interaction, communication and repetitive behaviour domain including one from the social interaction domain produced the best balance of sensitivity and specificity, resulting in the most optimal classification of PDD-NOS. Furthermore Buitelaar et al. (1999) concluded that the pattern of item endorsement supported PDD-NOS as a lesser variant of autism with impairments in social interaction as a key characteristic.

Impairments in social interaction make it very hard for children with PDD-NOS to work in groups and collaborate with peers. However group work and collaboration are key components of the educational renewals introduced in The Netherlands in 2005.

1.3. Dutch economy and educational system

The Dutch economy has increasingly become a knowledge economy and society in which knowledge has a central role. The economy makes the pursuit of innovation and globalisation of the economic activities matters of high importance. For workers this translates into a wider deployability and broader applicability of knowledge. This also sets new expectations on learning, education and educational support. Learning should not only result in factual knowledge but in wider competencies (Onderwijsraad, 2003).

In response to the changing expectations towards education a set of educational renewals were introduced in 2005 under the common name ‘het nieuwe leren’ or ‘new learning’. Key to the ideas of ‘new learning’ is that education should lead to insight and understanding. This led to problem-driven education where students have to work in groups using peer consulting and collaboration. Within these groups students have to solve realistic problems within their context. This will help them develop wider competencies and help understand why they have to learn certain material. The students follow their own knowledge strategy, set their own pace and determine their own progress. Furthermore peer collaboration will also help students to get a deeper understanding of the material.

Teachers from primary schools as well as teachers from secondary schools have however criticised the educational renewals. Teachers find it hard to stop lecturing and become tutors, and students complain about the lack of guidance. In a hearing of the Dutch parliament in 2008, professor Jolles of the University of Maastricht and Crone from the University of Leiden provided support for the criticisms based on neurological brain studies (Tweede Kamer, 2008).

Research during the 1970s revealed that some brain areas, in particular the prefrontal cortex, continue to develop well beyond childhood. During puberty and early adolescence the efficiency of the prefrontal cortex is low (Blakemore & Choudhury, 2006). There is an excess of synapses that have not yet formed specialised networks and the forming of myelin, which acts as insulation and dramatically increases the transmission speed, is ongoing. Imaging and lesion studies have found the prefrontal cortex is important in higher cognitive abilities such as planning, organising, decision-making and cognitive control (Fuster, 2001). Also the development of the prefrontal cortex is believed to play a key role in the maturation of these higher cognitive abilities (Hare & Casey, 2005; Casey, Jones & Hare, 1997).

According to Jolles and Crone it is wrong to expect from students that they are able to learn and make choices on their own while their prefrontal cortex is not fully developed yet. Students need guidance in planning and setting their goals. At the end of their education students should be able to work independently and make their own choices. However they still need a teacher who can help them with difficult choices and can give knowledge and inspiration during their education.

A group that especially has problems with ‘new learning’ is that of children with an autism spectrum disorder (ASD). Exactly the skills these children have a difficulty with, such as working in groups, co-operation and taking initiative are prerequisites to ‘new learning’. As a result a lot of children, who formerly could go to a regular school with some extra attention, now have to go to a school for special education because they can no longer fit in (Besseling et al. 2007).

1.4. Thesis overview

In this thesis, a study will be presented that aimed at improving collaboration in children with PDD-NOS. Better collaborative skills should allow these children a better chance in attending a regular school.

Chapter 2 reviews the literature on teaching social interaction. Social interventions and training programs for children with PDD-NOS are discussed. Furthermore the use of serious games and multi-touch technology are discussed. Chapter 3 describes a preliminary survey on the requirements for building an educational game. In chapter 4 the design of the game that was built for this study is discussed. The implementation of the game and the software and tools used are described in chapter 5. Chapter 6 discusses the methods used for testing the game at an elementary school for special education. Chapter 7 reports on the results of the tests. And in chapter 8 the results are discussed and a conclusion is presented.

2

Teaching collaboration

Learning to collaborate is very important for children with PDD-NOS; without collaboration they have little chance of transferring to a regular school.

This chapter starts with a discussion of research on collaboration. Section 2.2 discusses literature on teaching collaboration and social skills. Furthermore serious games and multi-touch technology will be discussed as a means to teaching collaboration.

2.1. Collaboration

The word “collaborate” is derived from the Latin “collaborare” which means, “to labour together”. The Oxford American Dictionary describes collaboration as “The action of working with someone to produce or create something”.

Kraus (1980) gave a more specific definition. He described collaboration as “a co-operative venture based on shared power and authority. It is non-hierarchical in nature. It assumes power based on knowledge or expertise as opposed to power based on role or function”. In his description, Kraus (1980) emphasises the equality of the individuals. They have to solve problems and make decisions together. Furthermore, their position in the group is based on their knowledge and expertise, instead of, who they are or what function they have.

Although there is sufficient literature describing the use of collaboration in a particular work field such as collaborative learning (Dillenbourg, 1999), collaborative design (Kvan, 2000) and collaborative planning (Healey, 1997), little research has been done describing the basic skills needed for effective collaboration.

Section 3.2 describes a preliminary survey in which teachers for special education and educational advisors were consulted on the specific problems children with PDD-NOS have with collaboration.

The next section discusses literature on teaching social interaction, as literature on teaching collaboration could not be found.

2.2. Teaching social interaction

Literature on teaching collaboration is scarce, however there is literature on teaching social interaction and social skills that will be discussed.

This section describes literature on various treatments: intervention based on theories of ASD, intervention on specific skills and group training.

2.2.1. Central Coherence Theory

The two most important theories on the cause of ASD are the Central Coherence Theory and the Theory of Mind (ToM) (Vermeulen, 2002).

Typically developing children and adults process incoming information for meaning and gestalt (global) form, often at the expense of attention to details and surface structure. Frith (1989) termed this tendency “central coherence” and hypothesised children with ASD have a “weak central coherence”.

The Central Coherence Theory considers the problems with social interaction as a malfunction in central information processing. According to this theory, children with ASD are not able to integrate the information they perceive into a meaningful whole (Frith, 1989).

Original suggestions of a core deficit in the central information processing have later been revised (Happé & Frith, 2006). Rather than a core deficit in the processing it is currently believed individuals with ASD process information with a bias towards local or detail-focused processing over global processing. When explicitly required to do so, children with ASD can process for global meaning.

The bias towards local processing means children with ASD do not construct an overview of the information they perceive. Inherently they are not able to discriminate between the principal case and the side issues, causing them to come to improper or incomplete conclusions. Furthermore the local processing bias is believed to disrupt facial recognition and reduce the context-sensitive interpretation of social utterances.

The inability to construct coherence not only has consequences for social interaction and communication but also for the learning process of these children. Most learning strategies are based on the idea of presenting different forms of a problem, to allow the learners to develop a general solution or system to solve a type of problem. However individuals with ASD find it hard to generalise. They are likely to perceive two similar problems with only one bit different as two totally different problems. This means they are unable to develop a general solution or system on their own.

A major limitation to the coherence account, to date, is the lack of specification of the mechanism. In their review, Happe & Frith (2006) discuss several computational and neural models that may suggest possible cognitive and neural bases for weak coherence. However imaging studies of individuals with ASD have not been able to confirm these models.

Related to the central coherence theory is the Theory of Mind (ToM). ToM is the ability to assign mental states to others and oneself.

2.2.2. Theory of Mind

At approximately the age of four, children start to develop a ToM. They start to realise other people can think and feel differently than they do. Gradually they develop the ability to empathise with the emotions of others. Eventually the child learns to do predictions about the intentions, emotions and plans of others.

Baron-Cohen, Leslie & Frith (1985) showed ToM is not well developed in children with ASD. The study used the, now classic, Sally-Anne false belief task. There are two dolls, Sally and Anne, a basket, a box and a marble. Sally places her marble in the basket. Sally leaves the room. Anne takes the marble out of the basket and places it in the box. Sally enters the room. The experimenter asks the child where Sally will look for the marble.

Typically developed children will know Sally believes the marble is still in the basket and will look for it there. In the study of Baron-Cohen et al. (1985) sixteen of the twenty children with ASD failed the false belief task answering Sally would look in the box. In contrast, only four of the 27 typically developed children failed the false belief task.

Begeer, Rieffe & Terwogt (2005) used a false-belief task with a reward and a no-reward condition. The child has to perform two easy tasks: solve a puzzle and record a story on tape. In the reward condition the children are told about a reward for successfully completing the two tasks. The experimenter leaves the room. The assistant of the experimenter takes two items essential to the tasks: a piece of the puzzle and the tape necessary for the recording of the story. The experimenter enters the room and prompts he wants to start the tasks. The number of prompts needed from the experimenter before the child started to resist was counted.

A control group, a group of children with ASD and a group of children with PDD-NOS performed the false belief task in both conditions.

Results showed the children with ASD were slower than the children from the control group. An interesting finding was that the children with PDD-NOS showed equal performance to the control group in the reward condition, however performed slower in the no-reward condition. Begeer et al. (2005) hypothesised children with PDD-NOS do have the competence for ToM reasoning but did not use this knowledge as typical developing children would, because of their delay in social interactions.

The lack or disuse of ToM-reasoning means children with PDD-NOS are unable to integrate information for higher-level understanding, resulting in poor social understanding and problems in social interaction. They are not able to empathise with others and unable to understand figures of speech.

Studies that tried to teach autistic children ToM principles had mostly negative results.

Ozonoff & Miller (1995) tried to teach non-retarded children with ASD ToM principles through social group training. The study had a treatment versus control design with five boys in the treatment group and four boys in the control group.

The treatment group participated in weekly meetings for a period of four and a half months. Each session consisted of casual conversation, trainer modelling and participant videotaped role-playing. The training program was divided into two units. The first unit discussed interaction and conversational skills. The second unit focused on perspective taking and first and second order ToM skills.

Before and after the training sessions the children performed a series of ToM tests. Furthermore, the parents and teachers rated the children on their social behaviour.
Although the training program showed substantial improvements on several false belief tasks the overall effects between the control and treatment groups were not significant. The parent and teacher ratings showed no or little effect as well. The magnitude of the group differences and the effect size, however, lead the experimenters to believe the intervention did have impact. Although the performance on the false belief tasks improved, it was the impression of the experimenters that the ability to translate these principles to everyday conversations and interactions remained limited.
Chin & Bernard-Opitz (2000) taught three boys with ASD conversational skills. On the basis of past research the experimenters argued that conversational skills, in particular, maintaining a topic of conversation require the understanding of mental states. The three boys received training in making a conversation, turn taking, listening, maintaining a topic and changing a topic appropriately. The experiment used four types of sessions: baseline, training, maintenance and generalisation sessions.
The children were evaluated through video recordings of the sessions. Nine students scored the video recordings on shared interest, contextually appropriateness of the response and the presence of ToM. Furthermore two first order false belief tasks and one second order false belief task were used.
The results showed that the children improved their conversational ability. The percentage of time spent in shared interest and the percentage of contextually appropriate utterances increased. Although the overall results were not significant the experimenters mentioned the caregivers did notice improved eye contact, turn taking and holding a topic of conversation.
However the children's performance on the false belief tasks did not change.

Both the Central Coherence Theory and the Theory of Mind are helpful in explaining the problems children with PDD-NOS have with social interaction however they are not able to provide a basis for improvement. Because of this, most studies on social intervention focus on improving problematic skills. This is the topic of the next section.

2.2.3. Social skills intervention

There is a vast amount of literature on social skills interventions for children with ASD. Typical social skills that have been the focus of treatment include eye contact, conversational skills (content and intonation of speech, number of words spoken and number of interactions), emotion recognition, understanding and prediction and social problem solving.
Bauminger (2002) did a seven-month trial with fourteen high-functioning children with autism. The children worked for three hours a week with their teacher on three topics: emotional understanding, social interaction and social problem solving. Twice a week the children also met with a peer and participated in social activities about the skills they learned while working with their teacher. Social problem solving and interaction were taught by using scripts and stories. Through these scripts and stories the children learned initiating a conversation with a friend, comforting a friend and sharing

experiences with a friend. The results showed improvements in emotional understanding, social interaction and social problem solving, but Bauminger (2002) questioned whether the improvements exceeded the learned areas and transferred to more global social competence.

LeGoff (2004) devised a LEGO© treatment program to improve the social competence of children with ASD. In his study he defined social competence as the total of three skills: (1) Initiation of social contact with peers, (2) duration of social interaction and (3) decreases in autistic aloofness and rigidity. 47 children waited at least twelve weeks (control condition) after which they attended one individual therapy session and one group session a week for a period of at least twelve weeks (experimental condition). The individual sessions were about developing communication and reciprocity as well as increasing self-efficacy and task focus through the building of LEGO© structures. The group sessions were about shared building and playing with LEGO©. The group session were structured by three set of rules: (1) LEGO© rules (e.g., “If you break it, you fix it”), (2) rules of conduct (e.g., “No climbing on the furniture”) and (3) social rules (e.g., “No teasing”). Results showed significant gains in the three measures of social competence.

Although there is a lot of literature on social skills intervention with components focusing on social interaction and peer involvement no literature could be found specifically discussing collaboration. The study concerning LEGO© therapy does illustrate the power of using toys and games for learning social interaction. When provided in combination with a structured environment, children with ASD find it fun to play together.

The next section describes social training programs used in The Netherlands.

2.2.4. Social training programs

There are a number of social skills training programs used in The Netherlands such as “Nietes-Welles”/No-Yes (Emmen & Plasmeijer, 1996), “Leren denken en leren begrijpen van emoties”/ Learn how to understand and think about emotions (Steerneman, 1995) and “Spelend leren, leren spelen”/ Playfull learning, learning how to play (Reenders & Spijker, 1996).

“Nietes-Welles” is the most used training program in The Netherlands. It is based on Skillstreaming (Goldstein, Sprafkin, Gershaw & Klein 1980) and adapted for children with ASD. The training consists of instruction and role-playing games and covers topics such as greeting adults and peers, listening and storytelling, controlling emotions and simple co-operation.

While “Nietes-Welles” does cover simple co-operation, this is only superficial. It does not teach the children how to really collaborate on a task.

Social training programs are usually given at separate clinics and are not part of the curriculum. In The Netherlands the parents of a child with ASD can influence the care their child receives. They can choose the school for the child and receive a fixed amount of funding that they can use to arrange additional care. However most social training programs are expensive and are not fully covered by the amount of funding the parents receive.

Furthermore, a study of Barry, Klinger, Lee & Palardy (2003) showed that social training programs given at separate clinics have the added difficulty of generalisation to a non-clinic setting. The study of Barry et al. (2003) examined the effectiveness of a clinic-based social training program for children with ASD. The children were taught social skills such as: greeting, conversation and play-skills.
Observations at the end of the training at the clinic indicated the training program was effective. However parent reports indicated only improvements in greeting skills. Barry et al. (2003) concluded generalisation to non-clinic settings is difficult and can pose an additional hurdle in teaching these children social skills.

2.2.5. Teaching social interaction summary

Section 2.2 reviewed literature on improving social interaction since no literature specific on teaching collaboration could be found. Studies trying to teach children ToM showed negative results. Furthermore theories on impaired social interaction could not provide guidelines for improving collaboration. Literature on social skill intervention showed positive results. However the focus of these social skills interventions was mainly on conversational skills, emotional skills and social problem solving and lacked collaborative elements. The LEGO© study showed playing games together can be effective in learning social interaction, although sufficient structure has to be provided. Literature on social training programs showed they can be beneficial, however they are expensive. Clinic-based training programs can reduce the overall effect due to difficult generalisation to non-clinic settings. Furthermore collaboration is only a small part of these training programs and no guidelines were provided.

The literature could not provide guidelines on teaching collaboration, so a preliminary survey was done. Section 3.1 describes the results of this survey in which special education teachers and educational experts were consulted on the problems children with PDD-NOS have with collaboration.

The next section describes the use of computer games in creating a fun and engaging learning experience.

2.3. Serious games

Most children find it fun to work with a computer at school. This is even more the case for children with PDD-NOS. School is a safe place, sheltered from the noise around and with a predictable setting, interaction and feedback. Working at a computer is very structured: a task needs the same steps to complete, every time. Furthermore the delivery of information is mainly visual, suiting these generally visually oriented children (Baltussen, Clijsen & Leenders, 2003).

2.3.1. Game theory

Only a few years ago, experts were questioning the appropriateness of multimedia and games as learning tools. Today major corporations and the military are relying on simulations to train new employees and even prepare soldiers for war zone action. But teachers still find the idea of using games as an instructional resource controversial. However games embody well-established principles and models of learning (Van Eck, 2006).

Play is a primary socialisation and learning mechanism used by both humans and animals (Salen & Zimmerman, 2003). Kittens for instance, practice attack skills through pretend-play and modelling. Their mother doesn't learn them to hunt through direct instruction. Games make use of the same principles of modelling and play as an instructional strategy. In games the learning takes place within a meaningful (to the game) context. What a player must learn is directly related to the environment in which he learns and demonstrates it. This type of learning is more effective than learning that occurs outside its context such as most formal instruction. This principle is referred to in the literature as situated cognition.

According to Piaget's theory (1962) children learn by encountering a cognitive disequilibrium. When retrieving new information a process of assimilation tries to fit this information in existing slots. When this new information does not fit, there are contradictory beliefs and through a process of accommodation, the existing model of the world has to be changed to fit the new information. According to Van Eck (2006) games embody this process of cognitive disequilibrium and resolution. Playing a game requires a constant cycle of hypothesis formulation, testing and revising.

2.3.2. Serious game definition

There are a lot of commercial simulation and role-playing games such as Civilisation® and Dungeons and dragons® that embody the above-mentioned learning principles. Games specifically build to deliver engaging learning experiences on a variety of topics are so-called serious games.

Michael and Chen (2005) give the following definition of a serious game: 'A serious game is a game in which education (in its various forms) is the primary goal, rather than entertainment'.

Injecting educational content into a game may take the fun and play out of the game.

The next section confronts these problems and discusses literature on designing serious games.

2.3.3. Designing serious games

The problem in designing serious games is to find a balance between educational and play elements. Taking a successful game and 'academizing' it or 'gaming-up' existing educational software can result in so-called edutainment software. This software has, instead of harnessing the power of games for learning, resulted in what Papert (1998) calls "Shavian reversals": offspring that inherit the worst characteristics of both parents (in this case, boring games and drill-and-kill learning). This is software that may be educationally sound as learning tools but has failed as a game (Van Eck, 2006).

According to Garris, Ahlers & Driskell (2002) the key aspect of effective learning is motivation. Motivation is termed as the willingness or desire to engage in a task. Motivation refers to an individual's choice to engage in an activity and the intensity of effort or persistence in that activity. Motivated learners are more likely to engage in, devote effort to and persist longer at a particular activity. They are enthusiastic, focused and engaged.

Garris et al. (2002) considered several models of both intrinsic and extrinsic motivation and suggested the Input-Process-Outcome model (fig. 1).

The input of the model is instructional content (educational elements) and game characteristics (play elements). This input triggers a cycle of user judgements (i.e. enjoyment or interest), user behaviour (i.e. greater persistence or time on task) and system feedback. A successful balance of educational and play elements should result in recurring and self-motivated game play. The outcome should be the achievement of the training objectives.

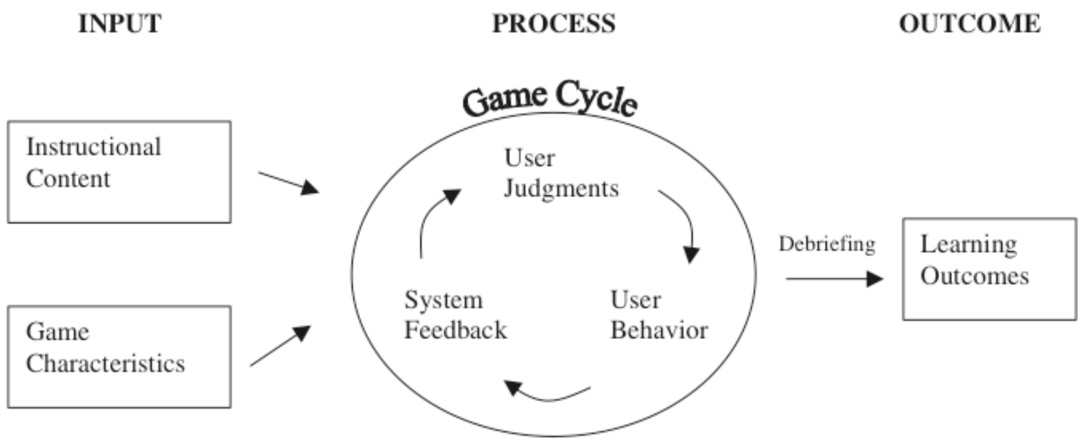

Figure 1. Input-Process-Outcome model by Garris et al. (2002).

Identifying the essential game characteristics is a subject of debate. Based upon a review of the literature Garris et al. (2002) suggested that game characteristics can be described by six broad categories: fantasy, rules/goals, sensory stimuli, challenge, mystery and control. The next sections give short descriptions of these categories.

2.3.3.1. Fantasy

Fantasy describes the use of imaginary or fantasy context, themes or characters. The use of fantasy worlds allows players to interact in situations that are not part of normal experience. They can explore these worlds without the real consequences of failure.

2.3.3.2. Rules and goals

Clear rules, goals, and feedback on progress toward goals can help the players to enhance their performance. They perceive goal-feedback discrepancies that are crucial in triggering attention and motivation.

2.3.3.3. Sensory stimuli

Games allow the players to experience a distortion of perception that stimulates and intoxicates the senses. Games can put the player into another reality with a mix of dynamic graphics and sound effects. Such an experience can be immensely gratifying and grabs the attention.

2.3.3.4. Challenge

Games should be challenging to the players. To accomplish this they should have an optimal level of difficulty: not to difficult and not too easy. Furthermore the player should be uncertain about whether he can meet his goals. Through performance feedback and scorekeeping the player can track his progress towards his goals.

2.3.3.5. Mystery

Mystery describes an optimal level of informational complexity. It is a human tendency to make sense of the world we are living in. We are curious about things that are unexpected or that we cannot explain. The optimal level of informational complexity lies between familiar information and information that is too confusing or bewildering to incorporate.

The optimal level of mystery provokes curiosity leading to enhanced motivation.

2.3.3.6. Control

Control refers to the ability of the player to regulate, direct or command. Active control leads to enhanced motivation even when the player regulates something of no importance. Games evoke a sense of personal control.

Although the categories by Garris et al. (2002) provide direction in designing an effective serious game they are not very specific. Section 3.2 describes a preliminary survey in which educational experts and game experts were interviewed to obtain more specific guidelines for designing an effective serious game.

As was mentioned earlier, large corporations and the military have seen the benefit of serious games and are using them to train their employees and prepare soldiers for battle. However there are not many serious games for primary and secondary school. The next section describes some examples of serious games for education with promising results.

2.3.4. Examples of serious games

Studies on the effectiveness of games as educational tool have consistently found they promote learning and reduce instructional time over multiple disciplines (Szczurek, 1982; Van Sickle, 1986; Randel, Morris, Wetzel & Whitehill, 1992). However the number of serious games available for primary, secondary or higher education is still limited. Some of the few examples are described in the next sessions.

2.3.4.1. Supercharged

Supercharged is a serious game designed by The Education Arcade, based in the MIT media studies program, to help students develop understanding of electrostatics. Players must navigate their ship through maze-like electromagnetic worlds. By changing the charge and placing it strategically, they can move the ship through space (fig. 2).

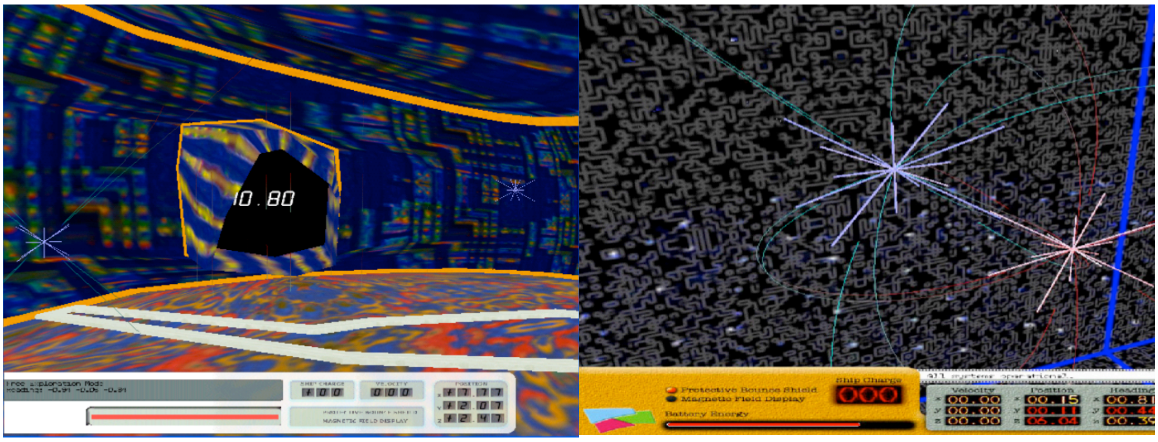

Figure 2. Screenshots from Supercharged.

Jenkins, Klopfer, Squire & Tan (2003) describe the use of the game in three middle-school classes of the Boston College. Compared to the students who were taught electrostatics through more conventional means, the students who used the game showed about twenty percent better scores on the electrostatics post-test. Furthermore interviews showed the students who had played Supercharged showed a deeper understanding of scientific visualisations and the principles of electromagnetism.

2.3.4.2. Environmental detectives

Environmental detectives is an outdoors game played by teams of students equipped with a GPS-enabled pocket pc (fig. 3). The students are “enlisted” through a video briefing from the University president to investigate the spill of a toxin. The students have two hours to locate the source of the spill, identify the responsible party, design a remediation plan and brief the University president on the health and legal risks. The students have to navigate to real locations on campus where they perform simulated field tests, consult with virtual colleagues and design solutions to the problems.
Environmental detectives was studied with high school and university classes at two locations. While the study is not extensively documented and does not seem methodological sound the results are promising. The researchers claim the game was effective in engaging students in the authentic practices of environmental engineers.

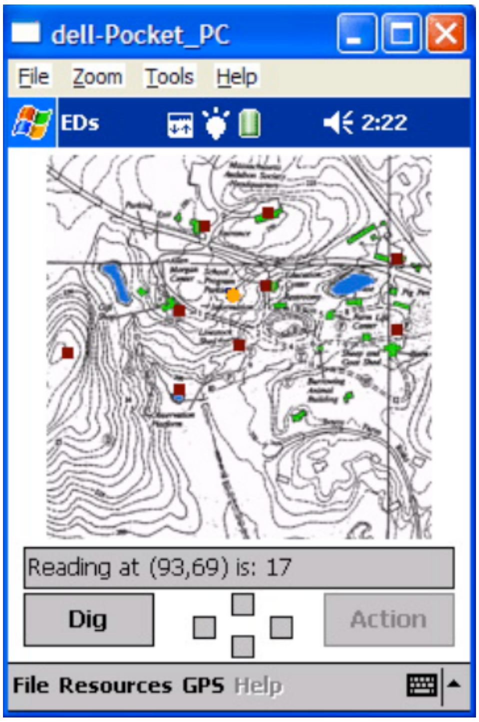

Figure 3. Screenshot from Environmental detectives.

2.3.4.3. River City

River City, developed by the Harvard graduate school of education, is a virtual world where students learn the skills of hypothesis formulation and experimental design with content from biology and ecology (fig. 4). River city is a virtual city populated by the students, the instructors and computer-based agents. The students have to work in teams to develop hypotheses regarding one of three strands of illness in the town (water-borne, air-borne or insect-borne). They can gain information by visiting the university or the museum and interviewing inhabitants of River City.

A large-scale test with eleven teachers and over 1000 students was conducted. Dede, Clarke, Ketelhut & Nelson (2005) found that students in the experimental condition improved their biological knowledge by 32 percent while the control students improved by only seventeen percent. Furthermore the students were highly engaged, attendance improved and disruptive behaviour dropped.

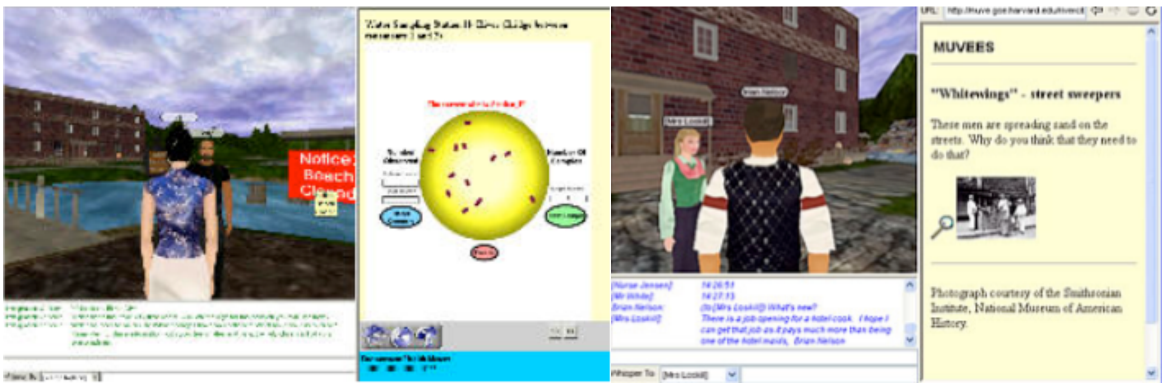

Figure 4. Screenshots from River City.

2.3.5. Serious games summary

Although major corporations have adopted games to train their employees, teachers are still hesitant to using games in the classroom. However the literature that was reviewed argued games embody well-established principles of learning. The three educational serious games that were discussed proved serious games can provide an engaging learning experience where students actually learn more.

Using a computer especially in combination with a serious game can be a strong tool in motivating children with PDD-NOS to study. However it is also antisocial. The child sits alone behind the computer, doing his/her task, without interaction with other children. Multi-touch technology can help overcome this problem.

2.4. Multi-touch

Traditional machine interfaces consisted of hard controls such as dials, switches, keys and pushbuttons. These hard controls promote easy learning as their form follows their function and they are operated with a one-to-one correspondence to their actions. However they are inflexible and not suited for complex tasks (Nakatani & Rohrlich, 1983). The use of computers allowed for soft controls in the form of graphical interfaces. These interfaces are flexible in that they can visualise the controls needed for a particular task. The use of menus allows for many controls in a little space making these interfaces better suited for controlling complex tasks. The downside of graphical interfaces is that they are operated symbolically through a keyboard and a mouse (indirect manipulation). There is no obvious relation between keys and buttons, and actions.

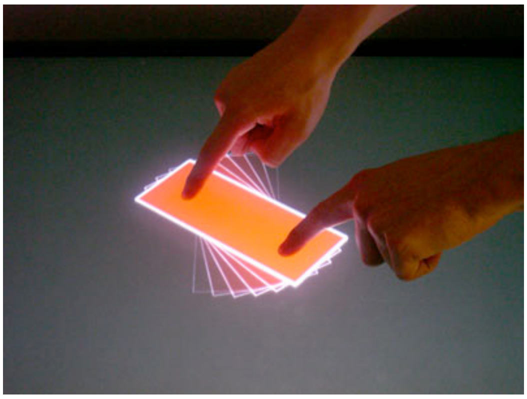

Figure 5. Rotating a virtual object with two hands on a multi-touch screen.

The use of a touch screen overcomes this problem as a user can touch the controls on the screen just as they would if they were hard controls (direct manipulation). This allows a more natural interaction while still benefiting from the advantages of a graphical interface. Multi-touch adds the ability of using multiple fingers and hands and enables natural gestures such as rotating (fig. 5) and pinching.

Inherently multi-touch also implies multi-user interaction as multiple users can use the screen simultaneously, enabling physical collaboration at a computer.

Multi-touch is a technology that has been around for some time but has only recently moved out of the research phase. Microsoft has just started sales of their Surface® tabletop but only to select companies and SMART, vendor of electronic whiteboards, will start sales of their SMART Table, a small multi-touch tabletop for primary schools. While these tabletops are becoming commercially available, the body of scientific literature is steadily growing with research focusing predominantly on the multi-user abilities of these tabletops, such as co-operative work and decision-making. Research regarding collaborative games on multi-touch tabletops is just starting to appear.

Gross, Fetter & Liebsch (2008) constructed a multi-touch table for exploring competitive and co-operative multi-player games. They developed a small Pong-like tennis game named Puh. Puh can be played with two to four players at the same time where players use two fingers to form a bat in their goal area. During three days some 100 players tested Puh in games of five to ten minutes. While no formal study was done, unstructured interviews and observations showed the emergence of co-operative behaviour. Some players taught other players how to play the game and some players of the same team started helping each other.

Piper, O'Brien, Morris & Winograd (2006) developed a game called Shared Interfaces to Develop Effective Social Skills (SIDES) (fig. 5). SIDES runs on a tabletop computer and is designed for teaching social skills to children with the Asperger's syndrome. It is a four-player puzzle game designed to increase collaboration and decrease competition. The game is about determining the optimal route for a frog over a raster board. By letting the route of the frog intersect with bugs and flies present on the board, the players can score points. Each user starts the game with nine tiles with arrows on them to determine the route. The players have to lay their tiles to form the optimal route of the frog together, from the start-lily to the end-lily. Once all tiles are on the board they can vote whether to test if the current route is the most optimal.

Figure 5. Screenshots from SIDES.

Observations of the first evaluation session of SIDES showed the players remained highly engaged in the activity and were excited by the novelty of the touch technology. They found the use of the touch-sensitive tabletop computer workable. The session outcomes also suggested that explicit game rules such as turn taking and piece ownership could help less-engaged and quieter players to be more involved.
Before the second evaluation session, computer-enforced turn taking and restricted access to game pieces was implemented based on the results of session one. The observation results of the second session showed, that the implemented changes encouraged co-operative group work. Although enforced turn taking and restricted access were turned off in the second session, the players kept working together.

The results of Gross et al. (2008) and Piper et al. (2006) show that multi-touch games can deliver engaging gaming experiences and can invite collaboration between players. Additionally, the SIDES study showed that a well-designed multi-touch game can help teaching children social skills by keeping them motivated and helping them to collaborate.

2.5. Collaborative multi-touch serious game

This chapter reviewed literature on teaching collaboration and social interaction, serious games and multi-touch technology. The combination of a serious game with multi-touch interaction for teaching children with PDD-NOS collaboration seems promising. The game aspect will provide a fun learning experience and stimulate the children to keep their focus and concentration throughout the game. It will allow for a structured and safe way of working together. The multi-touch screen makes it possible for the children to physically work together on the same computer. Additionally it will provide a more fun way of interacting with the game. The system as a whole should be an affordable and easy to use solution for schools to teach children with PDD-NOS collaboration.

Figure 6. Two children playing Raketeer on a multi-touch tabletop.

2.6. Research question

This study aimed at developing a serious game running on a multi-touch tabletop that is affordable and can easily be used by teachers in a school setting. The combination of a serious game with multi-touch technology should allow for an engaging learning experience of collaboration. The goal of the game was to teach children with PDD-NOS to collaborate in pairs with the use of a multi-touch tabletop.

The research question was formulated as follows:
How can a multi-touch-based serious game improve collaboration of children with PDD-NOS?
And is this improvement only showing while playing the game or is there also a transfer to the classroom?

3

Preliminary survey

The literature could not provide specific guidelines and requirements on developing a serious game for teaching collaboration, so a preliminary survey was done.
Interviews with teachers from schools for special education and educational advisors from the Regional Expertise Centre Northern Netherlands for behavioural problems (RENN4) were conducted. In these interviews the experts were questioned on specific problems children with PDD-NOS have with collaboration. Furthermore a project on using commercial games in primary education (Kennisrontonde) was contacted for best practices and guidelines.

3.1. Collaborative skills

As was mentioned in section 2.1 no literature could be found on the basics of collaboration. For identifying the practical problems, children with PDD-NOS have with collaboration, a series of interviews with teachers from school for special education and educational advisors were conducted. With these experts six basic collaborative skills were identified that these children have a problem with.

1. Waiting for their turn
2. Handling mistakes of the other
3. Receiving criticism
4. Sharing tasks and objects
5. Discussing a task with others
6. Realising one's action has implications for the other.

This research focuses on improving these six basic collaborative skills.

3.2. Educational requirements

In collaboration with the aforementioned educational advisors and two game experts from the Kennisrotonde project[1] the following educational requirements for the game were identified.

[1] http://www.kennisrotonde.nl

- Most information should be presented visually as children with PDD-NOS are generally of the visual type (i.e. they are visually oriented).
- The interface should be simple as the children are easily distracted and confused.
- Working towards collaboration should occur in small steps.
- Good behaviour and accomplishments should be rewarded.
- The game progress of the players should be comprehensible to the teachers.
- The game should feature real educational content from courses such as mathematics, language or history.
- The game should have variation in the game play or have multiple levels with different tasks.
- The level of difficulty should be adjustable for the game to be challenging to all players.
- Learning should take place in the context of the material that is being learned.
- The players should be able to compete with one another.

Chapter 4 describes the game that was built and how these requirements were implemented in the game.

4

Game design

The educational requirements and the six basic collaboration skills (see section 3.1 and 3.2) were combined into a game, called Raketeer. The game consisted of six levels in which the players have to solve equations and gradually learn to collaborate. The whole game was about building and launching a rocket and the equations are in that context. Although all six levels revolved around solving equations they were designed to teach the six basic collaborative skills defined in the previous chapter. To keep the players interested, each of the six levels had a different task to accomplish and had different game play.

At the start of the game each player choose a name and a character creating their own virtual identity. The teacher's rating of arithmetic level determined the level of the equations the players received to optimally challenge the players. The players were rewarded with math points and buddy bonuses. Each correctly solved equation was rewarded with five math points. An incorrect answer costed the player a math point. From level 3 on, players could also earn positive or negative buddy bonuses for collaborative behaviour.

Raketeer loged all the scores, all equations and the answers given. The game had a scoreboard where the players could evaluate their scores per level and could compare them with other players.

The design and interface of the game was kept clean and simple to avoid distraction and confusion. The use of auditory information was limited for the same reason.

Raketeer was played in games of four minutes and after each game, depending on the total score, a player could receive a promotion. However both players had to be promoted for them to be able to play the next level.

4.1. Game story

Raketeer is a company involved in space travel. When the players first start the game the boss of Raketeer explains the story. The players are hired by Raketeer to help build a rocket that can reach a newly discovered planet, called Verido. For the market position of Raketeer it is important to reach Verido before the competition does.

Through six levels the players have to collect parts for the rocket, collect inventory, mix fuel and defend their rocket to ensure its launch by solving equations.

4.2. Level 1 – collecting rocket parts

In level 1 the players have to collect parts for the rocket by solving equations (fig. 7). To enter a solution the players can adjust the green and orange dials by dragging one or more finger(s) over them. A correct answer is rewarded with a part for the rocket.

The goal of level 1 is to introduce the game, get comfortable with the controls and get used to working on the same machine with another player. The players start at level 1 with separate tasks. Each player has its own part of the screen and its own equations.

4.3. Level 2 – collecting rocket parts together

In level 2 the players again collect parts for the rocket by solving equations, however now they collect these parts together (fig 8).

The players stand next to each other and start working on the same goal. The players still have their own part of the screen and their own equations, but now collect components for the rocket together.

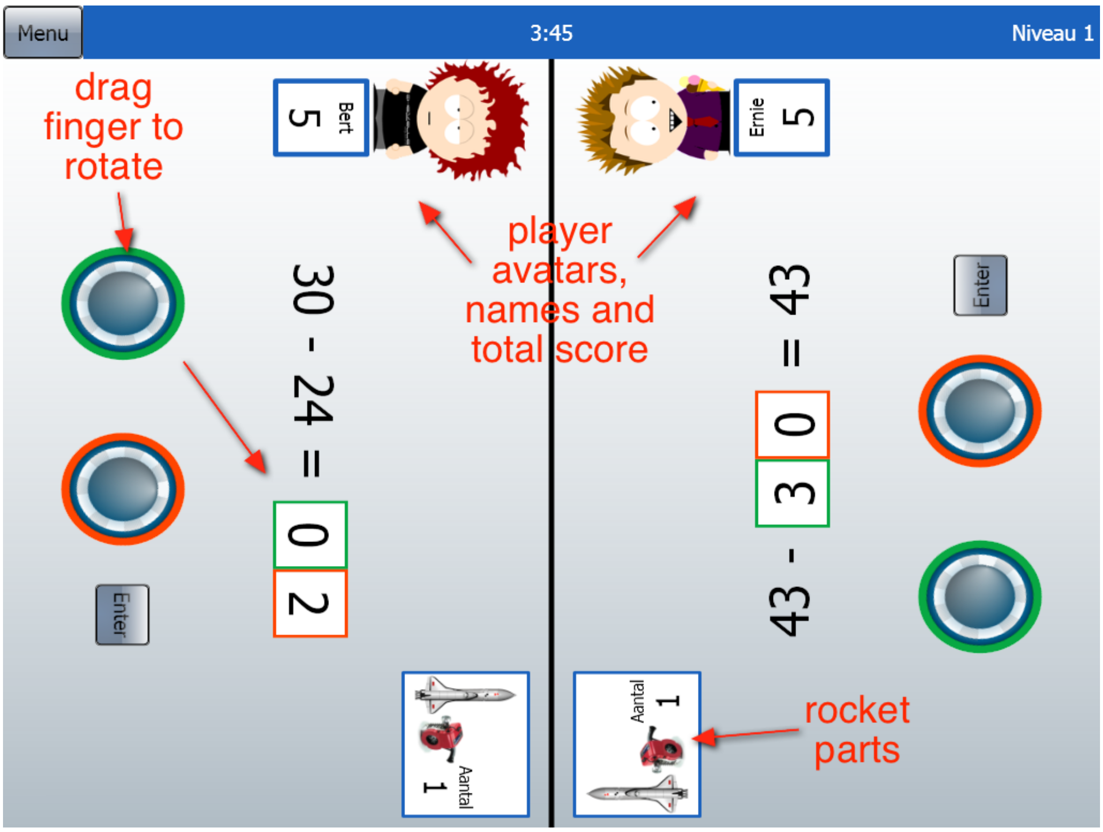

Figure 7. Level 1: Collecting rocket parts.

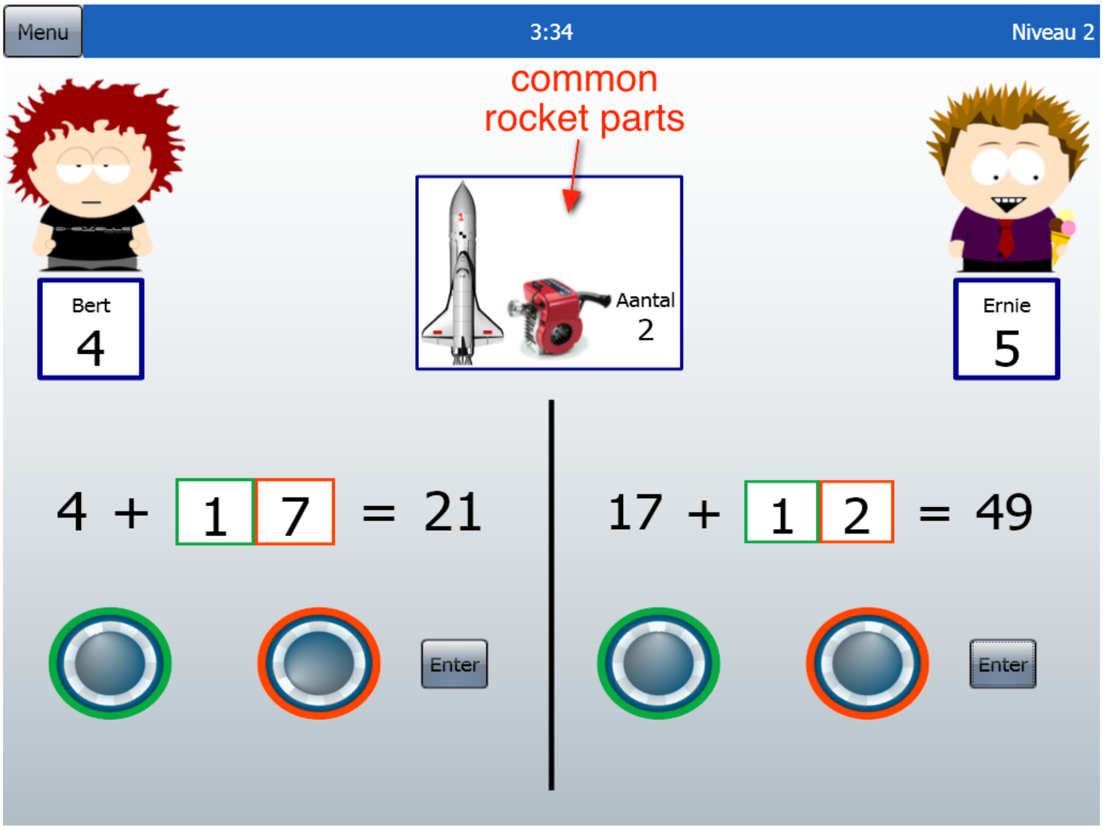

Figure 8. Level 2: Collecting rocket parts together.

4.4. Level 3 – counting passengers

In level 3 the players have to count the number of people working in the rocket so the boss can check for saboteurs and spies (fig. 9). The equations are composed of two parts: the left and the right side. The direction and the colour of the arrows indicate whether the passengers are exiting (subtraction) or entering (addition) the rocket. A green arrow pointing towards the rocket indicates passengers are entering the rocket. An orange arrow pointing away from the rocket indicates passengers are exiting the rocket. The equation pictured in figure 6 is 4 – 3 + 4.

The goal of level 3 is to teach the players to wait for their turn. The players are both presented with the same four possible answers to the equation. A green square indicates whose turn it is. Answering before your turn results in a negative buddy bonus and waiting for your turn is rewarded with a positive buddy bonus. The turn is chosen at random with an 'emax' maximum of consecutive turns. The 'emax' parameter is set depending on the player's total score at level 3. So as the players get higher total scores, they are provoked with an increasing possible waiting time.

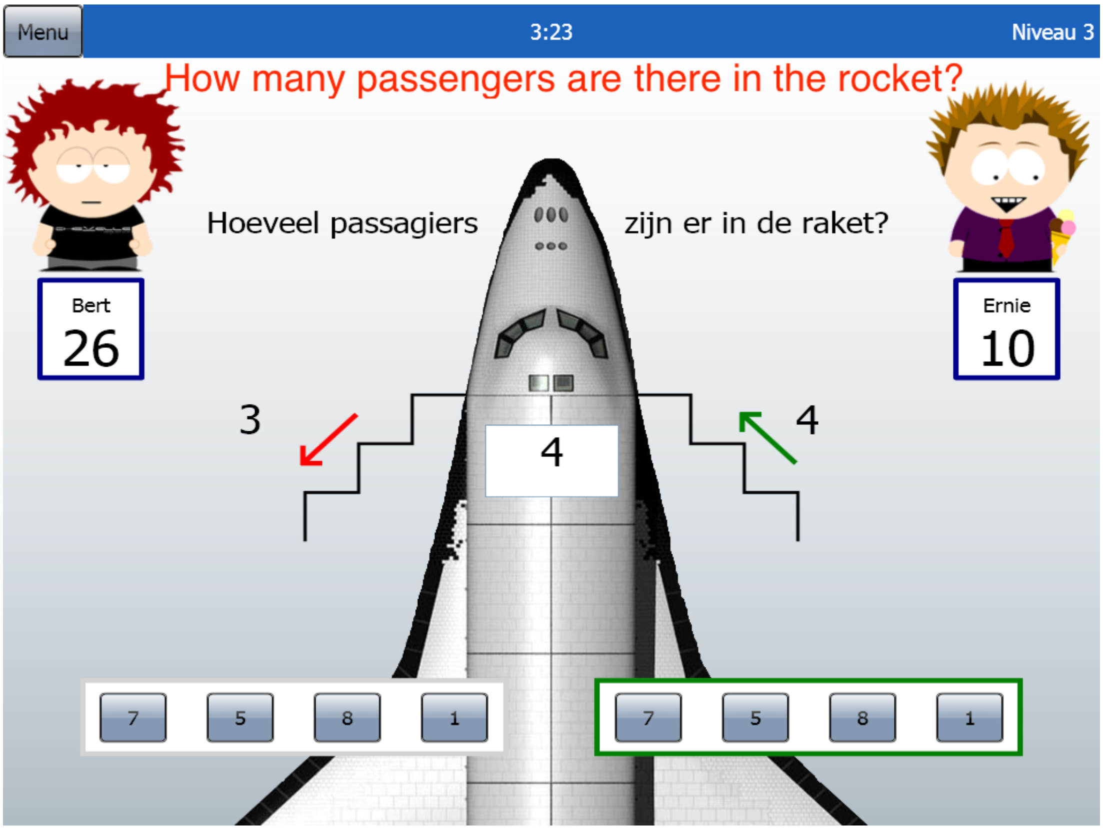

Figure 9. Level 3: Counting passengers.

4.5. Level 4 – collecting rocket inventory

At level 4 the players have to collect items for the first flight of the rocket (fig 10). The players have to solve equations to earn items. To finish level 4, the players have to collect ten pieces of ten items. The players can collect four different items at the time. Starting the level these four items are selected at random and showed in the green collection box of each player.

The goal of level 4 is to share items and to pay attention to the other player's task. When a player earns an item he can keep the item by dragging the item over his collection box or give the item to his buddy (the other player) by dragging it to the share box in the middle of the screen. However keeping an item the player currently does not collect or sharing an item his buddy currently does not collect wastes the item. So the players have to decide whether or not they want to share and monitor the other player's collection box.

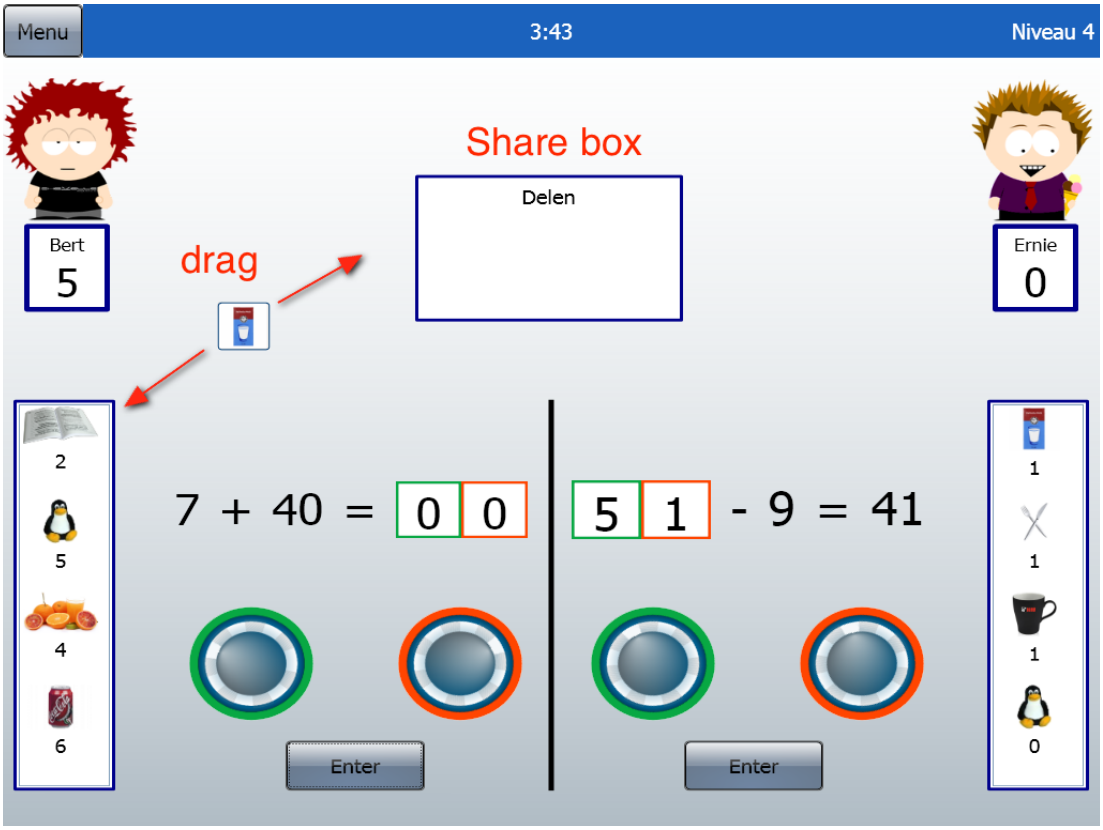

Figure 10. Level 4: Collecing rocket inventory.

4.6. Level 5 – mixing fuel

Starting level 5 the rocket is finished and the players can admire what they have accomplished. But now they have to mix fuel for the first launch (fig. 11).

The goal of level 5 is to perform a task together while communicating. The players have to make up an equation with the given sign and answer in the mixing bowl. The players have to decide on a solution together (depending on the equation multiple solutions are possible) and turn the dials accordingly to mix the fuel. Here they really have to collaborate to perform well.

4.7. Level 6 – defending the rocket

The rocket is finished and fuelled up, but the competition is trying to destroy the rocket before it can launch (fig. 12). The players have to shoot down incoming missiles before they hit their rocket.

The goal of level six is to perform two tasks at the same time, together, while under pressure. The players have to solve equations to earn shots, which can than be used to shoot down incoming missiles by touching them. After the players have finished level 6 the outro movie shows the rocket being launched. Afterwards the boss congratulates the players on their terrific job.

Figure 11. Level 5: Mixing fuel.

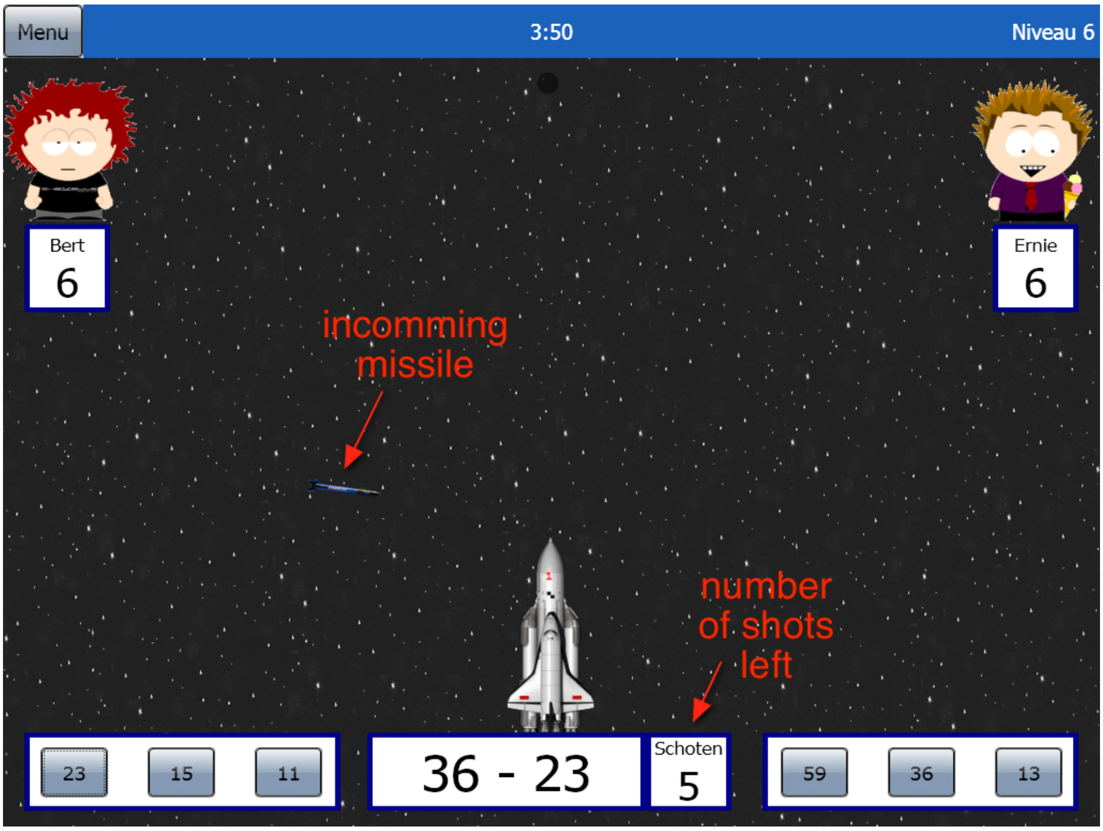

Figure 12. Level 6: Defending the rocket.

5

Implementation

This chapter describes the hardware and software that make up the Raketeer game.

5.1. Hardware

The set up consists of a prototype NUI multi-touch table with a standard desktop computer and speakers attached to it that are fitted in the table. The NUI multi-touch table uses the principle of Frustrated Internal Reflection (FTIR) to register touches as proposed by Han (2005). Figure 13 shows a schema of the multi-touch screen. The surface of the screen consists of an acrylic pane. Infrared lights surrounding the edge illuminate the pane. The principle of FTIR dictates that the light will bounce around in the pane until the external surface is frustrated. When a finger touches the pane the external surface is frustrated at the point of the touch and the light no longer travels through the pane but scatters outwards. An infrared video camera positioned below the surface is able to capture the infrared light escaping the pane. Through image processing the position of the touches can be determined from the images of the video camera. The addition of a diffuser allows for a projector, also positioned below the pane, to project an image onto the touch surface. By using infrared tracking lights the visible image from the projector is not disturbed by the tracking lights allowing for the touch surface and the projection surface to be the same surface.

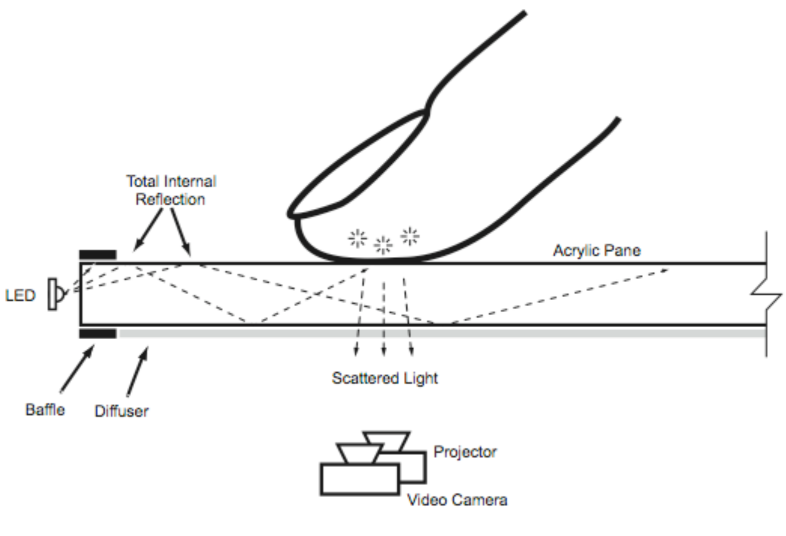

Figure 13. Schema of a FTIR multi-touch screen (Han, 2005).

5.2. Software

The computer has Windows XP from the Microsoft Corporation installed. The additional software can consists of three layers: the tracker, a framework and Raketeer.

5.2.1. Tracker

Tbeta is an open source cross platform for computer vision and multi-touch tracking. This software was used to interpret the images from the video camera and extract touch data. A filter was used to remove background noise, the signal was amplified and a threshold was used. The tracker broadcasts the touches through a server utilising the TUIO protocol (for more details see Kaltenbrunner, 2005).

5.2.2. TNO WPF multi-touch framework

TNO has built a framework that makes the touches available within the Windows Presentation Foundation (WPF) by the Microsoft Corporation. The framework connects to a TUIO server (the tracker) and converts the touches to touch events accessible through a touchmanager class. This way any WPF object or control can be fitted with a touchmanager and be made touchable.

5.2.3. Raketeer

While a lot of the development of multi-touch applications occurs in Adobe Flash, Raketeer was created using WPF. This is because WPF is a more powerful and faster programming language and TNO had already built a framework allowing for the handling of touch events in WPF. Raketeer has been built using an object-oriented architecture, allowing for components to be reused.

6

Testing Raketeer

This chapter describes the test set up and methods used for testing Raketeer. The set up, the selected participants and the test procedure and methods are described.

6.1. Setup

The same school for special education whose teachers helped in defining the six basic collaborative skills was willing to help test Raketeer.
The multi-touch table running Raketeer was set up in a vacant room on the upper floor of the school.

6.2. Participants

All children who participated in the experiment were attending the same school for special education. Inclusion criteria for selecting the children were: (1) diagnosed with PDD-NOS, (2) problems with social interaction and specifically with collaboration and (3) of age 8 till 12. Exclusion criteria were: (1) below normal IQ and (2) severe learning delays. The teachers selected 14 children from five classes considering the inclusion and exclusion criteria. The group consisted of 13 boys and 1 girl, roughly representing the normal autistic population. They were all diagnosed with PDD-NOS but had different additional problematic behaviour, such as: violent behaviour, rude language and lack of motivation.

6.3. Procedure

The experimenter escorted the children from their classroom to the test room. The children played a session of twenty minutes each day. During this session, four-minute long games were played. During play the experimenter made observations and occasionally had to intervene to stop arguments and fights. The children started a new game directly after the last game, or viewed the scoreboard. The experimenter told the children what score they needed to receive a promotion. However the experimenter refrained from telling details about the next level to keep the children motivated and eager to reach the next level. After the session the children were escorted back to their classroom.
The first session started with an explanation of the inner workings of the multi-touch computer and an introduction to the game. For each player an account was made and the boss of Raketeer (in the game) introduced the players to the game and their task.

During the last session all children played level 6 to finish the story and launch the rocket they had helped to build.
The prototype multi-touch table that was used is very sensitive to the external lighting conditions. On sunny days, rays of light that peeked through the sun-blinds could upset the vision system. Brightly lit parts of the screen would generate vast amounts of touches while only one finger touched the surface. This would hinder the game play or even crash the game. Blankets were used to cover the windows and the vision system was adjusted to resolve the issue. The adjustments to the vision system did result in a reduced responsiveness. The children had to press harder to register touches.

6.4. Method

Interviews, observations, video recording, data logging, score cards and card sorting tasks were used to evaluate the children's experiences, the results during play and possible transfer to the classroom.

6.4.1. Child experiences

To evaluate the children's experiences group interviews (the child with their buddy) were conducted. The children were questioned about what they found the most and the least fun about the game, if they would like to play it with more than two peers at the same time and whether they thought they had learned something.
Furthermore two card sorting tasks were used to allow the children to express the fun factor of Raketeer and of its levels. The use of sorting tasks was chosen to avoid influences from the interviewer and to allow the children an easy way to express the fun factor of Raketeer.
In the first sorting task the children were given cards with the six levels on them. The children had to sort the cards with the most fun at the top and the least fun at the bottom. Points were assigned to the ranks, ranging from six points for rank 1 to one point for rank 6. Following, per rank a total of points was calculated resulting in an overall ranking of the levels on basis of their fun factor.
In the second sorting task the children had to rank Raketeer against a number of other math games and against computer games at home. The cards read: doing math in class, playing math games in class, playing math games on the internet, playing Raketeer and playing computer or console games at home. Again points were assigned to the ranks, ranging from five points for rank 1 to one point for rank 5. The points per rank were added resulting in an overall ranking of math games on basis of their fun factor.
While the children were playing, the experimenter made subjective observations about the ease of interaction, eagerness to play, fun factor and difficulty of the equations.

6.4.2. Behaviour during play

To evaluate the children's behaviour during play the experimenter observed the children. Positive and negative behaviour was scored with focus on social interaction and collaborative behaviour. This resulted in positive and negative counts per child per game.

Furthermore, Raketeer recorded all data during play in four lists. A list of games with each game consisting of an id, date, time, duration, level, the two players and the points and bonuses earned. A list of equations consisting of a game id, the player, the time it took to answer, the sum, the answer given, whether the answer was correct and the points and bonuses awarded.
Furthermore there was a list with players consisting of the players name, the avatar, a ‘fingercode’ (password), level, math grade and the total points and bonuses per level. The last list holds data for level 4 and consists of the player and the number of items collected per type.
During nine of the twenty days video recordings were made. Because of limited time the teachers were shown video snippets showing their children play the different levels. Interviews were conducted in which the teachers judged the social behaviour of the children. For more questions see appendix C.

6.4.3. Transfer to the classroom

To evaluate overall changes in behaviour and transfer to the classroom teacher ratings were used. Before and after the game was played, the teachers rated the children on their arithmetic abilities and on the six collaborative skills (see section 3.1). The children’s arithmetic abilities were rated on a scale of six with one being the lowest and six being the highest score. Their collaborative skills were rated on a scale of five, with one being the lowest and five being the highest score.
At the end of the test period the teachers were interviewed on their experiences. The interview addressed behavioural change in the classroom and inclusion of Raketeer in the curriculum. For a complete list of the questions see appendix B.

7

Results

This chapter describes the results of the testing of Raketeer using the methods described in the previous chapter. First the subjective impressions of the observer are described. The results of the children's performance and behaviour are split up in two sections. The section "During play" describes the results of the data logged by Raketeer, observations made during play and the teacher interviews about the children's behaviour during play. The section "Transfer to classroom" describes the results of the teacher ratings regarding the six collaborative skills and the children's behaviour in the classroom. Furthermore the children's experiences are described by discussing the results of the children interviews and the results of both sorting tasks. Final, the overall opinion of the teachers on Raketeer is discussed.

First some remarks. The data of the first and the last test day were left out. After the first test day some major modifications had to be made to the six math grades to make them suit the children's arithmetic abilities. The last day the children played just two games at level 6 disregarding their game progress. This allowed the children to finish the story and launch their rocket. The results of this last test day are discussed separately in appendix E.
Furthermore, the names of the children mentioned in this chapter and in chapter 8 are pseudonyms for the sake of the children's privacy.

Starting this chapter, the next section describes the subjective impressions of the observer.

7.1. Observation about playing

Apart from two children all children were very enthusiastic about playing Raketeer and had no problem leaving their classroom and teacher. One child had not been informed by his teacher and refused to go. The other child did attend the first session, however he remained irritated and defensive for the first few sessions. During later sessions these children showed no problem any longer.
During the testing period the children stayed motivated and engaged in the game. One exception was a pair of children who got into a quarrel. The session was ended prematurely. After resolving the issue with their teachers it took the children another two sessions to become friendly again.

At the beginning of each new level the boss of Raketeer (in game) instructed the children on their task, points and bonuses that could be earned. However the instructions concerning the controls were such that they only stated the function and not how to use them.

None of the children had any problems figuring out the controls. In the case of level 1 they saw the dials had to be turned and intuitively dragged their fingers over the dials to turn them. Some children instantly figured out that the dials go from seven to eight to nine and than go back again to zero, and used this to be quicker in answering the equations. For others it took longer to figure this out. Some children did know the fact but could not use it to their advantage. They were not able to come up with good rules on when to use it effectively.

During the first sessions, most children started out a little distant and uneasy, as they were not acquainted with their buddy. After the first few sessions the children were used to the room, the computer, the game and their buddy.

The main force behind the children's devotion and will to keep improving was the competition with their classmates and their curiosity towards the next level. After nearly every game Raketeer's scoreboard was consulted to see if they had improved their position on the scoreboard and if they were close to a promotion. Furthermore the observer was asked on regular basis for details concerning the story line and the next level.

For a more elaborate subjective impression see Appendix C.

The next sections will try to determine the children's experiences and behavioural improvements during play and in the classroom in a more objective manner.

7.2. During play

7.2.1. Play time and progress

As was mentioned earlier in this thesis, Raketeer was tested at an elementary school for special education for four weeks. Fourteen children, including thirteen boys and one girl, played sessions of in total twenty minutes every day. While most children played around sixteen sessions, some children were regularly absent reducing their number of sessions and their total playtime. Three children only played around ten sessions each. Figure 14 shows the total time played per child. On average the children played for a total of two hours and 35 minutes.

Not all children progressed to level 6. One child only reached level 3, due to the lack of play-time (see figure 14 child 5). Figure 15 shows the game progress of the children after the second to last test day. Apart from one child, all children reached level 4. More than half reached level 5 and six reached level 6. Only one couple was able to finish Raketeer without help on the final test day.

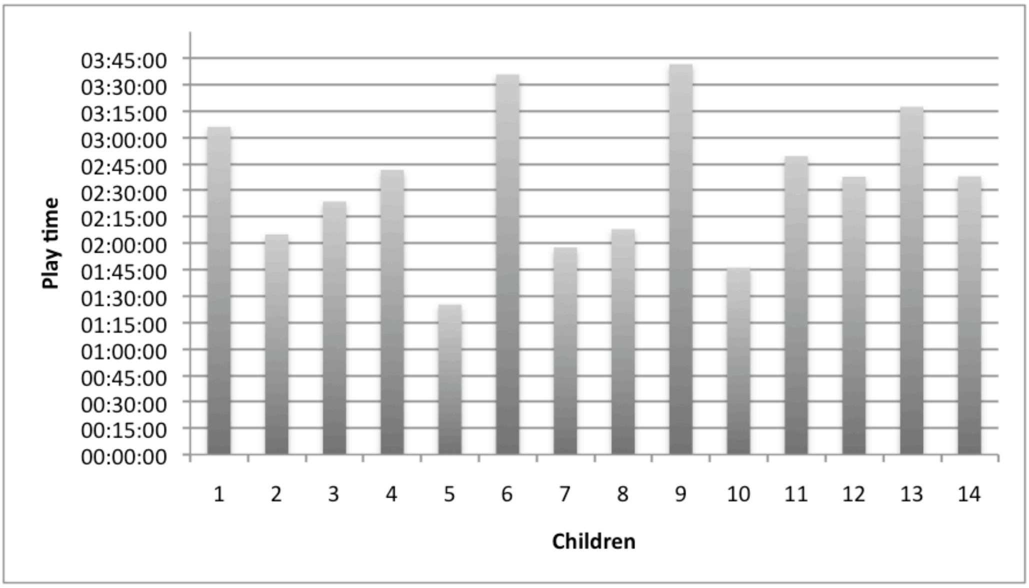

Figure 14. Total time played per child.

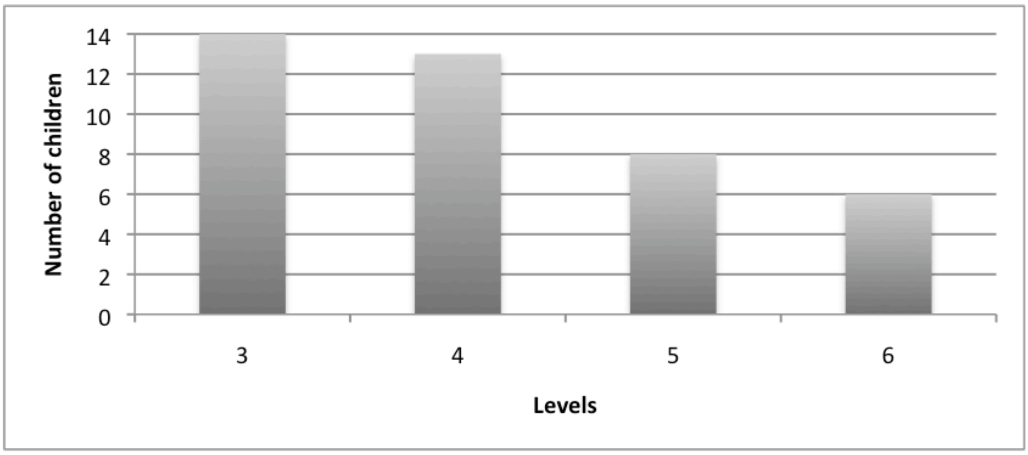

Figure 15. The number of children per level who reached that level.

7.2.2. Math points

The children could earn five math points for every correctly solved equation. Every erroneous answer lost the children one math point. Figure 16a plots the average number of math points per game in level 1. At level 1 the children start around 50 math points per game on average. From the first game to 7th game a rising trend can be seen as the children get better and earn more points. The average math points per game increase to about 65 points.

From game 8 on, a drop occurs to 30 points on average in game 10. Analysis of these games showed half of the children needed just seven games to complete level 1 and another five needed nine games. Thus the best performing children finished level 1 around game 7 and did not contribute positively to the average anymore. In figure 16b only the first seven games are shown to avoid the effect of the finishing children on the average. The added trend line reveals a positive trend. The children are increasing their performance.

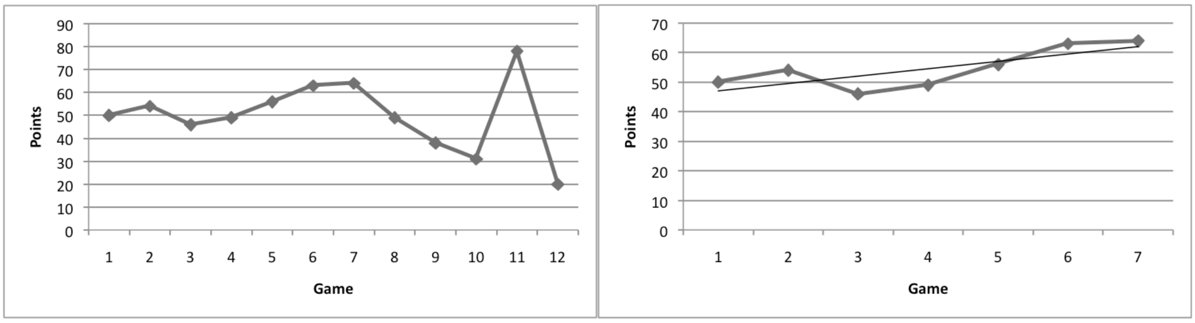

Figure 16. (a) Average math points per game in level 1. (b) First 7 games with linear trend line.

Figure 17 shows the average points per game in level 2. Starting at 60 points in the first game and increasing to 90 points on average in the last game. Although there are drops of the average in game 6 and game 10, the linear trend is positive showing increasing performances of the children.

The linear trend line through the average points per game in level 3 is even more positive (fig 18). Starting near the 45 points in game 1 and ending at almost 80 points in game 17. Nine of the fourteen children needed less than thirteen games to complete this level, resulting in a dip in the average points per game near game 10, 11 and 12.

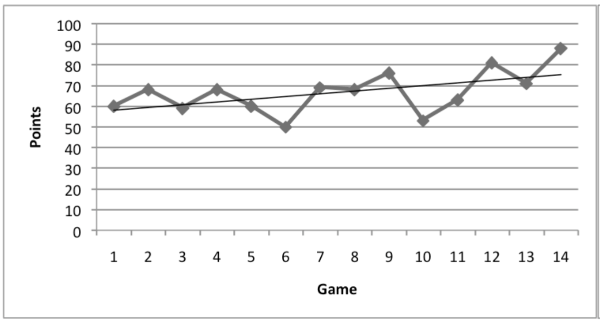

Figure 17. Average math points per game in level 2.

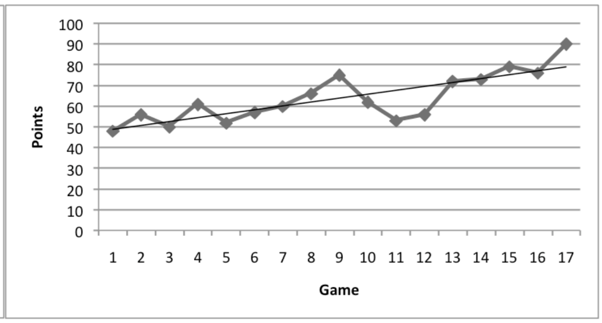

Figure 18. Average math points per game in level 3.

Seven of thirteen children who played level 4 finished it at or before game 9. Another three finished in game 11. After both game 9 and game 11 a dip is visible in the average points (fig 19a). Only two children played beyond eleven games to finish level 4. In figure 19b the last seven games are left out as the first eleven games describe the earnings of eleven of the thirteen children, hence are more reliable averages. The log linear trend line indicates the average points per game increased for the first four games and than started to flatten into an average of about 55 points per game. This indicates the children learned the most about sharing during the first four games of level 4.

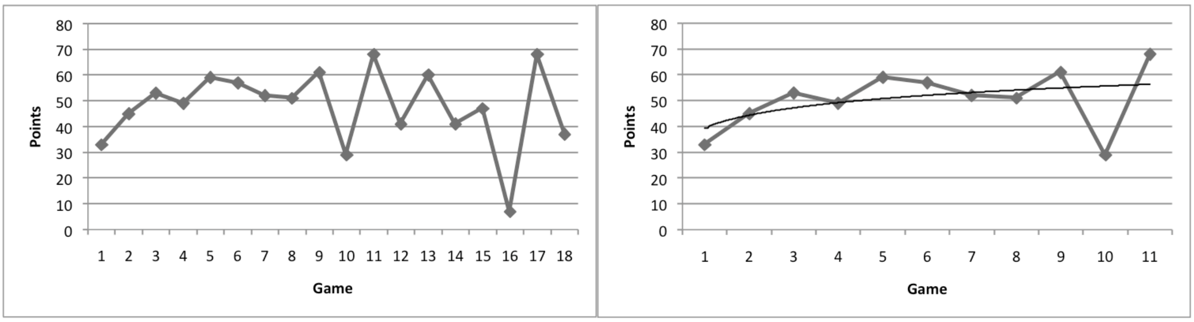

Figure 19. (a) Average math points per game in level 4. (b) First 11 games with log linear trend line.

Only eight children reached level 5 and six of these children also finished this level. Four of these six children needed seven games and the other two eight games to finish this level. The couple that finished the level in the 8th game was so enthusiastic about reaching enough points, they began to celebrate without having finished the game. This is visible as a dip in the average points in game 8 (fig. 20a). Figure 20b shows the average points without game 8 for a more reliable result. The trend line shows a positive trend, indicating the children increased their performance during this level. However there seems to be a maximum around 80 points on average per game.

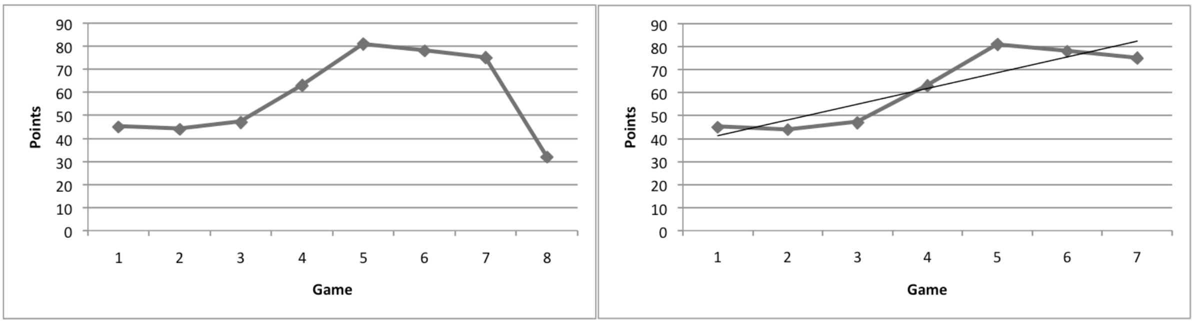

Figure 20. (a) Average math points per game in level 5. (b) First 7 games with linear trend line.

While these trends indicate the children improved their performance during every level, this does not necessarily mean they improved their collaborative skills. Although the game is designed to train the children in collaboration and the best way to earn a lot of points is through collaborative behaviour, it could also mean the children learned how to play the game better. To better assess whether the children improved their collaborative skills, the next session analyses the buddy points earned by the children.

7.2.3. Buddy bonus

Figure 21 shows the average buddy bonus per game earned in level 3, 4 and 5. This figure also shows the same effects as the figure of the average math points per game, due to a lot of children finishing the level simultaneously resulting in unreliable averages. In the figure 22, 23 and 24 the average buddy bonus per game of levels 3, 4 and 5 are plotted individually. The same games are left out, as is the case in the preceding figures plotting the average points per game.

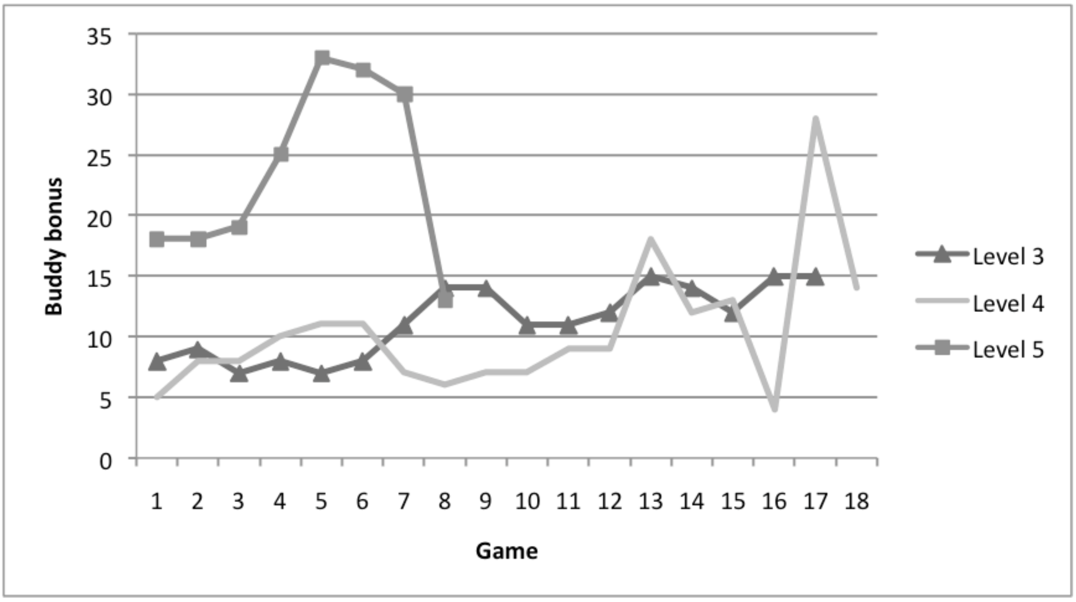

Figure 21. Average buddy bonus per level per game.

Figure 22a shows the average buddy bonus per game in level 3. The children can earn these buddy bonuses in level 3 by waiting for their turn. Although the averages swirl a bit there is a clear positive trend. The children earned on average an increasing amount of buddy bonus. This positive trend is a clear indication of improved turn taking.

In figure 22b the average buddy bonus per game in level 4 is plotted. To earn a buddy bonus in level 4 the children have to share items with their buddy.

Through the first six games there is a steady increase. However after the 6th game there is a drop and after the 8th game the average buddy bonus per game starts to increase again. The first six games indicate the children share increasingly with each other. Analysing the individual games an explanation was found for the drop in average after the 6th game. A quarrel between two children, already mentioned in section 7.1, lead to a prematurely ended session with a negative score for both children. It took a few sessions for the children to become friendly again and start sharing. These events correspond to the dip and the following recovery in the graph of figure 22b. Taking into account only the first six games, there is a clear positive trend indicating increased sharing between the children.

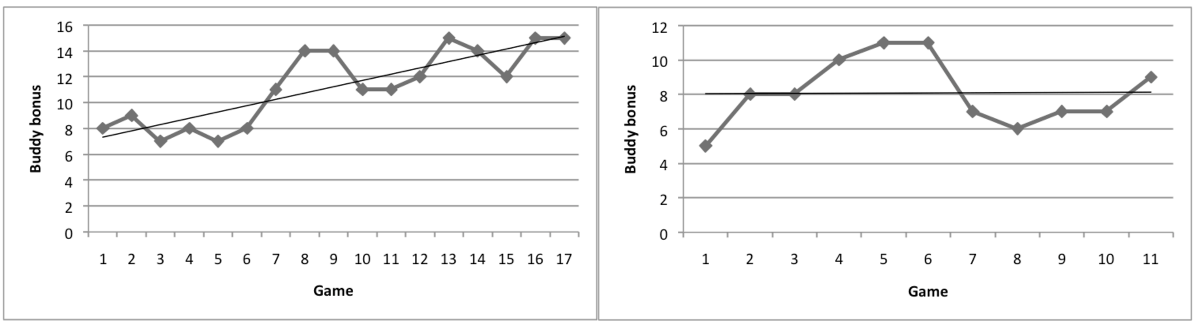

Figure 22. Average buddy bonus per game in (a) level 3 and (b) level 4.

The graph of the average buddy bonus per game in level 5 (fig. 23) looks exactly like the graph of the average points per game (fig. 20b). In level 5 the children have to solve equations together. This means they both have the same score and get a buddy bonus for every correctly solved equation. Thus the amount of buddy bonus is in ratio to the amount of math points, resulting in a similar graph and similar positive trend.

During the first five games the children increase their performance and there after, they seem to hit a ceiling. Whether their development of discussing a task with peers, continues from game 5 on, cannot be supported by the data.

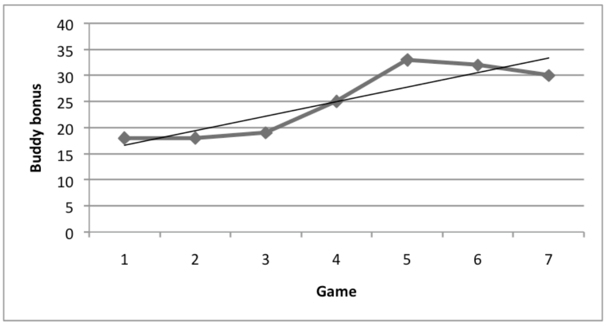

Figure 23. Average buddy bonus per game in level 5.

In all levels the trends seem positive, indicating improved collaborative skills. However the improvements in the children's scores, both math points and buddy bonuses, might also be due to learning the game rather than learning collaborative skills. However this is unlikely because of the direct link of the math points and buddy bonuses with the collaborative skills. In level 3 buddy bonuses can be earned by waiting for your turn. Going before your turn is punished with a negative buddy bonus of five. Thus an increasing buddy bonus directly corresponds with improved turn taking. In level 4 buddy bonuses are awarded for sharing items and an increase in buddy bonuses is directly related to an increase in sharing.

For level 5 and 6 there is a less obvious connection. In level 5 the children have to solve an equation together. Both children have to enter a part of the solution. A correctly solved equation is awarded with math points and a buddy bonus. Thus both their math points and their buddy bonuses are linked to the children's collaboration. However these points are not linked to whether they have improved in discussing the problem and possible solutions with each other. The case where one child solves the equation and orders the other child to input an answer could result in the same pattern of math points and buddy bonuses. To investigate whether this is the case the next section discusses the observations made by the observer during play.

7.2.4. Observations

As was described in section 6.4.2 the children were observed while playing and positive and negative social and collaborative behaviour was scored. Figure 24 shows the average counts of positive and negative behaviour per level. Starting at opposite ends in level 1 there are only a few positive and negative counts. In level 2 the children stand next to each other. The average positive counts doubles indicating more positive behaviour is occurring. While it may be tempting for the children to touch their buddy's controls, the negative count goes down, indicating less negative behaviour. In level 3 the average count of positive behaviour increases to nine counts per child. However the negative count increases as well. This supports the graph in figure 22a. The children find it hard to wait for their turn and receive a lot of negative counts for verbal expressed impatience. However they are improving and the observation reports show children helping each other with difficult equations. Level 4 shows a decrease in the average counts of positive behaviour. However the counts of negative behaviour have decreased even more.

The most interesting are the results for level 5. There is almost the same number of average counts of positive behaviour as in level 4 and the number of negative counts has dropped to less than a half count per child. This proves the positive trend seen in figure 23 is due to the children collaborating instead of one child being bossy.

7.2.5. Teacher interviews

Video recordings were made during play (see section 6.4.2). A compilation of these recordings was shown to the teachers after which they were interviewed about behavioural change during play. See appendix B for the full set of questions.

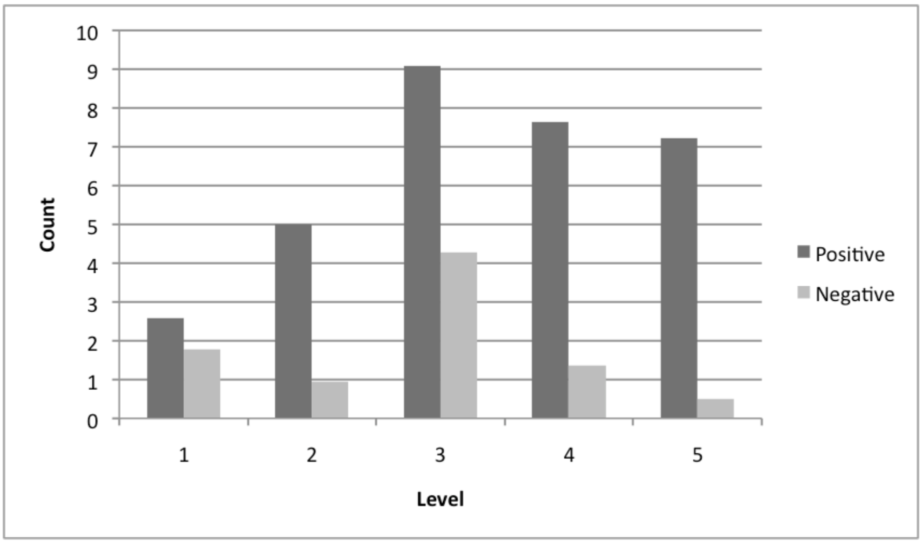

Figure 24. Average positive and negative observation counts per level.

The teachers were unanimous it was a valuable experience for the children. They agreed playing Raketeer was a positive experience. The children learned that working together can be fun and does not have to end in an argument or fight.

After reviewing the compilation video, the teachers commented on their children's behaviour. While all children were collaborating to some extend, not all children showed real behavioural changes.

For six of the fourteen children the teachers recognised improvements of behaviour. Christian and Jan, for instance, had been paired because of their problems on the playground. Nearly every soccer match ended in kicking and fighting. Although the two children started off being hostile, they later became friendly and social and collaborated well. Another example is Xander. As was mentioned earlier he had symptoms bordering on classic autism. Furthermore he was aggressive and hostile towards peers. His teacher stated Xander's behaviour was a considerable improvement. While the two children did show hostility towards one another, they collaborated well and occasionally made social talk.

However for eight of the fourteen children no real behavioural changes were noted.

A more elaborate description for all children can be found in Appendix D.

In conclusion, both the data captured during play and the observations showed improved social behaviour. The teacher interviews on the basis of the video compilation were positive, however the teachers did not recognise behavioural change in all children.

While improvements in collaboration during play are important, the broader goal is for these children to be able to collaborate with peers in the classroom. The transfer of the skills learned, while playing Raketeer, to the classroom is the topic of the next section.

7.3. Transfer to classroom

To assess the transfer of skills to the classroom pre and post-test teacher ratings were obtained and teacher interviews were conducted. The next session describes the results of the teacher ratings.

7.3.1. Teacher ratings

As was mentioned in section 6.4, before and after the test period, the teachers rated their children on their arithmetic abilities and on the six basic collaborative skills (see section 3.1). Figure 25 shows the pre and post-test results per child. About half of the children show no improvements of their arithmetic abilities ratings. Child 5 even has a lower post-test than pre-test rating. The other half do show improved ratings. However it is not clear whether these improvements are due to playing Raketeer or the normal math course the children attended also. Furthermore for children 7, 8 and 10 there could be a ceiling effect, as the arithmetic rating does not go beyond a score of six.

Figures 25 through 30 show the pre and post-test ratings per child of all six collaborative skills. The difference between the pre and post-test scores is an indication of the improvement of the collaborative skills of the children exhibited in the classroom.

While child 1 through 4 have improved more than two full points, children 5, 9, 10 and 12 have higher pre-test than post-test scores (fig. 26). In total ten out of fourteen children have higher post-test than pre-test scores indicating improvements in turn taking. A Wilcoxon signed rank test confirms the effect is significant ($Z = -2.460$, $p = 0.014$).

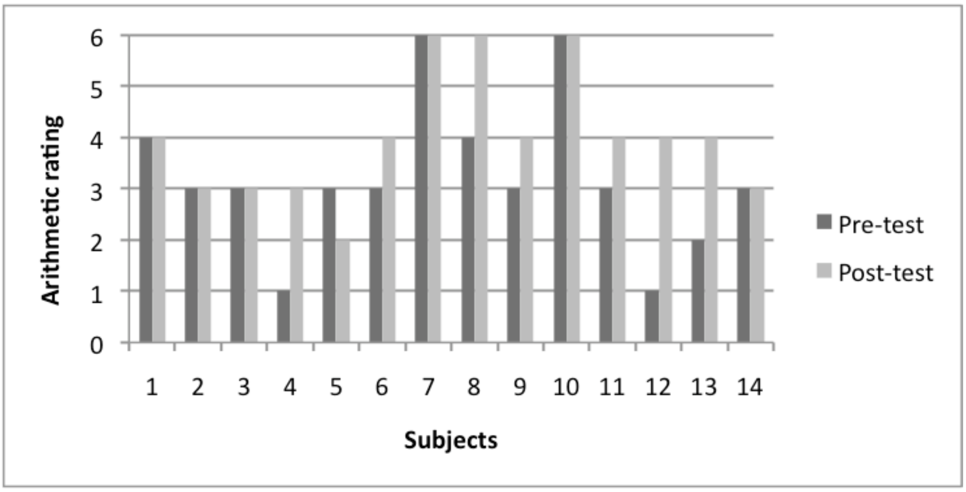

Figure 25. Average pre and post-test arithmetic abilities rating

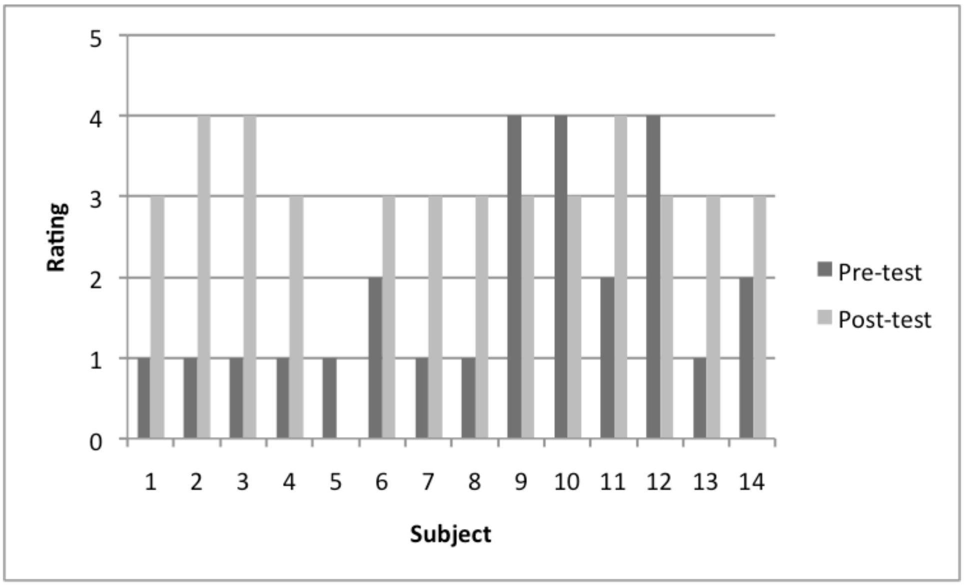

Figure 26. Pre and post-test ratings for "turn taking".

Figure 27 shows the scores for handling mistakes of the other. Children 9, 10 and 12 have equal pre and post-test scores indicating no improvement. The other eleven children do show higher post-test scores indicating improved handling of mistakes in the classroom. A Wilcoxon signed rank test showed a significant difference between the pre and post-test results, ($Z = -2.976$, $p = 0.003$) hence a significant improvement of "handling mistakes of the other".

Three children showed equal pre and post-test scores indicating no improvement of receiving criticism (fig. 28). Ten out of fourteen children do show higher post-test scores indicating an improvement of receiving criticism. A Wilcoxon signed rank test confirms the effect is significant ($Z= -2.877$, $p = 0.004$).

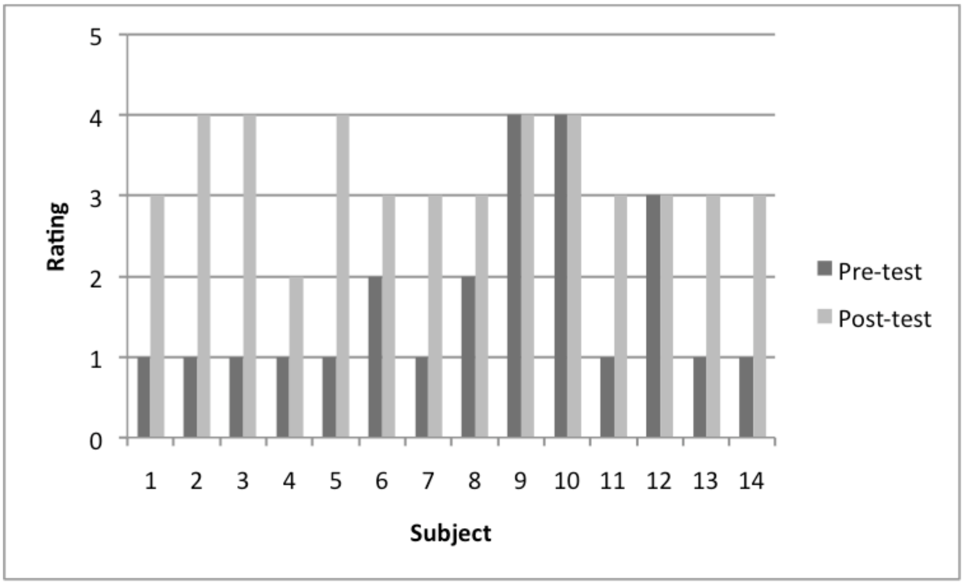

Figure 27. Pre and post-test ratings for "handling mistakes of the other".

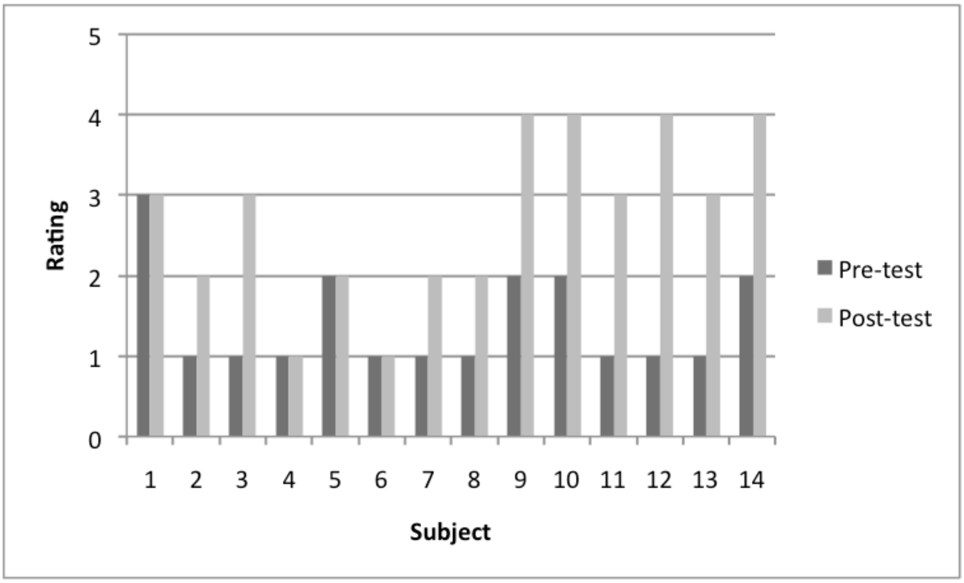

Figure 28. Pre and post-test ratings for "receiving criticism".

Figure 29 shows the pre and post-test score for sharing objects and tasks. Child 4 shows higher post-test than pre-test scores and child 5 shows equal scores indicating both at most no improvement. The other twelve children show good improvement, with child 2 improving a full four points. These results indicate improvements in sharing in the classroom. A Wilcoxon signed rank test confirms the effect is significant ($Z = -3.008$, $p = 0.003$).

"Discussing a task with others", shows lesser improvements (fig. 30). Although eleven of the fourteen children have higher post than pre-test results, eight of these eleven improve by just one point. A furthermore three children show no improvements. In total the majority of the children seem to show improved discussion abilities in the classroom. A Wilcoxon signed rank test confirms the effect is significant (Z = -2.801, p = 0.005).

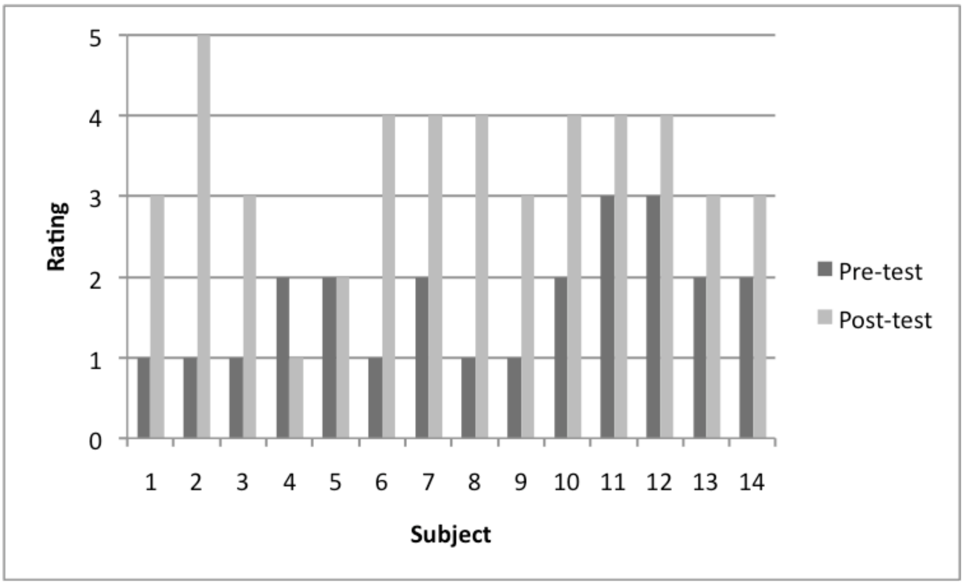

Figure 29. Pre and post-test ratings for "sharing objects, tasks and goals".

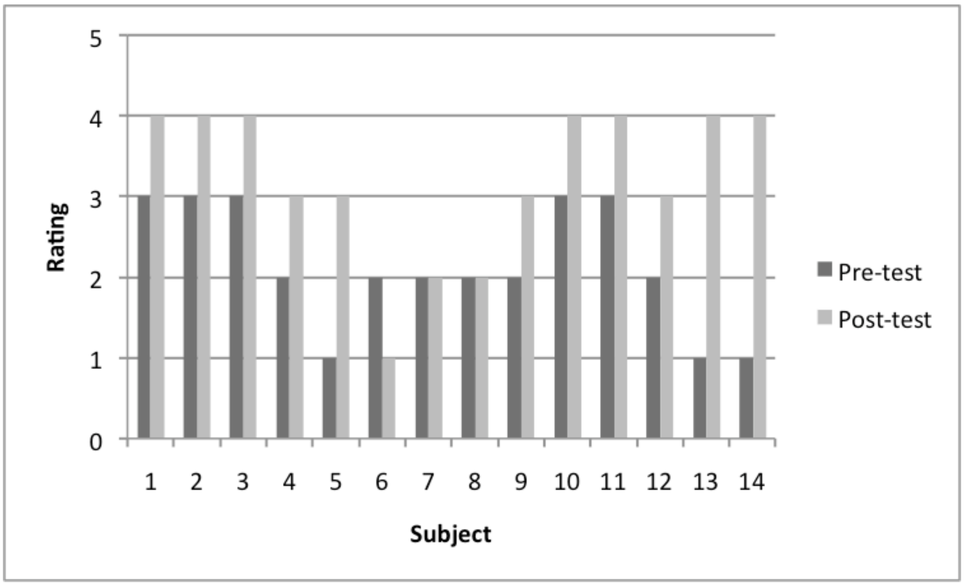

Figure 30. Pre and post-test ratings for "discussing a task with others".

"Realising one's action has implications for the other" shows the least improved scores of all collaborative skills (see fig 31). The score of child three has decreased, child 4 and 6 show no improvements. Eight out of fourteen children show an improvement of one point and three children show an improvement of two points. In total the results indicate improvement of "realising one's action has implications for the other" in the classroom. A Wilcoxon signed rank test confirms the effect is significant (Z = -2,804, p = 0.005).

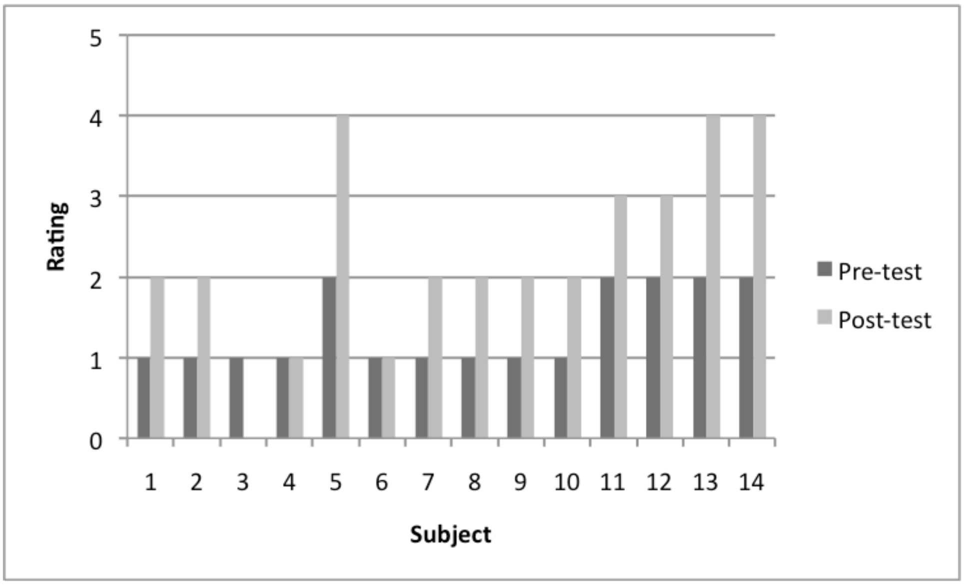

Figure 31. Pre and post-test ratings for “realising one’s action has implications for the other”.

The results of the teacher ratings show significant improvements in all collaborative skills. The next section describes the opinion of the teachers about transfer to the classroom.

7.3.2. Teacher interviews

This part of the teacher interviews addressed behavioural change in the classroom. For the full list of questions see appendix B.

While the teacher ratings showed significant improvements in all six collaborative skills, the teachers had a different opinion on the transfer of skills to the classroom.

Evaluating their children’s behaviour and social skills in the classroom the teachers noted little or no behavioural change and transfer of skills. Despite their social behaviour during play Chirstian and Jan still got into fights during soccer. Erik, an introverted and timid boy now does wanted to collaborate with peers on tasks in the classroom. However his teacher wasn’t sure whether this improvement was solely the results of playing Raketeer or that some of his own initiatives in class were also having effect.

One notable exception is Xander. He was described earlier in this thesis as a child with symptoms bordering classic autism who was anxious and aggressive towards other children. During the test period of four weeks his teacher claims Xander became increasingly social. Currently Xander does things his teacher had not thought possible four weeks ago. He now plays with LEGO© in between other children without a problem. Xander can play Boxhead[2] with one of his peers and is really good at it. According to his teacher Xander was stuck for years, showing no development in social skills, however by playing Raketeer this has changed.

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[2] Boxhead is a browser-based game where the player has to shoot down zombies. The children play it in pairs: one player controls the movement, the other player shoots. http://www.spele.nl/games/boxhead/boxhead.html

While only one child showed considerable improvements in the classroom the teachers did state they thought Raketeer was valuable for teaching math and collaboration. At the end of this chapter the teacher's opinions on topics such as daily usage and inclusion in the curriculum are discussed more in depth. The next section describes the children's experience with Raketeer and in particular the fun factor of Raketeer.

7.4. Child experiences

7.4.1. Math games card-sorting task

To determine the fun factor of Raketeer the children performed a card-sorting task. In this task they had to sort five cards: doing math in class, playing math games in class, playing math games on the internet, playing Raketeer and playing games on a console or computer at home. Figure 32 shows the overall ranking of the activities from the card-sorting task. Raketeer is ranked first with 60 points. It has even fifteen points more than playing regular console or computer games at home. Figure 33 shows the number of children per ranking Raketeer was valued at, in the sorting task. Eight out of thirteen children awarded Raketeer a first place and another three rewarded Raketeer a second place. One child was not able to complete the card-sorting task due to time constraints.

7.4.2. Children interviews

Most of the children had problems with collaboration resulting in irritation or even fights. One might think this results in a lack of motivation or even a fear for collaboration. However the children showed no fear for collaboration while playing Raketeer. In the interviews eight of the twelve children answered playing together was the best part of Raketeer. Another seven out of twelve children would like to play the game with more than one buddy.

As was mentioned in section 6.3 the multi-touch table had touch recognition problems on very sunny days. Covering the windows with blankets reduced the problem. However adjustments had to be made to the vision system regularly. In addition these adjustments reduced the responsiveness meaning the children had to press harder for proper recognition of their fingers. The interviews showed the children found these problems irritating, however not in an amount to spoil the game. nine out of twelve children did found it was the main point of the game that needed improving.

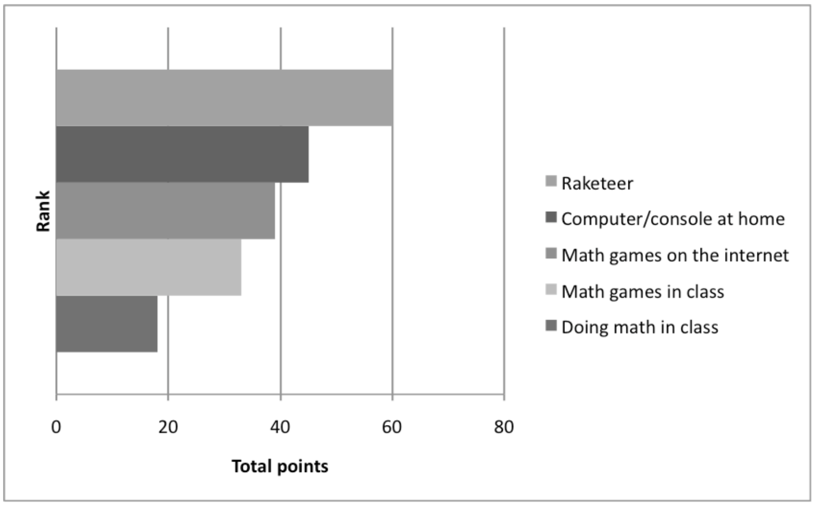

Figure 32. Ranking results of the math game card-sorting task.

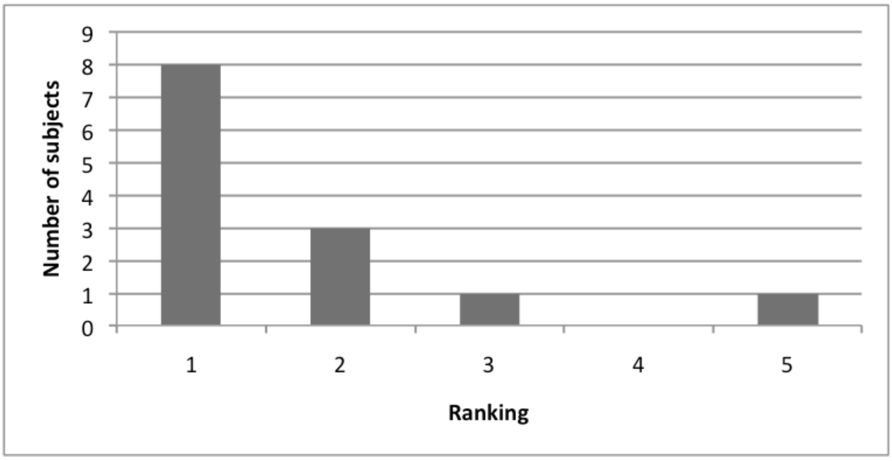

Figure 33. Rank distribution of Raketeer at the math game card-sorting task.

7.4.3. Raketeer levels card-sorting task

The children performed another card-sorting task to rank the levels of Raketeer on their fun factor. Points were assigned according to the ranking of the cards, from six to one point(s). The cumulative points per level from thirteen children are visualised in figure 34. Apart from level 5, there seems to be a linear increase in the fun factor as the level increases. Although level 6 has difficult equations that have to be solved under pressure from incoming missiles, almost all children found this level the most fun. While all children played level 6 during the final day, not all children had been able to reach level 5. This is probably the cause for the dip in points of level 5.

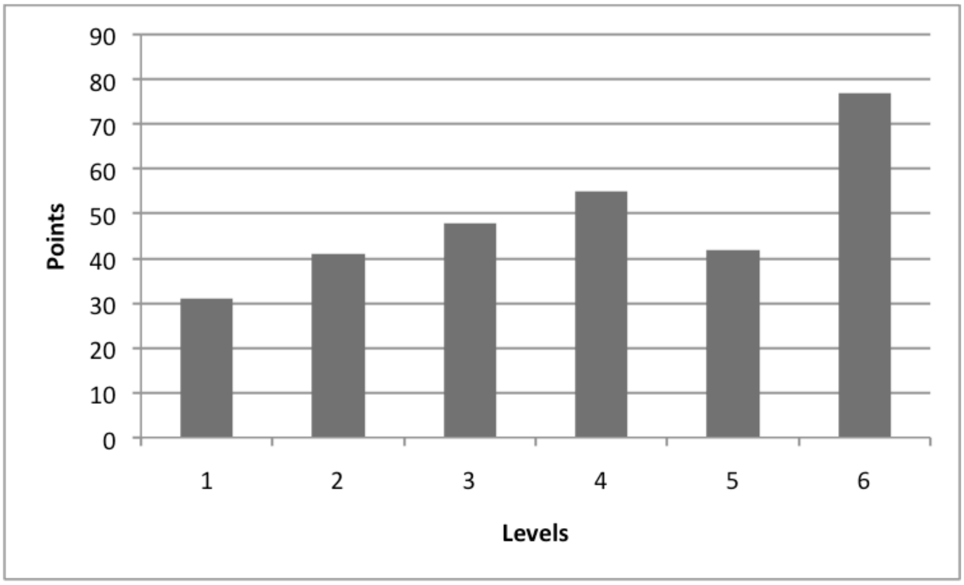

Figure 34. Raketeer level card-sorting task.

In evaluating their own performance and what they thought they had learned from playing Raketeer, eight out of twelve said they had improved their math abilities. Furthermore nine out of twelve thought they had improved their ability to work together. One child answered: “working together gets you further”. Another child said he had learned that working together can be fun. The graph in figure 33 supports these statements and even seems to imply more collaboration equals more fun. The number of points per level increases almost linearly with the level with the exception of level 5. The main element that increases also through the levels is the amount of collaboration. Thus, the fun factor seems to increase as the amount of collaboration increases.

Earlier sections showed improvements during play and in lesser extend in the classroom. This section showed the children found Raketeer fun and engaging. The next section discusses the teacher’s opinion on furthermore usage of Raketeer and inclusion in the curriculum.

7.5. Teacher experiences

A final part of the teacher interviews addressed the teacher’s opinion on using Raketeer for math and social skills training and on the inclusion of Raketeer in the curriculum.

According to the teachers, transfer of skills to the classroom is hard to accomplish. They argued the children should have to play regularly for at least three months, to accomplish better transfer of skills to the classroom.

While only one child showed considerable improvements in the classroom the teachers did state they thought Raketeer was valuable for teaching math and collaboration. Children who hate practicing math, enjoyed playing Raketeer. However they have to solve equally difficult equations as in their math book. The equations in their books might even be easier as they are presented in columns sorted by operator, while in Raketeer equations are presented with different operators mixed up.

The teachers confirmed Raketeer implemented the six collaborative skills. However they indicated “realising one’s action has implications for the other” was implemented only marginal by level 5. In this level the children can select possible answers that make it impossible for the other child to finish the equation. However it is not certain the children will come across such a situation.
The teachers stated they would like to incorporate Raketeer in the curriculum. They though it was a nice way to combine practising math and improving social skills and in particular collaborative skills. For some children they would use a session of Raketeer as a reward for good behaviour in the classroom, for other children it would be a fun way to do math. However for the children with the more severe social problems they would like to use Raketeer on a regular basis. For all these cases, but especially in the last case supervision of a teacher or assistant would be mandatory.
Furthermore the teachers could see the added value of a game to improve motivation and promote learning. They would like to have more collaborative tabletop games incorporating subjects such as: history, topography and language. Requirements for the success of a multi-touch tabletop for educational use included robustness, height adjustable and most importantly, a suite of full-proof software.

8

Discussion

As was stated in the first chapters, due to educational renewals a lot of Dutch children with ASD such as PDD-NOS can no longer go to regular schools. These educational renewals lead to problem driven education where children have to collaborate and work in groups. However group work and collaboration are very hard for these children. Literature on social skills, serious games and multi-touch technology was discussed to seek a solution for teaching children with PDD-NOS collaboration.

To provide a fun and exciting learning experience that improves motivation and can facilitate collaboration, a serious game with multi-touch interaction was developed. The game was thoroughly tested by fourteen children at a school for special education.

The experimenter's subjective experience was that the children found playing Raketeer fun and engaging. The card-sorting task supported this view showing that eight of thirteen children ranked playing Raketeer above playing computer or console game at home.

Data from Raketeer showed the children kept improving their math scores and buddy bonuses, indicating improved collaborative skills. The observations supported the notion of improved collaborative skills, through increasing positive behaviour and decreasing negative behaviour. Teacher interviews regarding the video recordings of the children playing Raketeer indicated the children's behaviour had indeed improved. Overall the children became more social and collaborated increasingly.

Teacher pre and post-test ratings of the children's arithmetic abilities showed improved arithmetic abilities for about half of the children. However the children followed normal math courses as well, thus it is not clear whether these improvements were due to the courses or due to playing Raketeer. As Raketeer only practises known math operations and does not introduce new type of equations, improvements in the children's arithmetic abilities are more likely due to the math courses.

Teacher ratings for the six collaborative skills all showed improvements, indicating transfer of skills and improved collaboration in the classroom. A series of Wilcoxon signed rank tests showed the effects for each of the six skills were significant. However the teacher interviews showed no or little transfer to the classroom apart from one child who showed considerable improvements. The teachers argued a period of at least three months was necessary to allow for any transfer. They stated Raketeer is valuable for teaching math and collaboration and they would like to incorporate Raketeer into the curriculum. Playing Raketeer gave the children a positive and fun experience of working together.

It is not exactly clear what the cause is for the conflicting teacher ratings and interview results. With scoring the children's collaborative skills the teacher indicated considerable improvements, however in their opinion the children showed no improvement.

It could be the case the ratings are correct, however in sharing their opinion the teachers judged the children more on their overall social skills. Another explanation is that the ratings are not formal enough, allowing different interpretations over a period of four weeks. However there is no data that can be confirm any of these explanations.

Data of the last test day were left out because all children, disregarding their game progress were allowed to play level 6. However during that last test day the children showed, more than on the other days, they had learned to collaborate. All children were concentrated and played enthusiastically. After the first game, without suggestions from the experimenter, three of the seven pairs distributed the two tasks: one child solving equations, the other shooting down missiles. The other four pairs adopted the same solution after the experimenter asked how they could improve their score. Four of the seven pairs arranged themselves around the table so that the child shooting down the missiles did not hinder the child solving the equations. For a more detailed description of the children playing level 6 see appendix E.

There are some words of caution about interpreting the results. This study was not designed to be a very strict experiment for a maximum result. Rather it was designed to have the biggest impact on the children.

The teachers selected children who had the most problems with collaboration and made pairs to fit around gym class. Furthermore some children were regularly absent. To allow the buddy of the absent child to play, pairs were switched and some children played twice on a particular day.

The experimenter observed the children during play and the teachers judged the children in the classroom and through video recordings. Both observers had no training in diagnosing social or collaborative skills. Also there was no control group and as the observers had full knowledge of the experiment, they were not blind observers.

Although there were some problems with the prototype multi-touch tabletop on sunny days, these problems had no influence on the performance or behaviour of the children. However in the case of future research it is recommended to use a tabletop that can handle different lighting conditions and that is more robust.

To provide more conclusive evidence on the use of a serious game with multi-touch interaction for teaching children collaboration a larger study is necessary. While the design of such a larger study should not hinder the children in their fun and learning, a design with a control group and using qualified blind observers would give more conclusive results.

A longer study could allow for better transfer of skills to the classroom. Furthermore an additional step, in between playing Raketeer and collaboration in the classroom, could be useful. For instance a board game using the same story and structure could help introduce the skills learned while playing Raketeer, into the classroom.

Xander, the boy with the symptoms bordering on classic autism, has improved the most. Testing with more children and children with different autism spectrum disorders could provide insight into why Xander improved far more than the other children. It could be because Xander had more severe symptoms or perhaps the current game is better suited for children with symptoms of classic autism.

In conclusion this study has shown how a multi-touch-based serious game can improve collaboration for children with PDD-NOS. The children improved considerable during play and showed improvements of their collaborative skills in the classroom. However teacher interviews showed no or little transfer of skills to the classroom.

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Appendix A

Children interview questions

Below are the questions (translated to English) of the children interviews.

1. What was the most fun part of the game?
2. What was the least fun part of the game?
3. What would you like to change about the game?
4. Do you like Raketeer more than playing computer or console games at home?
5. Do you think you have improved your abilities to work together?
6. Do you think you have improved your math abilities?
7. Do you like the touch interface?
8. Would you like to play Raketeer with more than 2 children at the time?

Appendix B

Teacher interview questions

Below are the questions (translated to English) of the teacher interviews.

General questions

1. Do you think Raketeer is a good way to practice solving equations?
2. Do you think the six collaborative skills are well implemented in Raketeer.
   a. Turn taking.
   b. Handling mistakes of a peer.
   c. Handling criticism from a peer.
   d. Sharing with a peer.
   e. Discussing a task with a peer.
   f. Realising one's action has consequences for a peer.
3. Would you like to use the Raketeer…
   a. For teaching math?
   b. For teaching collaboration?
   c. Regularly, in the curriculum or incidental?
   d. If so…
      i. In the classroom or in a different room?
      ii. With or without a tutor?
      iii. One or multiple machines?
4. What do you think of the multi-touch computer?
5. What would be the conditions for using the multi-touch computer?
6. What other possible applications can you think of?
7. Do you think Raketeer would be usable in regular education?

Questions on behaviour during play

These questions were answered for every child individually.

1. Did the child show changed behaviour?
2. If there was a change in behaviour:
   a. What was the change?
   b. How was that change visible?

Questions on behaviour in the classroom

These questions were answered for every child individually.

1. How did the child return to the classroom?
2. Was playing the game a topic of conversation?
3. Did the child show changed behaviour?
4. If there was a change in behaviour:
    a. What was the change?
    b. How was that change visible?

Appendix C

Subjective impressions

This appendix describes the subjective impressions of the testing period in more detail.

From the initial meetings regarding the design of the game the word had already spread throughout the whole school about a ‘massive finger computer’. These first visits were to the two highest classes before the end of the school year. At the time the game was finished and the testing could begin, the next school year had begun and some of the children had graduated. However at the first meeting in the new semester almost all children seemed to be aware of the ‘mister with the big computer’ and everyone kept asking whether they could play.

Apart from two children, all were very enthusiastic about playing and had no problem leaving their classroom and teacher. Xander, a child with symptoms bordering classic autism, could not be persuaded to attend his first session. The teacher had failed to tell him beforehand about playing the game. He did not wanted to deviate from the program on the chalkboard even though the teacher encouraged him to take part. The next session this was no problem anymore.

Bert started very apathetic needing encouragement at every step. He did not want to co-operate and solved only four easy equations in four minutes time, constantly playing with the controls. In discussion with his teacher it was decided to change his buddy. The teacher found out Bert was intimidated by his buddy’s sarcastic and hateful behaviour. Partnered with another buddy he improved considerably and they even made it to level 6.

At the beginning of each new level the boss of Raketeer (in game) instructed the children on their task, points and bonuses that could be earned. However the instructions concerning the controls were such that they only stated the function and not how to use them.

None of the children had any problems figuring out the controls. In the case of level 1 they saw the dials had to be turned and intuitively dragged their fingers over the dials to turn them. Some children instantly figured out that the dials go from seven to eight to nine and than go back again to zero, and used this to be quicker in answering the equations. For others it took longer to figure this out. Some children did know the fact but could not use it to their advantage. They were not able to come up with good rules on when to effectively use it.

During the testing period the children stayed motivated and engaged in the game. One exception was a pair of children who got into a quarrel. Remco had been the first to finish levels 1 and 2. He had no problem with playing the same levels until his buddy, Paul, had earned a promotion as well. However at level 3 Paul was the first to finish, and he did not want to play any further. At level 3 the children have to wait for their turn to solve equations and earn points. Paul actually began to sabotage Remco by stalling and lingering before solving his equations, so Remco could not earn enough points for a promotion. This got Remco really upset and they got into a fight. The session was ended and both children returned to their classroom. The teachers of the children both discussed the fight with them. During the next few sessions the children could earn an extra reward in the form of candy for good co-operation and effort. This helped and soon Remco and Paul were sharing more than necessary in level 4 and were friends again.

The main force behind the children's devotion and will to keep improving was the competition with their classmates and their curiosity towards the next level. After nearly every game Raketeer's scoreboard was consulted to see if they had improved their position on the scoreboard and if they were close to a promotion. Furthermore the observer was asked on regular basis for details concerning the story line and the next level.

Playing Raketeer seemed to influence the children's mood. Teachers commented that children who had been rebellious and were tormenting their teacher all morning returned to the classroom in a far better mood after playing Raketeer.

During the first sessions, most children started out a little distant and uneasy. Although some children already knew the child they were paired with, most of them did not. After the first few sessions the children were used to the room, the computer, the game and their buddy. They were immersed in the game and during play their enthusiasm would give rise to social talk about the boss, the level or points earned. As the children progressed through the game and had to increasingly collaborate they seemed to form a bond, of them against the computer.

Although this section should give the reader a feel for the way the children played the game it is a subjective judgement of the observer. The next sections will try to determine the children's experiences and behavioural improvements during play and in the classroom in a more objective manner.

Appendix D

Results teacher interviews

This appendix describes the results of the teacher interviews on behavioural change during play in more detail.

The teachers were unanimous it was a valuable experience for the children. They agreed playing Raketeer was a positive experience for the children. They learned that working together can be fun and doesn't have to end in an argument or fight.

Christian and Jan had been paired because of their problems on the playground. Nearly every soccer match the two played together ended in fighting and kicking each other. Seeing the two being at hostile at the beginning was a familiar sight. However their teachers were amazed about their progress. Soon Christian and Jan were making fun and working together.

The most improvement was that of Xander. As was mentioned earlier Xander is a child with symptoms bordering classic autism. Xander is aggressive and hostile towards other children. Furthermore he does not play outside with the rest of the children but stays in the classroom. When playing he keeps the other children away. His teacher was amazed by his improvement. While there was tension and some hostility between Xander and his buddy Jelke, they did collaborate and even reached level 6. Furthermore there were some moments where they had social talk about the movie film that was on that evening.

Ivan is a child who does not talk much in class and is aloof. However during play his teacher stated Ivan was more open and regularly into social talk with his buddy Bert. Bert showed no significant behavioural change during play.

Daan showed no real improvements. His buddy, Erik, was somewhat aloof and to one self, but during the game started making comments and some social talk.

There were also children from whom the teachers did not see big improvements in behaviour in the videos. Sjaak, a very energetic child, was a bit bossy and his teacher recognised this same behaviour also while playing Raketeer. The teacher of Jeroen, Sjaak's buddy, did not recognise any changes in the behaviour of Jeroen. However she stated Jeroen had never had so much fun doing math. Jasper and Job both showed no changes in behaviour. The teachers of Remco and Paul, also did not see a difference in behaviour. Again they did think it was a good experience, but this was not visible in changes in behaviour.

Both the data captured during play and the observations showed improved behaviour. The teacher interviews on the basis of the video compilation were positive, however did not recognise behavioural change in all children.

Appendix E

Results of level 6

This appendix describes the results of level 6.

During the last test day all children, disregarding their game progress, were allowed to play level 6 so they could finish the story and launch their rocket.
In level 6 the children have to do two tasks at the same time together. They have to solve equations to earn shots and with these shots they have to shoot down incoming missiles, before they hit their rocket.
The boss (in game) instructed the children on the two tasks. He also told the children the answer buttons on the lower part of the screen were common buttons and could be used by both players. Furthermore no instruction was given concerning the distribution of the two tasks.
The observations and video recordings showed the children found level 6 stressful. After they had spent the 5 bonus shots they had started the level with, they began to panic over the incoming missiles. The typical reaction was to keep pressing the incoming missile until it hit the rocket, although they knew there were no shots left.
Most children got on track fast solving the equations, however some children needed encouragement to stop panicking and start solving equations.
Apart from one pair, all worked together well and achieved scores of over 50 points during the two games. The pair of Xander and Jelke scored around the 100 points, however there was some provoking and teasing between the two. Xander, who was in charge of shooting down the rockets, provoked Jelke on numerous occasions by shooting down rockets at the last possible moment.
In spite of the stress the children were strongly motivated and found the level much fun. The level card-sorting task described in section 7.4.3 supports these findings as it showed the children found level 6 the most fun level of Raketeer.
All children started the first game of level 6 doing the two tasks together. However, it was interesting to see that after the first game, three of the seven pairs decided on their own to distribute the tasks: one child solving the equations and one child shooting down missiles. The other four pairs came up with the same solution after the experimenter asked them how they could improve their scores on this level. In four of the seven pairs the children arranged themselves so the child with the missile task stood at the top of the table allowing the other child better access to all the answers.
Although the end animation of the rocket being launched was very simple, most of the children were very enthusiastic. They were proud to have finished the game. Some children mentioned they regretted the test period had ended. Xander was very proud of himself and Jelke and even wanted to shake his buddy's hand.

Level 6 showed the children were well capable of working together under the right circumstances. The level showed the children that collaboration can be fun and does not always have to end in a fight.