Combining Inclusion and Individually Adaptive Learning in an Educational Game for Preschool Children

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Abstract

Digital educational games have been around for a long time and have shown to be pedagogically valuable. Unfortunately most games do not utilize technology to the extent that is possible. Not the least this applies to mathematical educational games for younger children.

This work aims to combine several educational scientific approaches using current technologies, which traditionally had been very difficult or not economically viable in the non-digital context. Especially we focus on combining Inclusion with Adaptive Learning while simultaneously use the beneficial properties that Learning by Teaching offers and find additional synergies to improve mathematical learning in preschool children.

No studies have yet been carried out with this system, but it has opened up for several potential studies and offers a mean to carry out cost effective studies, including cross-cultural studies.

Preface

This master thesis work has been done as a part of the Information and Communication Engineering Technologies program at Lund University, Faculty of Engineering (LTH).

I would like to give a special acknowledgement to my mentors Magnus Haake and Agneta Gulz for all the help and support they have contributed with during the journey. I would also like to thank examiner Joakim Eriksson, as well as all other helpful people at the university. To my opponents Jessika Nilsson and Sofie Eliasson for their valuable comments.

To family and friends for their support and for always being there.

Contents

1 Introduction

Mathematics is important. If you fall behind at an early stage it can be very hard to get back on track, but it can also halter development in other learning areas, directly or indirectly.

One of the more important reasons to make sure that young children develop an awareness of learning is that failing to do so may result in that the children develop an Entity Theory of Intelligence — that is a perception of one's own intelligence as something fixed, where it is not possible to expand the level of understanding in a subject. This can be devastating if the teachers don't discover this and let it go even further. The reason for this problem is often a lack of awareness in the teachers, insufficient funds, absence of decent tools, or a combination of these.

This work aims to teach mathematics to children, while preventing some students to fall behind, using today's technology with educational scientific approaches. More specifically it will make use of Teachable Agents, Inclusive Pedagogy and Adaptive Learning using computers and automatic processes. These will all be explained in the next chapter.

The educational game that has been developed runs in modern webbrowsers. This will let the game be readily accessible for a wide range of users while the system can be easily maintained and updated. Webbased games will keep the costs down, while still having the benefit of an automated system, compared to investing in consumables, powerful computers or expensive software. The game aims at identifying students who tend to fall behind compared to other students by collecting data from the players in a structured way. The data will be presented for the teachers and supervisors to enable them to get an overview of the students' progression and development. The system can automatically send warnings to the supervisors if there seem to be problems, and the teachers and supervisors themselves can identify which students may need special support.

Additionally, the game uses adaptive difficulties to keep challenging the students at their individual level of knowledge and mastery, while enabling the teachers to have more control of the students performance over a longer period. This is implemented by collecting game data when the student plays the game and then analysing the data on the server and then adjust the difficulty on the next game based on previous performances. This will also let several children play the exactly same game, independently of their individual skill, which will not exclude any students from doing the same learning activity as the other students.

No studies have been carried out with the system, but there are studies planned in the near future. Worth mentioning is also that this project builds on a master thesis carried out at Lund University [Norrliden, 2012] and can be seen as a sort of extension of that work.

2 Theories and Methods

2.1 Number Sense

Longitudinal studies have shown that children that are late adopters of Number Sense may have difficulties coping with mathematics in school [Griffin and Case, 1997; Hannula et al., 2005; Jordan et al., 2006; Hannula et al., 2007, 2010]. Children that fall behind at an early stage risk severe problems repairing this in school and risk to be out of phase for years to come. It has also been shown that children who develop their mathematical skills early on will perform better when starting to attend regular school [Griffin et al., 1994]. Therefore it is essential to develop a basic understanding of numbers: their magnitude, how they relate to each other, that they can be manipulated and how that can be done — which is known as Number Sense. A person with good Number Sense will [Reys and Reys, 1995]:

- Look at the problem as a whole, before going into details
- Look at relations between number and operations, and take the problem's context into account
- Find methods that corresponds with one's own perception of numbers and strives for finding the most efficient representation or interpretation the problem
- Use reference points to decide a numbers magnitude
- Recognize unreasonable results in computations

One of the most fundamental virtual representation of numbers and their relation is the number line [Griffin et al., 1994]. A number line can support one performing various operations on numbers, as well as understanding the order of magnitude of a number. Since this is such a fundamental piece of knowledge it is essential that we emphasize the knowledge and learning of this. Studies have shown that children are often able to learn to adapt the concept of a number line and these children proved to perform better in school [Griffin et al., 1994].

2.2 Incremental Theory of Intelligence

Studies have shown that one can perceive ones intelligence in mainly two ways: as fixed (Entity) and as something that can grow (Incremental). Having an Incremental Theory of Intelligence means to view one's intelligence as something under development where one can expand ones current level of knowledge and understanding by learning. Having an Entity Theory of Intelligence means to view intelligence as a fixed depth of understanding and knowledge. A child's theory of intelligence can fundamentally influence his or her achievment goals [Dweck, 2000].

Studies show that children who have an Entity Theory of Intelligence tend to choose easier tasks to improve their chance to get positive feedback, or avoid negative judgement, over a task they could learn well from but not necessarily perform well on [Dweck, 2000].

This may prove to be dangerous if a child believes to not be smart enough or is perceived this way by others, e.g. her mother, see figure 2.1. Ones ability to learn might be inhibited and then risk to fall behind other students. This can be the start of a vicious circle, especially since this is highly self fulfilling [Pomerantz and Dong, 2006].

By relatively easy means is it possible to change from one mindset to the other, at least temporarily, [Dweck, 2006] and there are ways to prevent and overcome an Entity Theory of Intelligence. As we will mention later on a Teachable Agent is a way to support a development of Incremental Theory of Intelligence. Likewise Inclusion and individual adaptive difficulties have positive effects.

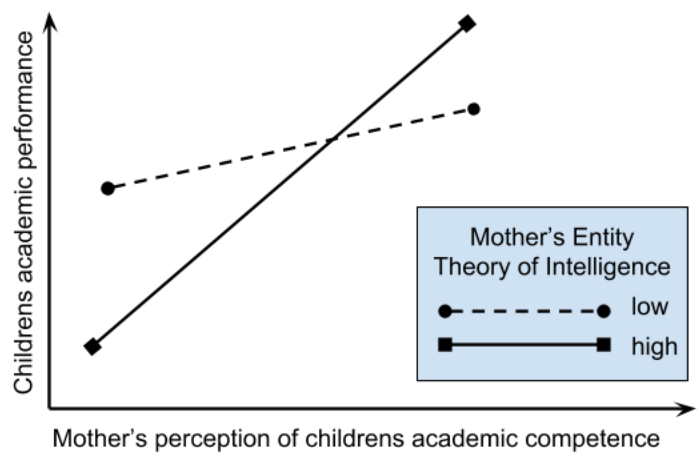


Figure 2.1: Mother's effect on children's academic performance. The children's grades are shown as a function of the mother's endorsement of entity theory of intelligence and their perception of the children's academic performance. Adapted from [Pomerantz and Dong, 2006]

2.3 Teachable Agents

Having a digital tutee, commonly referred to as a Teachable Agent, have shown several positive properties in studies [Chase et al., 2009]. Integrating a Teachable Agent, TA, into the game can prevent the development of an Entity Theory of Intelligence, or overcome if it already have been developed. It can further improve a student's learning by offering new ways of thinking and reasoning.

To fully understand the concept of Teachable Agents, and other parts of this article, we need to establish a few terms: Agent and Avatar. In a computer game there are often several social entities. One of the more common entities is the non-playable character, NPC, which we will refer to as an Agent. The

Agent is an entity that a player cannot directly control but that is controlled by the computer. An Avatar on the other hand is a character that represents the player in the game. The player will usually control this entity directly with a mouse, keyboard or gamepad.

Knowing the differences between an Agent and an Avatar we can define the Teachable Agent as a hybrid between these two. The player does not directly control the Teachable Agent, but rather interacts with the game environment to influence it. The TA will learn och be influenced by the player's actions in the game and can therefore also be seen as an Avatar.

There are several reasons why a Teachable Agent really works and improves learning. One important aspect is that the player will share some of the responsibility with the TA. A so called Ego-Protective Buffer will thus shield the player from forming negative beliefs about themselves if they should perform poorly [Chase et al., 2009]. Another aspect is that the player wants to learn and develop the TA and the approach known as Learning by Teaching has shown great results [Blair et al., 2007]. These aspects will all be explained in the coming sections. Recent studies also indicate that the sole presence of a Teachable Agent can have positive effects on the student's performance on tests [Sjoden et al., 2011] and that a social entity may reduce the effect of distraction a student is exposed for [Axelsson, 2013].

2.3.1 The Media Equation and Theory of Mind

In order for Teachable Agents to work it is required that a player has the ability to realize that other persons may have beliefs and knowledge, that differs from one's own, and apply this to the virtual entity in the game.

The ability to attribute mental states to others is know as a Theory of Mind [Premack and Woodruff, 1978]. Studies have shown that this can be applied to computers and virtual characters as well. This is known as The Media Equation meaning that people tend to treat virtual characters and computers as real persons or places [Reeves and Nass, 1996; Johnson et al., 2004].

2.3.2 Protegé Effect and Learning by Teaching

Studies have shown that teaching another is an effective way to improve one's own knowledge and understanding of the subject [Biswas et al., 2005]. To properly teach a subject it is often required to approach the problem in a different way which encourages the student into new ways of reasoning and thinking. In other words, Learning by Teaching is a powerful pedagogy.

Since a player is able to see the agent as a protegé [Dweck, 2000] Learning by Teaching can be applied to Teachable Agents as well as humans. Having a digital protegé has shown to yield several positive benefits in learning. A collection of these benefits have been termed the Protegé Effect. The player has a sense of responsibility to teach her protegé and will invest more time and effort into teaching the agent, than she should if she were to learn for herself.

From the student's perspective the time spent is not perceived as learning but rather to become able to teach the TA more [Chase et al., 2009].

2.3.3 Ego-Protective Buffer

One of the more important properties of a protegé is the Ego-Protective Buffer. Sharing the responsibility for what happens with the protegé can decrease or lessen a student's blaming herself when failing an assignment. She may reason that it was the Teachable Agent that did not know enough, or that her own ability to teach the TA was not good enough yet, instead of her own knowledge in the given subject. This will greatly prevent the player from developing an Entity Theory of Intelligence, all the while perceiving that the TA's intelligence as incremental [Chase et al., 2009].

This may result in that the player dares to take greater risks while learning without loosing motivation in case of failure. Learning by trial-and-error often yields at least a small increase in knowledge and understanding. It has also been shown that the learning results are better if the Teachable Agent behaves like a good student and promotes self-regulation [Biswas et al., 2005].

2.4 Adaptive Learning

Dynamic difficulty can be used to enhance the players learning efficiency [Sampayo-Vargas et al., 2013]. With problem sets that are adjusted based on the players current level of knowledge and understanding, a system can attract a wider target audience as well as make it possible to follow each player for a longer time. This will result in having more accurate data, that can be used in the system to enhance the learning efficiency even further, as well as it makes it easier to do longitudinal studies. If the degree of difficulty is adequate enough, based on the current skill and mastery, the student will be able to stay focused longer — since a too easy, or too hard, assignment will make the student lose motivation.

> "Development and learning advance when children are challenged to achieve at a level just beyond their current mastery, and also when they have many opportunities to practice newly acquired skills."
> – [Copple and Bredekamp, 2009]

To be able to adapt the difficulty level there's a need to know the student's current depth of understanding as well as to know how difficult the next problem should be in relation to that. This can be approximated with an approach known as Dynamic Assessment. Furthermore there are approaches such as Vygotsky's Zone of Proximal Development, section 2.4.1, to take advantage of the knowledge of the player's depth of understanding and Scaffolding, section 2.4.3, to give support to the player.

2.4.1 Zone of Proximal Development

A method that is widely used in the study of children's mental development in relation to education is the Zone of Proximal Development, ZPD. There are several common conceptions of what this zone is [Chaiklin, 2003], and in this article we will make use of several of those aspects. The common interpretation can be defined as the distance between what a student is able to learn on his or her own, and what can be done with the help of a peer [Vygotskiĭ, 1978]. Figure 2.2 illustrates how the Zone of Proximal Development relates to the player's current knowledge, the Comfort Zone, and what is currently beyond the student's reach.

> "It is within this zone that a person's potential for new learning is strongest" – [Fabes et al., 2001]

The Zone of Proximal Development is not a fixed attribute, but is something that is constantly in change as in relation to the student's development of new understandings and knowledge. As the student learns more the Comfort Zone will grow and the ZPD will stretch further into what was before the out of the student's ability to learn, even with aid.

This can be interpreted as the zone of difficulty where the assignments should be based in order to challenge the student, but still be possible to solve [Berk and Winsler, 1995]. The zone is were the children will be challenged just beyond their current mastery and the children's development and learning will advance [Copple and Bredekamp, 2009], and will advance the most [Fabes et al., 2001].

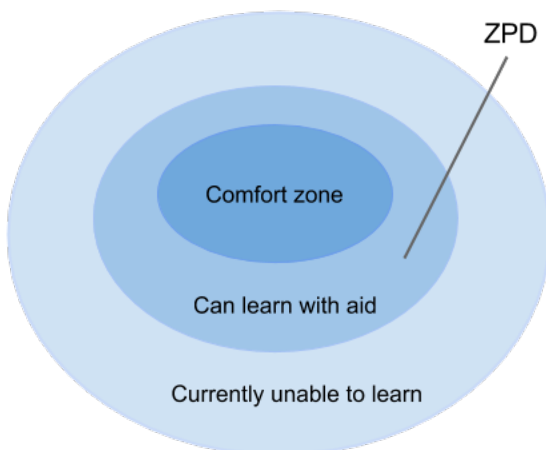


Figure 2.2: Zone of Proximal Development

2.4.2 Locating the Zone of Proximal Development

One way of understanding the Zone of Proximal Development is to know the player's current depth of understanding and what is currently beyond reach. There's one approach, known as Dynamic Assessment, that this project adapts in order to locate the zone. The term Dynamic Assessment, DA, is used in several contexts and here we make us of it as finding the student's learning potential as well as the student's current knowledge. This use is in-line with the general core criteria, which can be described as the three following characteristics [Lidz, 1991]:

- Test-Intervene-Retest format
- Modifiable
- Provide useful information for interventions

By assessing the player, evaluating the result and then adjusting the difficulty before assessing the player again, will the system be able to see a gain, or loss, in the potential of solving assignments in the assessed difficulty zones. By continually adjusting the difficulties, based on previous assessments, and reassessing will the game be able to have an approximated view of the player's ZPD. This process is illustrated in figure 2.3.

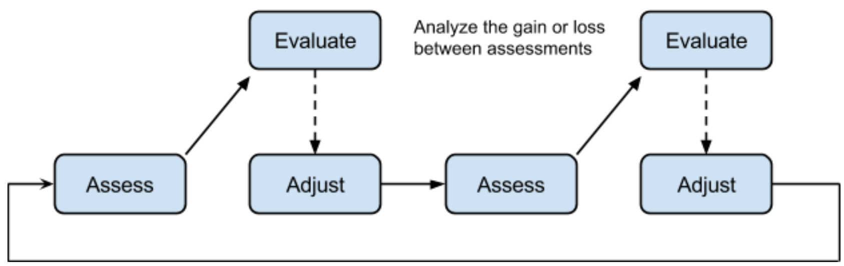


Figure 2.3: Dynamic Assessment

2.4.3 Scaffolding

As stated before, when defining the Zone of Proximal Development, on one's own one can only accomplish a task within the comfort zone, and in order to complete a task in the ZPD aid is needed from a peer, or other.

> "What the child is able to do in collaboration today he will be able to do independently tomorrow" – [Vygotskiĭ, 1978]

When a player is first introduced to a new assignment in the ZPD there's a need to have some aid in order to be able solve it. This is of course also true for a problem in a field already know, but outside of the current depth of understanding. Typically the aid can be given as templates and guides, or as a more capable peer giving hints and supervising. The best scaffolding provides this help in a way that encourages the player to actively participating in constructing the new knowledge [Sawyer, 2006].

> "Scaffolding is the help given to a learner that is tailored to that learner's needs in achieving his or her goals of the moment"
> – [Sawyer, 2006]

Gradually as the player's skill and mastery is increased the scaffolding can be removed and the player finally be able to stand on his or her own. This can be seen as analogous with the scaffolding at a construction site were the workers gradually adds scaffolds and then remove them until the building stands on it's own. The scaffold is never meant to be a permanent aid, but rather a help to let player complete a task within the ZPD which would otherwise not be possible without aid [Sawyer, 2006].

2.5 Inclusion and the Golem Effect

One common occurrence in the classroom is the teacher labeling the students into different groups based on their performance and perceived intelligence. This has proven harmful for children that are labeled as low performers by the teachers. When a student has low expectations it is very likely that the expectations are fulfilled, which is known as the Golem Effect [Babad et al., 1982]. This can in some manners be compared to the Entity Theory of Intelligence, which is the student's perception of her own intelligence as fixed and thus being unable to learn, while the Golem Effect refers to the expectation of not being able to perform good enough.

To prevent this self-fulfilling prophecy there's a need to make the student feel part of the group and not be treated differently. Inclusive pedagogy usually aims to mainstream people, often children with special needs, into groups with "normal" children [Allen and Cowdery, 2011]. Several studies have proven that inclusion in education yields great results [Madden and Slavin, 1983; Banerji and Dailey, 1995; Wolfberg and Schuler, 1999].

There are several difficulties with having students with diverse capabilities in the same classroom. Not only are the teachers required to spend more time with the students with lower capabilities, which gives less time for the other students, it will also be required that the material used in class is at a level that suits every student in the room, which generally costs more.

2.6 Developing Back-ends

2.6.1 Introduction

In order to be able to have persistent data in the game and analyze a player's development over time we need to store the data in some structured way. The data is most commonly stored and processed on a server, which is also known as a back-end. This back-end is then connected in some way with the visual part of the game, often with a predefined protocol for communication between the two parts. Using the protocol the front-end can send information to the back-end, and request stored and processed information when needed.

2.6.2 Ruby on Rails

One of the first decisions when developing a back-end is to chose a language in which it will be developed. After some research Ruby on Rails seemed to be a good choice. Ruby on Rails, often referred to as Rails, is a powerful framework to develop both prototypes and full fledged webb applications. Among the advantages of Rails we find:

- Follows the Model-View-Controller software pattern
- A large base of complete modules of functionality, referred to as Gems
- Offers simple and easy means to do testing
- Follows "Convention of Configuration", meaning that the layout of the files and functionality of the application follows a certain pattern in all applications, which makes it easier to share it with other coders
- Follows a RESTful and resource orientated approach
- A great and up to date community with a lot of open source projects

It is also used by several large and established web sites today. Twitter was until recently one site that used Ruby on Rails for it's back-end. There are also Basecamp, Github, Groupon, YellowPages, Kickstarter.com and several more known sites [Ruby on Rails]. We can also see an increase in job trends, see figure 2.4, over the past years compared to other popular languages used in back-end development [Indeed].

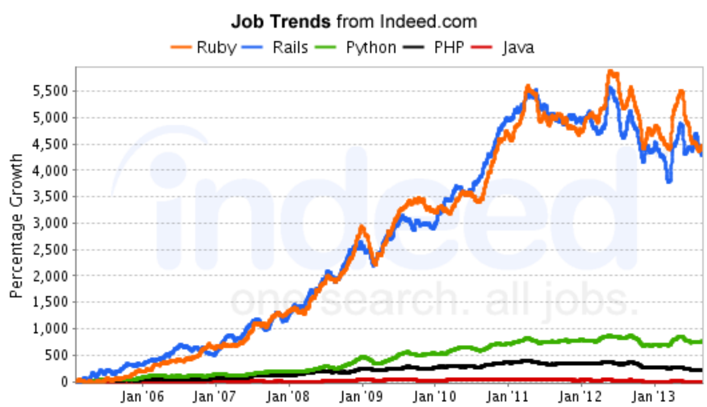


Figure 2.4: Trends of jobs in Ruby on Rails during the last few years, in relation to other popular languages

One particularly neat feature is the above mentioned Gems. These gems contain functionality and behavior packed in a way that makes it very easy to integrate code produced by other developers and companies. As an example there is a gem to provide login functionality to the site [Plataformatec], with all the necessary parts and security needed, with just a few lines of code and some configuration. This functionality could take days, or weeks, to implement from scratch and would possibly be less secure — with the gem it can instead take half an hour to get it up and running properly.

2.6.3 Storage and Hosting

Before a user can visit the site it needs to be put online. Hosting is the term for how and where the site is stored. There are several possibilities to host a site. One way is to personally use a computer where all the files used are stored, this requires a lot of configuration and is quite expensive if one doesn't have all the hardware already. Another way is to buy a part of a computer from a web hosting company, or web hotel, this is one of the more common cases. Recently there have come up several Platform as a Service, PaaS, solutions were one doesn't need to bother with unnecessary configurations if you don't want to and is most often much cheaper. A PaaS that is often used together with Rails is Heroku [Heroku]. Heroku offers free hosting until the service needs to be upgraded to support more simultaneously visitors on the site. It is also a stable and reliable service which is easy to use.

Media files are often large and need to be accessed quickly by the user. Amazon offers a service named Amazon Simple Storage Service, shortened Amazon S3. It provides a simple service that can be used to "store and retrieve any amount of data, at any time, from anywhere on the web." [Amazon Web Services]. It is secure, fast and reliable and easily integrated with Rails through gems. Using the combination of Heroku with Amazon S3 makes the system completely cloud based and accessible from all over the world with minimal effort, costs and loading times.

3 Results and Discussion

There have been no studies carried out yet with the resulting system, but we have come a long way with enabling individual learning in an inclusive environment.

3.1 Technology and Privacy

3.1.1 Sensitive Data

When developing a game to be used by such a broad audience as this, and for educational purposes, we need to take privacy into consideration. There are several privacy laws, and they often differ from country to country. Sweden for example regulates storage of citizen numbers outside the country's boarders. Therefore we have decided to not store sensitive data at all in this system, since it doesn't effect the game or educational values, in the current state of the game.

All information should not be publicly available to all users, therefore we have implemented an authentication system in the game. Each registered user has a specific role, e.g. student, supervisor or administrator with their own set of rules of what data they have access to. An example is the supervisor. A supervisor is only allowed to see his or her own information and certain selected information about the supervised students. More on supervising is explained in section 3.2.6.

The authentication system used in this game is a proven system used in several commercial products today and uses strong encryption, in case of intrusion.

3.1.2 Implementation

The visual part of the game, the front-end, is implemented in HTML5 and JavaScript and the server side, which is also known as the back-end, is developed in Ruby on Rails. This have several benefits. First and foremost it's a web-based game which enables everyone to be able to play the game as long as they have a browser installed on the computer — which every computer ships with nowadays.

This work have focused more on the server side of the game, since the basics of the front-end of the game was developed at an earlier stage. This article will not go into details regarding the front-end; the interested reader is encouraged to read the work by Norrliden, which describes the design considerations and the process of developing the front-end [Norrliden, 2012].

At the start of this project the game did not provide different levels of difficulties and did not remember any information from previous sessions and the students performances. A basic structure enabling persistent states have been implemented in the back-end and the data is stored in a database. This information can then be processed and presented to the front-end when required. In the database we store information such as the players' performances and other data related to previous sessions. We also store individual information regarding the student, as well as information about the teachers and supervisors and their academic relation to the student.

Now that we have persistent data stored in a database we need to provide the front-end with the appropriate data when needed. We have therefore created an API through which the front-end will communicate with the back-end. This API ensures that the data sent between the server and the game is sent in an organized way. The API is enforcing a RESTful architectural style which, among other things, enables us to easily change the behaviour of one part without affecting another part. Eg. altering the way the difficulty is computed doesn't interfere with how the game is presented to the other player, as long as the new way still follows the protocol set up with the API. Vice versa, if we change how the game looks and interacts we know it won't effect how the difficulty is computed. The illustration in figure 3.1 shows how the game communicates with the back-end through the API. In this illustration we can see that altering the system on either side of the API doesn't interfere the other as long as they communicate accordingly through the API.

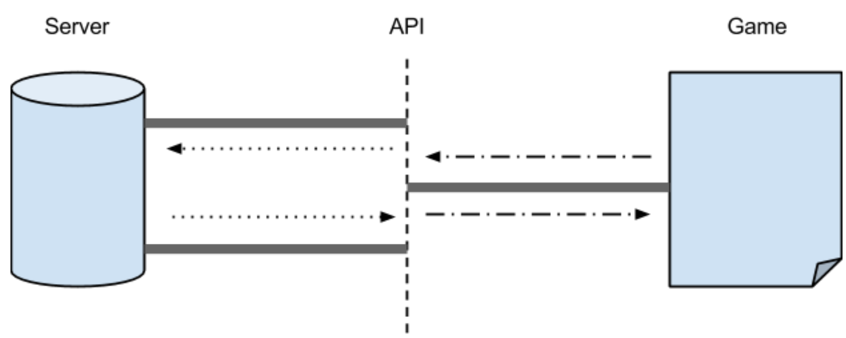


Figure 3.1: Communication between server and game is via an API. The API enforces the game to communicate with the API in a predefined way and it communicates with the server in a different way.

This game makes use of several third party code and services. We used Heroku [Heroku] as the platform for hosting. It allowed us to have the game up and running online on the web without any costs, since we don't have that many visitors at the beginning, and it's easily scaled up to support a lot of users. All media files are hosted on a service on Amazon known as S3 [Amazon Web Services]. Amazon S3 stores the files a very low cost and provides a great bandwidth — letting them be distributed to the visitors all over the world in no time. The combination of Heroku with Amazon S3 is widely used in commercial projects and ensures a stability and uptime of the system with minimal effort and low costs. The code bases we used where often packed in so called Gems. These Gems enabled us to add stable and good functionality to the system with ease. More specifically we used Gems such as:

ActiveAdmin for creating a usable system for the administrators where all data can be modified and viewed.

Devise for authentication and login system

CanCan for having different roles for the logged in users, which let us present different information depending on their individual access.

The use of Ruby on Rails was a good decision. It allowed us to build a prototype rapidly which enabled us to focus more on the educational scientific approaches instead of the implementation, while still having a reliably and well working system. Among the best parts are the Gems provided by the great community — which enables us to implement functionality, e.g. authentication, with minimal effort while maintaining the stability and performance needed — and the scaffolding to quickly create a model of a resource which should be stored in the database.

3.2 The Game

The goal of the game, from the student's point of view, is to help her digital tutee to grow his or her garden while playing mini-games. At the moment there are currently two different scenes which the mini-games are built upon, but the system is implemented to handle more. The term "scene" can be simplified as to how a mini-game looks and behaves. This look and feel will always be the same, but its content can be changed depending on the information supplied from the back-end. As an example we have the scene in figure 3.2 which displays how a mini-game with the Lizard scene looks like. In the figure we see that there are a couple of dices ranging from one to six. These dices can be replaced with digits, or other representations, to adjust the difficulty while maintaining the same look and feel. Each combination of Number Representation, Number Range and Scene is referred to as a mini-game. The mini-game also has information about what is the maximum score for that particular combination, as well as what thresholds are considered a good and poor performance in relation to that score.

3.2.1 Playing the Game

In its current state it's always a teacher or supervisor that initiates a new session for the student. This is based on that the children most likely can not read and write yet and thus would have difficulties to initiate the game by themselves.

The game starts with the supervisor logging in to the webpage where she will see an overview of his students. Here the supervisor may choose to view statistics about the student or initiate a new session. When the session starts the student first receives instructions by the game before she takes over and starts to play the game. The session is split in two rounds, which are divided into three parts each.

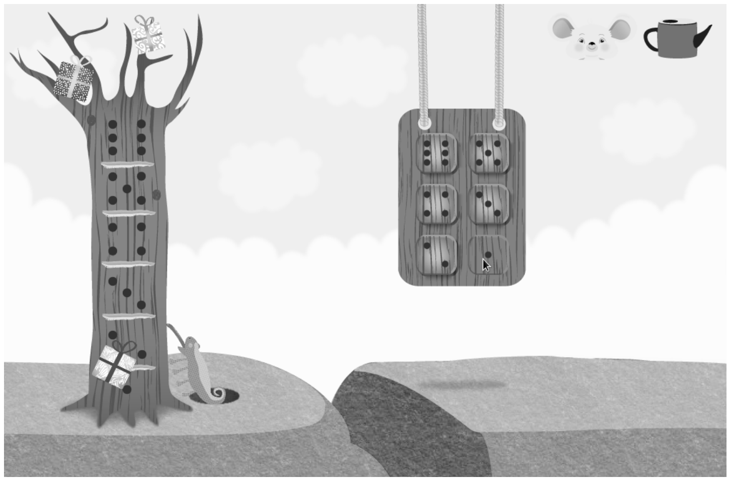


Figure 3.2: Screenshot of the Lizard scene with dices as Number Representation with the range from one to six.

First the player plays by himself. This part is where the student learns the mechanics of the mini-game and practices it. There are no indications that the TA is involved in the game in any way. In figure 3.2 we can see how the TA is hiding in the back in the top right corner.

Next is part is were the player plays but the TA is clearly visible, see figure 3.3 in the game and is perceived to be watching the players action — this is one of the stages were the student is teaching the TA to play. The scoring result of this part will affect the TA's performance later.

The last part is one where the TA plays and the student supervises the TA's actions. In this stage it is the TA that selects the answer. The answer is a weighed randomization where the chance of picking the correct one is partially based on the player's performance. After the TA has chosen it is up to the player to confirm the answer as the correct one, or to rectify it if the player thinks that the TA was wrong. In figure 3.4 we can see TA's role in the final stage.

These three parts are repeated twice to make up the whole session. The reason for playing two rounds in each session is to reduce some level of uncertainty in the game that might be introduced by guessing, luck or other reasons for the student to perform divergent. A session has a maximum score that can be obtained, which is only possibly if the user have managed to have zero wrong answers. The way scoring works is that for each incorrect answer we deduct one or several points from the maximal amount, depending on the severity of the incorrectness. After the session is over we have a total score that represents the performance. The mini-game also has a certain threshold that represents what a good session is versus a bad. As an example we may state that the student masters the topic if he scores more than 80 percent. If the student then

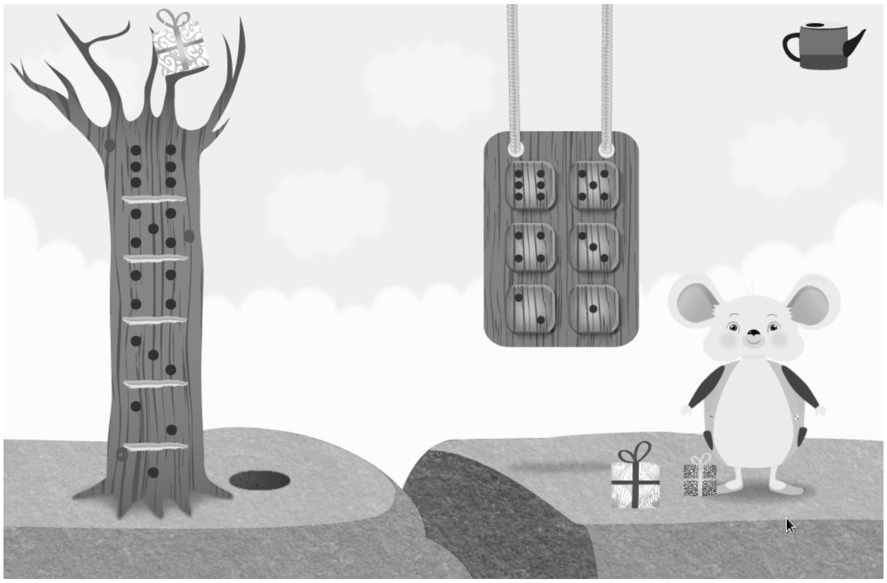


Figure 3.3: Screenshot of the Lizard scene with the Teachable Agent clearly visible.

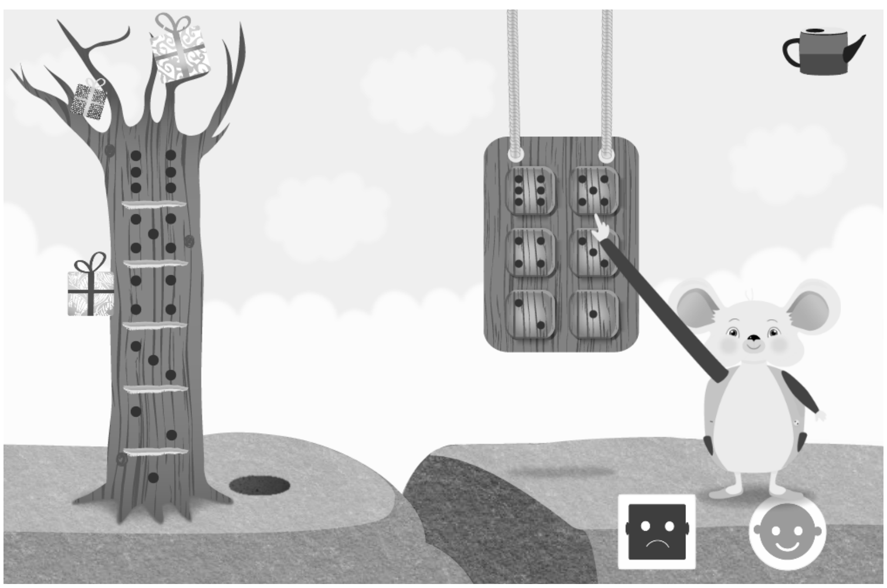


Figure 3.4: Screenshot of the Lizard scene with the Teachable Agent playing the game by pointing at an answer and the child is encouraged to decide whether it was correct or not.

scored 28 points out of 34 possible we assume that the student mastered it and the game will then adapt to this in future sessions. If the score was below the threshold it will have a different effect on the system.

3.2.2 The Process in a Short Step-by-Step List

To get a better overview of how everything is connected, here follows a short step-by-step list of the process which is also illustrated in figure 3.5. These steps are all explained more in depth in the following sections.

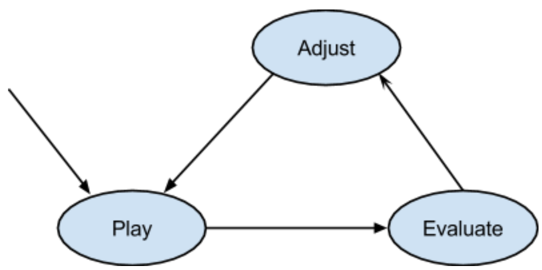


Figure 3.5: Play - Evaluate - Adjust

1. **Play** The student plays a session and collects information
   - Among the collected information we find:
     - the number of correct/incorrect answers
     - who plays the game
     - which supervisor initiated it
     - which difficulty settings are in play
   - When the session has ended this information is sent to the back-end.
2. **Evaluate** When the session has ended the collected information is used to analyze the performance and find the student's current depth of understanding.
   - In the back-end the new data is analyzed together with the previous session data
   - This results in that the system can form a view of which depth the player is currently at
   - Knowing what the student is able to, and not able to do, we are able to approximate the player's ZPD
3. **Adjust** Knowing the player's ZPD, in relation to the system's difficulty levels, are we able to set an appropriate difficulty on the next assignment
   - Outcome of the evaluation

  - If the student shows a tendency to have gained knowledge then we let the player play the same game again, until there's a more stable depth of understanding
  - If the student is able to solve the assignment with a good result, and has proven to do this a few times such as it can be interpreted as a stable result — then we increase the difficulty
  - If the student performed poorly we will decrease the difficulty

- Adjusting the difficulty based on the outcome of the evaluation
  - To adjust the difficulty we mainly focus on changing the following attributes: Number Representation, Number Range, the Scene and the amount of Scaffolding
  - After the system has chosen an appropriate level of difficulty this information is stored in the database linked to the student
  - Next time the student initiates a new session this information will be fetched from the back-end and will thus, hopefully, be presented with a challenging, but solvable assignment

3.2.3 Finding the Players Current Depth of Understanding

Every session can be seen as an assessment. When we assess the player we know what the maximum score can be on that level. After each session the game will send the results to the back-end were it will be saved and analysed before presenting the next assignment.

If the player scored above a certain percent of the maximum we can interpret this as that the player knows the fundamental pieces of the subject and can then proceed to a more difficult assignment. The processing of the results follows the set of rules explained in section 3.2.1. This method is not one hundred percent accurate since the player might have guessed the correct answers, or otherwise performed divergent from his or her actual capabilities.

To increase the certainty of the method we always assess the player with the same difficulty at least two times, to prevent situational data to affect the rating. It is not very likely that the player is able to correctly guess the correct answers and score above the threshold two times in a row.

Now when we know how to find the player's capability to solve an assignment of a specific difficulty we can start to investigate an appropriate difficulty level to base the coming assignments on. The investigation follows the pattern of Dynamic Assessment, explained in section 2.4.2, where we continually asses the player and then analyse the gain or loss in outcome between each assessment in order to understand the limits and borders of the player's current ZPD.

Figure 3.6 illustrates how the Zone of Proximal Development is related to the student's current depth of understanding and shows the process in locating it. The red dot is an assessment above the ZPD, that is the student wasn't able to solve the assignment properly. After that the difficulty was decreased (green dot). The new assignment was too easy, and was thus below the ZPD. Next time we increased the difficulty and the student's scores on this difficulty

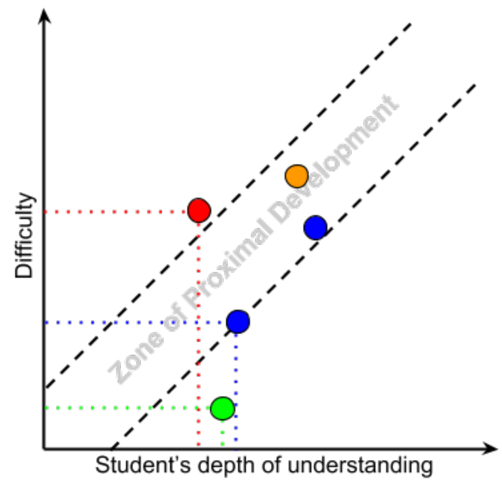


Figure 3.6: Difficulty in relation to the player's Current Depth of Understanding

indicate that it was challenging but solvable (blue dot) and was thus nicely placed in the ZPD.

As the player's depth of understanding increases we have to increase the difficulty of the subject, by either introducing new fields, e.g. representing numbers with digits instead of fingers, put the subject in a new environment, or increase the difficulty within the same field; e.g. increase the number range. The logic of adjusting the difficulty is further explained in section 3.2.4.

3.2.4 Adjusting the Game Difficulty

Until now we have assumed that we are able to adapt the difficulty of an assignment, but haven't discussed how this can be done. With the assessments we make in section 3.2.3 we are able to find how capable a student is to manage an assignment on that difficulty.

There are several factors that we can alter in order to affect the difficulty of the game. In this game we currently focus on:

- The Number Representation
- The Number Range
- The Scene
- The Amount of Scaffolding

For each factor we have a set of available options. The first factor for discussion is the Number Representation. A child not yet exposed to mathematics is most likely to use the fingers to represent numbers and cardinality, since this is one of the most basic ways of representations and the child is unlikely to be able to read at this age. The representations we make us of in this game, in order of difficulty, are: objects, fingers, dots and digits. Changing from one representation to another greatly affects the difficulty of the assignment.

Therefore are we also able to change other attributes, such as the Number Range, in order to have a more fine grained modification of difficulty. When a child first learns to count will it only be able to count up to a limited range. As the child's understanding and knowledge grows will it be able to count even further. By decreasing the maximal number in the range, and presenting a short range of number, the assignment will be easier than if the range of numbers is larger and contains numbers of greater magnitude.

As the student plays the same game over and over again he or she will become familiar with the environment. By changing the scene of the game, but still maintaining the same mechanics, we are able to add a little confusion to the student and address the mechanics in a different way — as well as contributing to that the student won't lose interest because of too much repetition in the game.

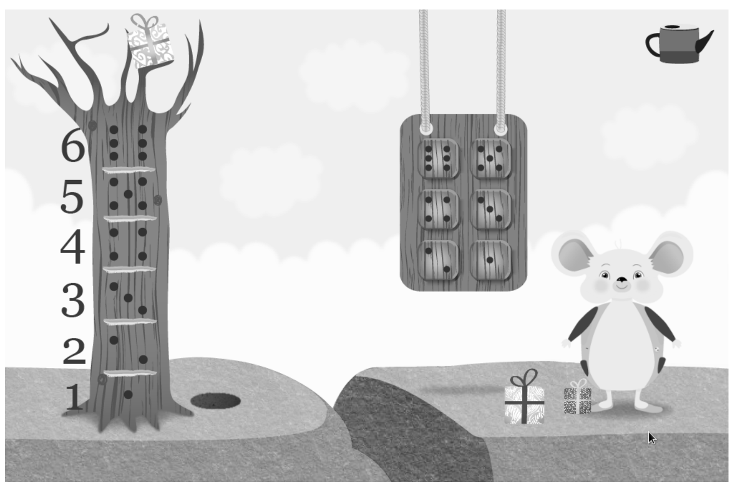


Figure 3.7: Providing scaffolding by double-coding two number representations. In this case numbers along with dices.

Finally we are able to adjust the level of scaffolding provided by the game. The teachable agent will always provide some hints when it plays and suggest an answer to the given problem, but will also be able to drop hints a long the way in the form of questions while the child plays. One of the more distinguished ways we use scaffolding in this system is by double coding one level of number representation with another level. In figure 3.7 can we see how the same assignment is presented with two different difficulties, the one to the left is single coded with digits only, while the one on the right is double coded with both digits and dots to make the transition between dots and digits easier by mapping them together while the student solves the assignment.

As a note is it important to clarify that the scaffolding in this game is not meant to replace the scaffolding provided by the teacher.

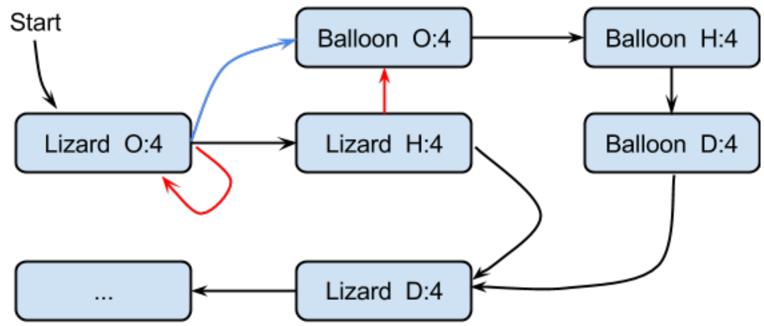


Figure 3.8: An example of a map illustrating difficulties and their relations

In the current state of the game the degree of difficulty is not entirely adaptive but the behavior rather follows a predefined pattern. In figure 3.8 we can see an example flow that the user can be subject to. The user first starts with the Lizard game with a small number range, and numbers represented with simple objects. If the player performed well, black lines, on that level he or she will proceed to the next level which is the same Lizard game with the same range but with the numbers represented as hands. If the player performed mediocre he or she will follow the blue line instead, and will then play the Balloon game with the same difficulty for representation and number range. In the illustrated example only two red lines, which are followed in case the student performed badly and the assignment was above the student's current depth of understanding.

The illustration is a simplified version of the real map, since the real map is much more complex and the illustration would then be incomprehensible. One of the things the illustration does not show is when the double coding takes place. For this we refer to figure 3.9 which is an isolated occurrence of how double codes is related to the map; the color coding in this illustration is as described earlier. First the player plays the Lizard game with dots and with the range up to 4. If it went well the player will proceed to an assignment with digits instead of dots. The step from dots to digits is quite large, therefore we are introducing a double coded level where there will be both dots and digits next to each other to simplify the transition.

3.2.5 Including Everyone

In section 2.5 we discussed the importance of inclusion in the classroom. If a child is labeled as less capable he or she is highly likely to perform worse and might develop an Entity Theory of Intelligence.

Our take on the problem, in this project, is to adapt the difficulty level for

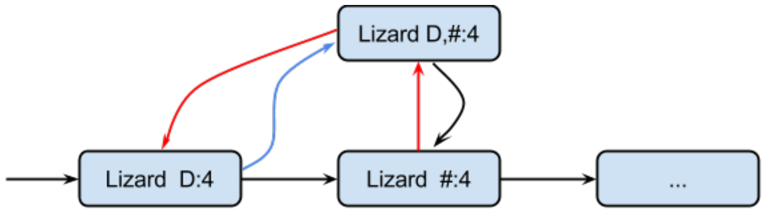
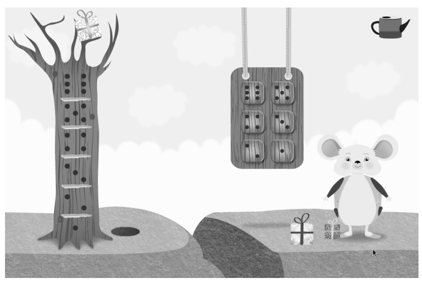


Figure 3.9: Illustration of the use of double coding in the flow



(a) Dices

(b) Numbers

Figure 3.10: Screenshot of same scene, but with different level of difficulties.

each individual student while keeping the same scene and appearance independent of the difficulty.

This will make the game look very similar for both the developed student and for the late bloomer. By changing small parts of the environment, adjust the difficulty level, and keep the scenes the same the children will not be able to see the differences that easily, see figure 3.10.

To further enhance the feeling of playing the same game there's the concept of the garden — which is the grander goal that connects all mini-games. This will shift some of the focus to develop the garden from the actual contents of the game. When the children communicate about the game they will be able to talk about the garden and what nice items they have decorated it with, instead of game content differences.

In this way all the children get the sense of playing the exact same game, while in reality they are playing a game which is very individualized.

3.2.6 Tracking Players Development

One advantage of having educational software is the amount of data that can be mined and the short delay between the student's actions and the teacher's feedback on the matter. By gathering data for every action the student takes we are able to analyze the progress of the student afterwards in a structured way.

We have built a supervisor zone where the supervisor, or the teacher, will be able to login and see information about his or hers students. The children's progression through the difficulties is easily visualized and the scoring can be nicely viewed in charts.

There are great possibilities to present data that would compare students with students, as well visualizing the progress of a single individual. With these possibilities we are on to one of the maybe most important parts: the ability to locate students that show tendencies to fall behind. If the system is smart enough we are able to see tendencies before the student is too far behind, and thus be able to give extra support for the player before the damage is done.

Another project focused on presenting student data to the teachers have been carried out in parallel with this work, [Anderberg, 2013]. I recommend reading the article to get further information about the subject. The article investigates what kind of data the teachers are interested in and how they emotionally feel about having digital tools to aid them in their work, among other things.

4 Final Words

4.1 Conclusion

Even though no studies have been carried out yet with this system we have managed to come a long way with combining Inclusion with Adaptive Learning in order to enhance learning.

This work has resulted in theories about how inclusion can be realized with adaption of levels of difficulties, as well as a prototype webbased game with a back-end that implements this behavior. There have been several aspects to consider when implementing educational games for a broad audience with persistent data, such as handling sensitive data, stability and accessibility.

Theoretically, this game seems to have managed to combine several educational scientific approaches that traditionally would have been very difficult to realize. Most notable is the ability to adapt the game to each individual using the player's approximated depth of understanding in that moment. This will result in a game that looks alike for every player, independently of the various players' capabilities — which can be used in education to include children with mild disabilities.

Furthermore we enhance all students learning by adapting Learning by Teaching through Teachable Agents. We also protect the children from developing an Entity Theory of Intelligence.

Large parts of the front-end in this work had already been developed in a HTML5 game earlier [Norrliden, 2012]. The state of the game were we took over was that the game was able to run two different scenes in the game with a teachable agent, but no effort to having persistent data between the sessions was in place. We were therefore required to do several changes to the game in order to have persistent data, and apply the adaptive difficulties and other aspects to the game. Most notably we had to develop a back-end to process and store data and adapt the game to communicate with this and use the processed data appropriately.

The choice of using Ruby on Rails as the language of the back-end turned out to be a good decision. It enabled us to develop a prototype of the back-end at an early stage to use with the game. Several concepts could easily be tried out and discarded because of the nature and ease of the framework. Open source packages for a lot of basic functionality, database handling and "convention over configuration" together with the enforcement of the Model-View-Controller pattern contributed to having a solid and stable system.

In the back-end we saved all the sessions linked to each player and we were able to use this information in order to analyze the current depth of understanding. Using this analytics we could then adapt the difficulty of the next problem that was presented for the user and thereby enhance the learning of the student — while including each and every student into being able to play the same game.

Because of this, we dare say that we have succeeded, theoretically, in creating a tool that can be used in education which will educate children in mathematics and number sense — and prevent less capable children from notable falling behind the other students in class.

4.2 Future Work

Although we have come a long way in improving the learning of mathematics in children, we still have much more we can do to improve the system even further.

4.2.1 Improved Supervisor Zone

Considering the supervisor zone only a fraction of our ideas have made it into the system in its current state. Among the missing functionality we find functions such as:

- More options to filter and search the data
- Better visualization of data
  - A single student's development
  - A single student's performance
  - Students compared to each other
- Export options
- Synchronization with other student management tools

4.2.2 Automatically identify children in a risk zone

One of the great possibilities with the supervisor zone is that the teachers are able to see when a student tends to fall behind the others. Even though this is great there's still manual work to do and a supervisor, especially if overstrained, might overlook the indications. To reduce some manual work and human errors we should be able to improve the system to let it send warnings to the concerned teachers and supervisors when there are indications. With an automated process in parallel with the manual work we should be able to enhance the ability to identify the children in the risk zone and limit the damage before it's done.

4.2.3 More generic difficulties

When we started this project there was an idea of making the difficulties more generic instead of having a fixed map that each student would follow. This idea was soon put aside due to time constraints since it could be rather complex.

The main idea was to have a rating system of each student's capabilities in several areas. The proposed solution would be to track the development of a student's knowledge for Number Representation, Number Range etc separately. This would for instance enable us to adjust the Number Range on an assignment without the student necessarily would have to master Number Representation, which otherwise be needed in our current system.

The rating system would thus enable us to present the student with a more fine grained difficulty for an assignment based on each attribute; as well as open up for even more fine grained data that can be used by the supervisors to track the students progressions in several areas.

4.3 Potential Studies

The system and the game that have been developed are well suited to make studies with. Unfortunately the time frame in this master thesis did not cover enough time to carry out a study, but have opened up for several interesting studies.

Since the platform is webbased and most parts of the game is made up of symbols it would be very easy to use it in different countries with different languages, which opens up to do cross-cultural studies in a relatively smooth manner.

4.3.1 Can we motivate all children to learn math

The ultimate goal is to have all children knowing the fundamental parts of Number Sense and mathematics. The first step to understand math is to practice it. An interesting study could be to see if we can motivate all children to learn math by playing an educational game.

4.3.2 Are there any cultural differences

Are there any cultural differences between Swedish children and the children in the US? Even though we assume that they are similarly, that's just an assumption. The system is not limited to Swedish and US schools but can also be used all over the globe and with slight modifications also be used at home.

A lot of the theories that's applied to this work is based upon research and studies carried out in the US. Will this game work in other cultures as well?

4.3.3 Are we able to identify underdeveloped children early on

This system mines a lot of information about the players and presents them in a comprehensible way. Is the system really able to present the data in such a way that the teachers and supervisor can see which students falls behind in an early stage? Ultimately, can the system automatically find the underdeveloped children and notify the teachers in such an early stage that it makes a difference?

4.3.4 Do Teachable Agents really work on younger children

We make an assumption that Teachable Agents work on young children as well. Most studies that have been referred to are carried out on an older audience. Even though there are a few studies that have shown tendencies that a TA can be used with children at this age [Axelsson, 2013] we need to make longitudinal studies to support this claim further.

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