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Smart Study: An Educational Platform Using Digital Pen and Paper

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the degree of Master of Science in Applied Science and Engineering: Computer Science

Dieter Van Thienen

Promoter: Prof. Dr. Olga De Troyer
Advisor: Pejman Sajjadi

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Smart Study: An Educational Platform Using Digital Pen and Paper

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Dieter Van Thienen

Promotor: Prof. Dr. Olga De Troyer
Begeleider: Pejman Sajjadi

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If we teach today as we taught yesterday,
we rob our children of tomorrow

JOHN DEWEY

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Abstract

Education is an essential part of a child's development. It gives them a perspective on how to look at life, and teaches knowledge about the world around them. Through a variety of ways, knowledge, skills, and habits are acquired. Education evolves, changing through the course of time, adapting to its environment and shaped by the community that wields it. The introduction of the digital era brought a wave of change in the world we used to know. From home computers and mobile phones becoming standard apparatus in every household, to the booming growth of the World Wide Web, social media, and cloud computing. This change also enabled the further improvement of education, switching from traditional methods, to digitally enhanced ones.

In this thesis, Smart Study is presented. Smart Study is an educational platform that aims at helping primary school children to work more independently, stimulate their read/write learning style, and display the results of their written answers, the corrections, and feedback in a clear way. This is accomplished by using a digital pen, which writes like a normal pen on paper, and a tablet on which the questions, answers, possible corrections, feedback, and overall results are displayed. By storing all digitalized answers, reports can easily be generated, and because all answers are corrected automatically, the teacher's work is relieved. The platform is evaluated by means of a case study involving a group of 15 children of the fifth grade. The results of this study showed that children are very motivated when using the platform, and perform better when doing exercises compared to traditional pen and paper. The read/write learning style of children, the importance of paper in this digital era, and the use of pen and paper compared to a stylus and capacitive screen, are also discussed.

Keywords: Handwriting, ICR, Smartpen, Penlet, Anoto paper, Educational software, Android, Smart Study

Samenvatting

Onderwijs is een essentieel onderdeel in het ontwikkelingsprocess van een kind. Het geeft hen een kijk op het leven en brengt hen kennis bij over de wereld rondom hen heen. Kennis, vaardigheden en gewoonten kunnen op verscheidene manieren worden opgenomen en aangeleerd. Onderwijs evolueert doorheen de loop van tijd. Het past zich aan zijn omgeving aan en wordt gevormd door de gemeenschap die het hanteert. Het begin van het digitale tijdperk bracht een golf van veranderingen. Van computers en mobiele telefoons, meer en meer aanwezig in elk huishouden, tot de groei van het wereldwijde web, sociale media en cloud computing. Deze veranderingen stelt het onderwijs in staat mee te groeien en de methodieken te verbeteren, door over te schakelen van traditionele methoden, naar meer digitale methoden.

In dit proefschrift wordt Smart Study gepresenteerd. Smart Study is een educatief platform dat zich richt op kinderen in het basisonderwijs, om hen meer zelfstandig te laten werken, hun lees -en schrijf methodiek te stimuleren en feedback weer te geven op een duidelijke manier. Dit wordt bereikt met behulp van een digitale pen, die schrijft als een normale pen op papier, en een tablet waarop de vragen, antwoorden, eventuele correcties, feedback en algemene resultaten worden weergegeven. Door het opslaan van alle gedigitaliseerde antwoorden kunnen rapporten eenvoudig worden gegenereerd, en omdat alle antwoorden automatisch worden gecorrigeerd, wordt het werk van de leraar verminderd. Het platform werd geëvalueerd door middel van een case studie met een groep van 15 kinderen van het vijfde leerjaar. De resultaten van deze studie tonen aan dat kinderen erg gemotiveerd zijn bij het gebruik van het leerplatform, maar ook beter presteren in vergelijking met traditioneel pen en papier. Verder wordt ook de lees -en schrijf methodiek van kinderen besproken, het belang van papier in dit digitale tijdperk en het gebruik van pen en papier in vergelijking met een stylus en capacitieve scherm.

Sleutelwoorden: Handschrift, ICR, Smartpen, Penlet, Anoto paper, Educatieve software, Android, Smart Study

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June, 2014

Contents

I Introduction **1**

1 Introduction **2**

1.1 Motivation 4
1.2 Research Goals 5
1.3 Research Methodology 5
1.4 Outline of the Dissertation 8

II Background **9**

2 Digital Pen and Interactive Paper **10**

2.1 The Evolution of Input Devices 10
2.2 Types of Digital Pens 11
2.2.1 Accelerometer 11
2.2.2 Camera 12
2.2.3 Positional 13
2.3 Interactive Paper 14
2.4 Handwriting Recognition Software 15

3 The Importance of Paper **16**

3.1 Why Paper Is Still Important 16
3.2 Paper Versus Screen 17
3.3 Paperless School 18

4 Learning Styles **20**

4.1 Introduction 20
4.2 Neil Fleming's VARK Model 20
4.3 Multiple Intelligences 23

5 Related Work **27**

5.1 Pen-based Learning for Children 27

5.2 Educational Software for Children 28
5.3 Using Tablets in a School Environment 29
5.4 Master Thesis Map-Based Pen Interaction 30
5.5 PhD Thesis HCI Approach Geometry Education 30
5.6 Symphony 32
5.7 Golem Arcana 33

III Development 34

6 Analysis 35
6.1 Introduction 35
6.2 Livescribe Platform 36
6.2.1 Livescribe SDK 36
6.2.2 Penlet 39
6.2.3 Paper Design 41
6.3 Android Platform 44
6.3.1 Android OS 44
6.3.2 Android SDK 44

7 Design 46
7.1 Introduction 46
7.2 Requirements 46
7.3 Architecture 48
7.4 Interaction Between the Nodes 49
7.4.1 Scenario Platform Setup 49
7.4.2 Scenario Working With the Platform 49
7.5 User Interfaces 52
7.5.1 Smart Study Paper Designs 52
7.5.2 Smart Study App Screen Designs 60
7.6 Database Design 70

8 Implementation 74
8.1 Introduction 74
8.2 Smart Study Penlet 74
8.3 Smart Study App 77
8.4 Smart Study Synchronisation Program 79
8.5 Database Implementation 81
8.5.1 PHP Files Used By the Windows Program 82
8.5.2 PHP Files Used By the Tablet App 83

9 Evaluation and Results **85**
9.1 Introduction 85
9.2 Setup 85
9.3 Methodology 86
9.4 Results 91
9.5 Discussion 103

10 Conclusion **105**
10.1 Introduction 105
10.2 Summary 105
10.3 Limitations and Future Work 106

Bibliography **109**

IV Appendix **115**

A Code **116**
A.1 Penlet 116
A.1.1 Java class: XMLUtils2 116
A.2 C# program 118
A.2.1 Method: PenAttachEvent() 118
A.3 PHP 120
A.3.1 PHP file: programDoProcess 120

B Evaluation forms **123**
B.1 Pre-experiment 124
B.2 Experiment 125
B.3 Post-experiment 126
B.4 Teacher 128

List of Figures

1.1 Solving exercises the traditional way with pen and paper 3
1.2 Solving exercises using the Smart Study educational platform . . . 4
1.3 Design Science Research Process Model 6

2.1 Coordinate frames inside an accelerometer digital pen 11
2.2 The infra-red digital camera in an Anoto digital pen 12
2.3 Functional overview of the Livescribe Echo Smartpen 13
2.4 Wacom Inkling digital pen and positional device 13
2.5 Printed paper with the Anoto dot pattern on it 14
2.6 Anoto dot pattern 14

4.1 Distribution of all VARK profiles 21
4.2 Distribution of VARK types when preferring all four learning styles 23
4.3 Overview of all types of intelligences described by the MI theory . 24

5.1 Using the Livescribe Echo Smartpen on the printed map 30
5.2 The Metroscope, a camera-projector augmenting system 31
5.3 Collaborative working using the Symphony system 32
5.4 Playing Golem Arcana using a digital pen for interaction 33

6.1 Overview of the Eclipse IDE with the Livescribe SDK integrated . 37
6.2 Overview of the Eclipse IDE with the Paper Design view active . . 38
6.3 Smartpen Debug when activating the Penlet view 38
6.4 State transition diagram of a Penlet life cycle 40
6.5 Overview of the Paper Design view with the tools to the right . . . 42
6.6 Overview of the Paper Design view of an element's properties . . 43
6.7 Android OS version history 44
6.8 Distribution of devices running a version of the Android platform . 45

7.1 Overview of the Smart Study project in GuideaMaps 47
7.2 System architecture of the Smart Study platform 48
7.3 Information flow between the nodes of the Smart Study platform . 48
7.4 Exercise page of addition and subtraction 54

7.5 Exercise page of multiplications 55
7.6 Exercise page of geometry: triangles 56
7.7 Exercise page of geometry: rectangles 57
7.8 Active regions in the Paper Design of an exercise page 58
7.9 Active regions in the Paper Design of the geometry exercise page . 59
7.10 Splash screen of the Smart Study app 60
7.11 Login screen of the Smart Study app 61
7.12 Home screen of the Smart Study app 62
7.13 Check solutions screen of the Smart Study app 63
7.14 Waiting on response from the Smartpen screen 63
7.15 Addition/subtraction activity of the Smart Study app 64
7.16 Multiplication activity of the Smart Study app 65
7.17 Geometry/triangles activity of the Smart Study app 66
7.18 Animated feedback when tapping questions 66
7.19 Geometry/rectangles activity of the Smart Study app 67
7.20 Animated feedback when tapping questions 67
7.21 Report activity of the Smart Study app 68
7.22 Storyboard of the Smart Study app 69
7.23 Smart Study database model 70

8.1 Comparison between Eclipse with ADT and Android Studio . . . 78
8.2 Smart Study Synchronisation program 80

9.1 Bar chart of the mathematical knowledge 91
9.2 Chart of the experience with computer devices 92
9.3 Chart of the experience with educational software 93
9.4 Chart of the experience with computers and educational software . 93
9.5 Chart of the amount of recognition attempts 94
9.6 Chart of the accuracy of the ICR 95
9.7 Chart of the pen grip with the ICR accuracy 97
9.8 Chart of the performance of the participants 98
9.9 Chart of the synchronisation time 99
9.10 Results of the questionnaire for all participants 101

B.1 Evaluation before the test 124
B.2 Evaluation during the test 125
B.3 Evaluation after the test (page 1) 126
B.4 Evaluation after the test (page 2) 127
B.5 Evaluation of the teacher after evaluating all children (page 1) . . 128
B.6 Evaluation of the teacher after evaluating all children (page 2) . . 129
B.7 Evaluation of the teacher after evaluating all children (page 3) . . 130

List of Abbreviations

ADT	Android Development Tools
AFD	Anoto Functionality Document
API	Application Programming Interface
APK	Android Application Package
AR	Augmented Reality
BCNF	Boyce-Codd Normal Form
CRUD	Create Read Update Delete
CTT	Concur Task Tree
E Ink	Electrophoretic Ink
HWR	Handwriting Recognition
HD	High Definition
IDE	Integrated Development Environment
ICR	Intelligent Character Recognition
IWB	Interactive WhiteBoard
IWR	Intelligent Word Recognition
JSON	JavaScript Object Notation
LCD	Liquid Crystal Display
NDK	Native Development Kit
OCR	Optical Character Recognition

OHA	Open Handset Alliance
OLED	Organic Light Emitting Diode
ORM	Object Role Modelling
OS	Operating System
PDA	Personal Digital Assistant
RAM	Random Access Memory
RDBMS	Relational Database Management System
SDK	Software Development Kit
SQL	Structured Query Language
UHD	Ultra High Definition
USB	Universal Serial Bus
XML	Extensible Markup Language

Part I

Introduction

Chapter 1

Introduction

Education is an essential part of a child's development. It gives them a perspective on how to look at life, and teaches knowledge about the world around them. Through a variety of ways, knowledge, skills, and habits are acquired. Education evolves, changing through the course of time, adapting to its environment and shaped by the community that wields it. The introduction of the digital era brought a wave of change in the world we used to know. From home computers and mobile phones becoming standard apparatus in every household, to the booming growth of the World Wide Web, social media, and cloud computing. This change also enabled the further improvement of education, switching from traditional methods, to digitally enhanced ones.

In this thesis, Smart Study is presented. Smart Study is an educational platform that aims at helping primary school children to work more independently, stimulate their read/write learning style, and display the results of their written answers, the corrections, and feedback in a clear way. For the writing part, a Livescribe Echo digital pen will be used. This pen writes like a normal pen, but can capture everything written down on a piece of paper. On the paper itself, an Anoto dotted pattern is printed. These are very smalls dots that have unique positions, so the digital pen can determine the exact location of the tip of the pen on the paper. By writing on the paper, and thus not lifting the pen, these coordinates are linked. The Intelligent Character Recognition (ICR) engine of the pen can then try to recognize handwriting such as letters, words, and numbers. Once the answers have been written down on the paper, an external event signal needs to be given to retrieve the data from the pen, since this version of the pen cannot call any other program or client. This is accomplished by using an Android tablet which has the Smart Study app installed on it. It requires a single user login, meaning that all the data is always linked to one user. The app can be used to correct solved exercise pages, but also look up all the results of previously solved exercises. When an exercise page has been filled out, and the app on the tablet is used to trigger the process cycle, a screen on the tablet is presented showing the questions, answers, possible corrections, and animated feedback. All data is stored in a database located on the university's server, so an active internet connection is an all-time requirement. The data that is stored can be easily mined for generating reports, and since all answers are corrected automatically, this part of the teacher's work is relieved.

A comparison between traditional exercise solving using a real pen with normal paper, and using the Smart Study educational platform, is illustrated in Figure 1.1 and Figure 1.2. Smart Study offers a non-intrusive solution for digitalizing handwritten answers, automatic correction and convenient representation of information by creating a familiar environment for the student. Pen and paper are still used, the only difference is that the pen is a digital one, but since it writes like a normal pen, it should be of no concern to the student. By displaying the information on a tablet, the platform offers a lightweight and mobile way for making and correcting exercises, while presenting all the information in a clear way that is accessible and easy to use for children.

Furthermore, the read/write learning style of children, the importance of paper in this digital era, and the use of pen/paper compared to stylus/capacitive screen, assessing the added value of using this type of input, is discussed. This will be discussed in Chapter 4.

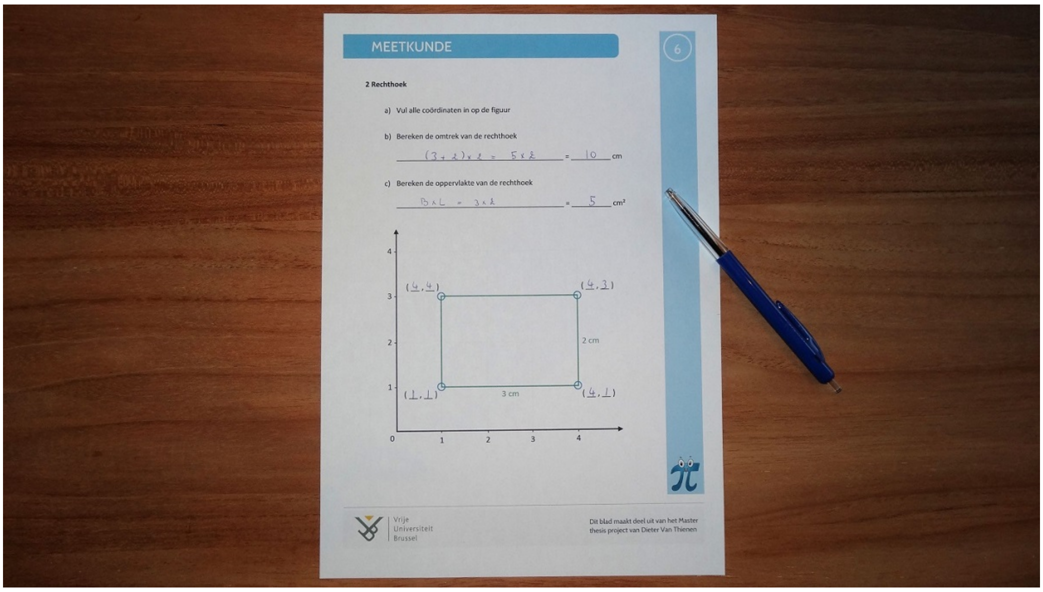


Figure 1.1: Solving exercises the traditional way with pen and paper

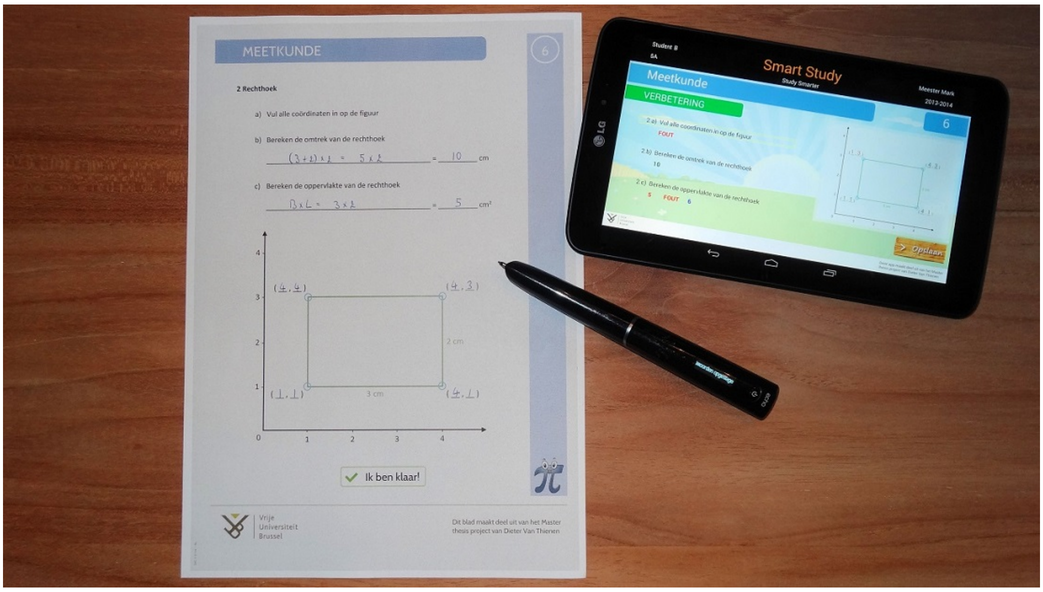


Figure 1.2: Solving exercises using the Smart Study educational platform

A demonstration video was created and uploaded to Youtube[1], showcasing the final product and explaining the entire platform in an easy and accessible way.

1.1 Motivation

Due to the rapid evolution of mobile and interactive technology, pen and paper could be quickly replaced by tablets or other touch-enabled devices, because of their advantages over pen and paper. A paperless environment could be realised whereas paper is no longer a cost, making all access and manipulation of information digital. This environment could be an office where people do work, but it could as well be a school. Nowadays, even school environments tend to go along with this technological evolution (DBW, 2013), (Brustein, 2013), buying computers, tablets, and other electronic devices for teaching, and for their students to work with.

But as this digital shift happens, the traditional way of writing with a pen on paper tends to diminish. However, one of the most commonly used learning styles of children is the read/write learning style (VARK, n.d.). Writing on a tablet or other digital device still does not provide us with the same experience as writing with a pen on paper. This topic is further discussed in Chapter 3. Therefore, the research question that is investigated in this thesis is: *What can be done in order*

[1] `http://youtu.be/eoEacSLyfOY`

to go along with the digital evolution, while preserving a commonly used learning style of children, i.e. the read/write learning style, and stimulate children to keep practising their writing? This thesis will propose a solution for this problem. Primary school children of the fifth grade are targeted for this research, but the proposed solution is not limited to this age group of children. The solution is based on the use of a digital pen for the writing, which is combined with a tablet for providing digital feedback to the child.

1.2 Research Goals

The major goal of the thesis is to come up with a solution for the research question, i.e., to create a learning environment in which the primary way of interaction would be by means of a pen, while also go along with the digital evolution. The use of the digital evolution aims at helping primary school children to work more independently, while still stimulate their read/write learning style.

1.3 Research Methodology

A research methodology based on Design Science (Peffers et al., 2006), (Takeda, Veerkamp, & Yoshikawa, 1990) was used in order to achieve the described research goal. Figure 1.3 gives an overview of the used methodology.

Awareness of the Problem

In order to gain more insight into the problem and come up with a proposal, a general literature study has been performed on the hardware and software relevant for this project, the importance of paper in this digital era, and learning styles. The important elements for designing educational games were studied as well.

Solution

An educational platform, named Smart Study, is proposed. All specific needs for creating this platform were analysed. Before doing the actual implementation, it was necessary to get familiar with the digital pen and the Livescribe SDK in order to study its capabilities and limitations.

After this step, the actual software platform was designed, the way of communicating between the different hardware and software was established, and some rough sketches are drawn (i.e. paper prototype) were drawn of how the paper design and on how the app on the tablet would look like.

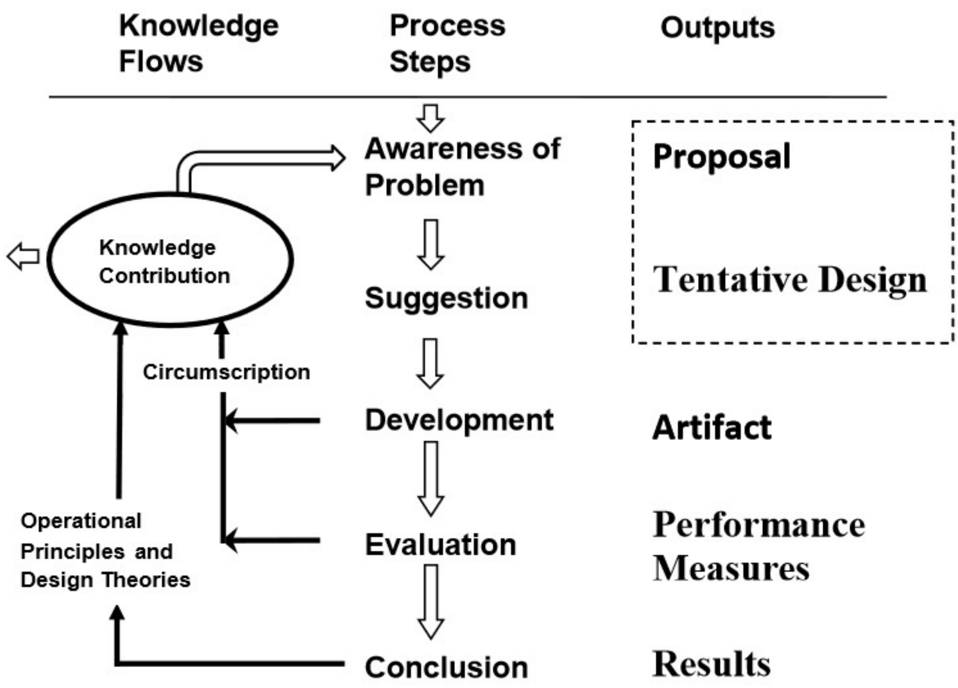


Figure 1.3: Design Science Research Process Model

Development

The first element of the platform that needs to be implemented was the paper the digital pen will be writing on. The paper that was designed in the previous phase was implemented. Next, the Penlet used by the digital pen, which was based on the Paper Design, was developed. All handwritten answers were stored on the internal memory of the pen in Extensible Markup Language (XML) format. The C# application that retrieves the data from the pen when signalled by the tablet was implemented. This program needed to be carefully designed as it synchronises everything between the outer ends of the platform, which are the Smartpen and the tablet, and should capture all errors, failures and anomalies that occur. The database, in which all of the final and formatted data is stored, was designed and implemented. The PHP files necessary for executing all database operations, which are called by the program and Android app, were implemented. These are necessary because direct communication between a client program and the database is restricted. The last part of the platform, the Android app, was then implemented. The app can trigger the extraction process of the program for retrieving the XML file on the Smartpen, show all data on the tablet screen, and give an overview of all solved exercise pages. Finally, all processes were linked in order to complete the cycle and make the platform fully functional.

Evaluation

Before being able to evaluate the implemented platform and answer the previously defined research question, certain methods for testing and evaluating the platform needed to be designed. Methods for evaluating the performance of the digital pen, Android app, and overall platform were created. Participants for the evaluation, belonging to the target audience, were recruited by contacting regional primary schools. The evaluation consisted out of several phases. Before evaluating the platform, the mathematics skills of each student were acquired by questioning the teacher. All names of the participating students are added to the database, and their exercise papers were customised. In the next phase, the student's computer knowledge was determined by asking a few simple questions to the student. The results of the evaluations per student would be matched with their skill levels. In the next phase, the evaluation of the platform was performed. The accuracy of the ICR of the Smartpen was measured, the synchronisation time was recorded, and any upcoming problems were noted. After the student had worked with the platform and solved at least two exercise pages, a questionnaire was used in order to evaluate the opinion of the student. The answers to these questions determined whether the platform and its components are easy to use and child-friendly, but were also used to assess the effectiveness and clarity of the explanations, and whether this platform could be useful for the children compared to normal pen/-paper usage and manual corrections by their teacher. When the evaluations of all students were done, the teacher's opinion was measured through a questionnaire, questioning whether they would find it feasible to implement Smart Study in their school, and whether their student's motivation, autonomy, and learning outcome could increase in this way. The evaluation methods will be explained in detail in Chapter 9. All forms used for the evaluation can be found in Appendix B.

Conclusion

After the evaluation,the last part of the thesis reflects on the accomplishments and the results of the evaluations. The benefits and contributions in the studied field were summarized, and limitations and improvements were identified for future work.

1.4 Outline of the Dissertation

The first part gives a general introduction, stating the research goals, motivation and challenges of this dissertation. The second part focuses on the background information necessary to fully comprehend the rest of the thesis. Chapter 2 discusses the digital pen and interactive paper, giving an introduction to these topics. Chapter 3 emphasizes why paper is still important, even today, and discusses why a paperless environment is not yet feasible. Chapter 4 introduces learning styles. The second part is concluded with Chapter 5, which gives an overview of related work, including pen-based learning. The third part describes the development of the solution. It starts with Chapter 6 describing the analysis phase. It explains how the Penlet and Paper Designs for the Smartpen work and how the Android platform is used for the tablet app. Chapter 7 discusses the design of the platform. It also discusses the design choices made for the app. It presents the architecture of the platform, the communication between the different components of the platform, the design of the user interfaces, and the design of the database. Chapter 8 discusses the implementation: the Penlet, the Android app, the intermediary software, and the database. Chapter 9 contains a description of the evaluation, its results, and a discussion. Chapter 10 concludes the thesis mentioning some future work, and a summary of the work that was accomplished.

Part II

Background

Chapter 2

Digital Pen and Interactive Paper

2.1 The Evolution of Input Devices

As computer systems evolve, so do input devices. Capacitive screens are a good example of this. Nowadays, they are heavily used in mobile devices and offer an easy way of giving input to your device. Adding tactile feedback can improve the overall experience even more (Hoggan, Brewster, & Johnston, 2008). Another trending example is the use of video input devices using tracking software to capture input, like Microsoft's Kinect (Zhang, 2012). By making use of the Kinect sensor combined with complex models and algorithms, finger, hand, and even body gestures can be captured (Frati & Prattichizzo, 2011), (Oikonomidis, Kyriazis, & Argyros, 2011), (Raheja, Chaudhary, & Singal, 2011), (Suau, Ruiz-Hidalgo, & Casas, 2012).

This thesis will focus on another type of input, namely the use of a digital pen with interactive paper. A digital pen is an input device that can capture handwriting. A specific type of pen will be used for this purpose, namely one that can capture handwriting by using a miniature camera in the head of the pen, which is used on a special type of dot patterned paper to enable recognition. Throughout the years, these camera-based digital pens have undergone improvements to make them more accurate and responsive. The interactive paper used by these pens has undergone improvements as well. In a paper by Signer and Norrie (Signer & Norrie, 2010), Anoto interactive paper is introduced and the authors give an overview of the development and evolution of interactive paper in the last years.

The use of such a digital pen does not just allow the digital capture of handwriting. Further research on these input devices made it possible to use them as a tool to control and annotate Microsoft PowerPoint slides (Signer & Norrie, 2007), and even make it possible to proof-edit documents by making changes on the printed document, which can then in turn map with the changes necessary on the digital instance of the document (Weibel, Ispas, Signer, & Norrie, 2008). In a paper presented by Signer et al. (Signer, Norrie, Weibel, & Ispas, 2012), the creation of an integrated authoring and publishing solution based on existing document editing processes is discussed. Their approach supports development of paper-digital systems, a comparable type of system that needs to be implemented in this thesis.

2.2 Types of Digital Pens

There currently exist a number of digital pens using different techniques to achieve specific goals. The following sections give an overview of digital pens using different technologies that are the most common.

2.2.1 Accelerometer

This type of digital pen is equipped with an accelerometer, which enables the detection of movement and contact with a writing surface (Wang, Hsu, & Chu, 2013). The 3D accelerometer in the pen constantly keeps track of the pen's current position. It has the advantage that it can write on any type of surface (Wang & Chuang, 2012), while keeping track of everything you write down. Figure 2.1 (Wejinya, n.d.) shows such a pen's 3D accelerometer, 3D gyroscope, and 3D magnetometer. The combination of all these integrated parts enables an accurate reconstruction of a handwritten character or glyph on a writing surface.

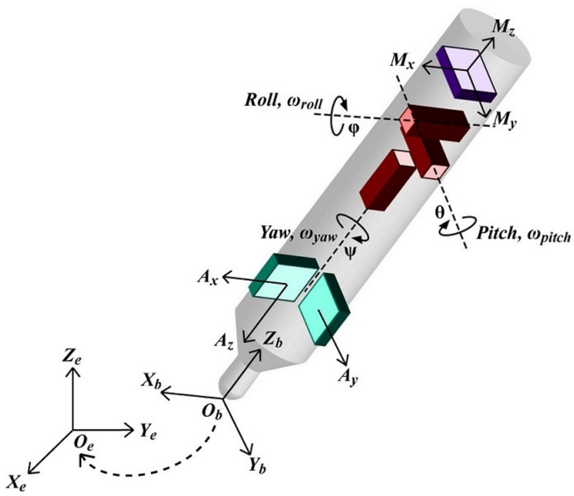


Figure 2.1: Coordinate frames inside an accelerometer digital pen

2.2.2 Camera

Besides digital pens which are motion based, there also exist pens which rely on the pen's position on the paper. These pens have a tiny infra-red digital camera next to the tip of the pen, which can be seen in Figure 2.2. This camera tracks the position of the pen by reading tiny printed dots on specially printed Anoto interactive paper. This type of printed paper will be discussed in detail in the next section. A pressure sensor located in the tip of the pen activates the camera when the pen touches the surface of the paper, registering the movements made by the pen (Shelly & Vermaat, 2010).

This type of digital pen has been used for this thesis, more specifically a Livescribe Echo Smartpen (Livescribe, n.d.). Figure 2.3 gives a functional overview of this digital pen. It has an Organic Light Emitting Diode (OLED) display which can present information when certain actions have been done, a microphone to record audio which can come in handy when attending a lecture and writing down information while recording what the teacher says, and a built-in speaker which can play back recorded audio or give audio feedback when performing certain actions with the pen. It has a micro-Universal Serial Bus (USB) connector which enables to have a wired connection to a computer device supporting this digital pen. Newer versions of the Livescribe Smartpens have the ability of connecting to a computer device, tablet or smartphone in a wireless way, over Bluetooth or WiFi.

Figure 2.2: The infra-red digital camera in an Anoto digital pen

Figure 2.3: Functional overview of the Livescribe Echo Smartpen

2.2.3 Positional

Digital pens that are position based use a positional device in order to detect the location of the pen when writing on a surface. This surface can be a graphics tablet or a normal piece of paper. This type of pen is often used by graphic designers (TutsPlus, 2013). An example of such a pen using paper as a writing surface is the Wacom Inkling (Wacom, n.d.), shown in Figure 2.4.

Figure 2.4: Wacom Inkling digital pen and positional device

2.3 Interactive Paper

Camera-based digital pens, such as the Livescribe Echo Smartpen, make use of the Anoto dot pattern printed on a surface, which consists out of very tiny dots. A side-by-side view of such a printed paper with a zoomed-in part can be seen in Figure 2.5. When looking at the image to the left, the dots on the paper can be hardly seen. The image to the right is a zoomed-in view of the same paper, making the dots more apparent. The dot pattern enables the digital pen to detect pen events and capture handwriting (Anoto, 2014). Figure 2.6 shows a small area of such a dot pattern. Every such area has a unique combination of dots that have different positions. Handwriting is captured by registering the related pattern closest to the pen tip, taking snapshots up to 100 times per second, ensuring fast and accurate data capture. Because of this unique dot pattern, the exact position of the pen on the surface can always be located.

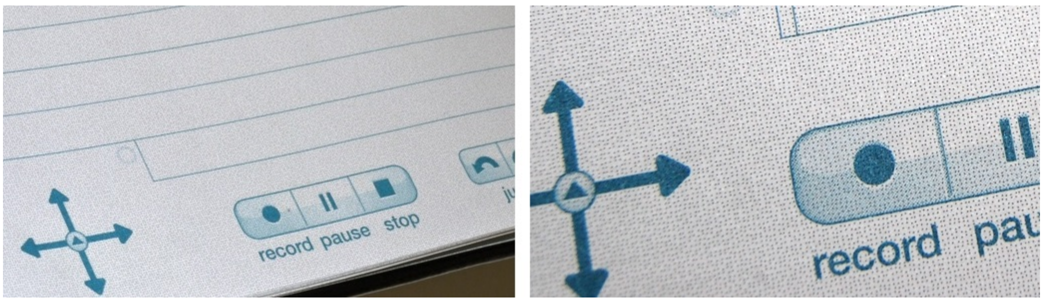


Figure 2.5: Printed paper with the Anoto dot pattern on it

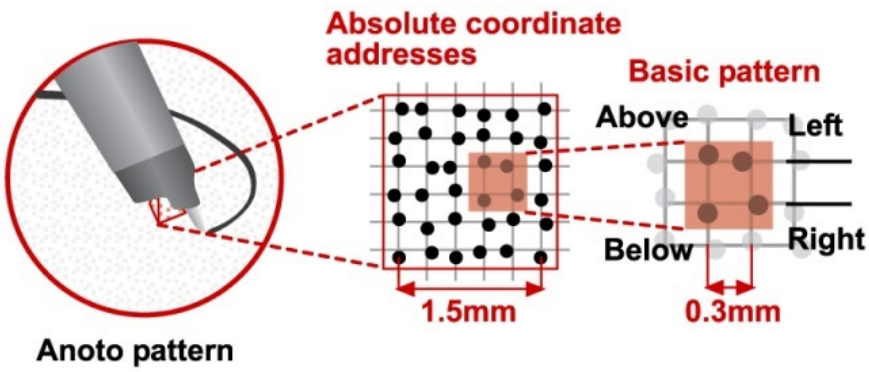


Figure 2.6: Anoto dot pattern

2.4 Handwriting Recognition Software

Handwriting can be interpreted using handwriting recognition software, such as Optical Character Recognition (OCR), ICR, Intelligent Word Recognition (IWR), or newer technology which can combine all these techniques (Health IT Outcomes, n.d.).

OCR is designed for recognizing character-by-character, doing one glyph or character at a time, targeting typewritten text. Two basic methods can be used for this type of recognition. Matrix Matching compares the similarities of the character, with one in an existing library of character matrices or templates. Feature Extraction on the other hand does not use strict matching but computer intelligence. This technique is also known as ICR, which is the next type of recognition explained below.

ICR is designed for recognizing one glyph or character at a time using machine learning, targeting handwritten text such as block letters and cursive text. It is an advanced form of OCR, as different styles of handwriting can be learned by the computer in order to improve accuracy and recognition. This can be further improved by constraining it to a lexicon, however doing so might be problematic when characters or words are not contained in the specified lexicon. The Livescribe Echo Smartpen and its SDK, used for the thesis project, use this type of recognition engine.

IWR is designed for recognizing entire words instead of one character at a time, targeting handwritten text such as block letters and cursive text. It matches the handwritten words to a user-defined dictionary, which can significantly reduce errors compared to recognition engines such as OCR or ICR. It is thus ideal for processing documents that contain handwritten data in a specific language.

In the process of research training, which was a part of doing the Master thesis, this domain has been examined more thoroughly. The recognition of graphics in modelling tools, used for creating models such as Object Role Modelling (ORM) and Concur Task Tree (CTT), is investigated whether the use of a digital pen can improve the ease and usability when making these models (Van Thienen, 2014).

Chapter 3

The Importance of Paper

3.1 Why Paper Is Still Important

With the technological advancements of displays used in tablets, smartphones and other devices, one can question whether paper still has any usefulness. Information on paper is static, while being displayed on a screen it becomes dynamic. What benefit could paper still give us, while any display could simply replace that piece of paper? The book *The Myth of the Paperless Office* (Sellen & Harper, 2003) gives a very good overview of why paper is still important nowadays, even with all the technology that is available and is replacing the paper world. The book focuses on an office environment, but the reasoning can be applied to an everyday, non-working situation as well. It discusses why paper is still important, but also the downsides of paper, mainly the cost and its limitations, non-interactivity being one of those limitations.

The authors of the book mention some interesting points as why paper is still important nowadays. Paper is still the preferred way of reading and writing. You simply pick up the paper and start reading, or pick up a pen and start writing on it. It is a very natural behaviour, which is learnt when we were little. Electronic devices could simulate this, but writing on a capacitive screen with a stylus does not provide the same experience as writing with a pen on paper. The software on the device also needs to be able to detect the writing fast enough so no data is lost. In addition, the side of your hand usually rests on the surface you are writing on, so that needs to be detected as well in order to capture the writing successfully. Electronic devices are also dependent of a power source. Paper does not need this, however your pen could run out of ink, a very low-cost replacement. Besides the familiarity of writing with a pen on paper, the authors mention that physical paper is still the most common method of information exchange compared to its digital surrogates. Even today, there are still people who are unfamiliar with modern technological devices (very young children, elderly people, etc.), whereas paper does not give any problems as it is something physical, common and understandable.

This book has a very strong connection to this thesis. The downsides that are mentioned in this book can be eliminated by making a bridge between the paper and digital world using a Smartpen and interactive paper, and thus acknowledge that paper still is important and useful in this digital era.

3.2 Paper Versus Screen

Not only the writing, but also the reading aspect is important when it comes to processing information. In the book mentioned in the previous section, the authors also did a study comparing reading text from paper versus screen. They conclude that people using paper had an easier time reading text and writing annotations. It is important to mention that this book was published in 2002, and since then displays have undergone serious technological advancements, making them more pleasant to read on. Normal Liquid Crystal Display (LCD) screens, such as Retina displays from Apple, are a good example of this. There also exist screens using Electrophoretic Ink (E Ink), which mimic printed text on paper (Comiskey, Albert, Yoshizawa, & Jacobson, 1998), making reading even more pleasant and not strenuous on the eyes compared to regular LCD screens. High Definition (HD) and the newer Ultra High Definition (UHD) displays provide the user with pixel perfect quality, bridging what you see on a screen, and what you see in real life (McCormack, 2013).

Still, the authors mention some important points which currently still pose difficulties. One of those points is flexible navigation. Modern hardware and software try to make this as easy as possible, so going from one digital page to another can easily be done. But comparing this with a real book or magazine, navigation is done by simply flipping from one page to another. The authors state that clicking or scrolling to pages in a digital way will never be as fast as doing this with real paper. Today, this is still true, as scrolling, swiping, or other gestures are still slower than physically moving to another page. However, an upside of digital use is the ability to jump to a specific page, or searching for terms. Besides navigation, another point worth mentioning is the use of space. Here, the authors mention that in their case study, the subjects who used physical paper had no problems in spreading out the papers, cross-referencing to other papers, and were able to manipulate and rearrange physical documents easily. The subjects who had to do the same in a digital way were frustrated by the limited ability of doing the same tasks as the other group. This is a problem that in my opinion will never be solved by simply using flat displays. If you have several different physical paper documents, and you want to rearrange or read different papers side-by-side, then this can be best done on a table. Doing the same in a digital way, namely on a display, can be very problematic due to the screen size, software limitations, and usability of the device. This problem could be eliminated, and even prove to be better than the use of physical paper documents, by using holographic technology so that a 3D space around you can give you the freedom to do the necessary actions (Logan, 2013), (Page, 2013). However, at the time of writing, this is a concept that is still being studied, which is in a very early development stage.

Older studies and papers give a comparison of reading and working on paper and screen. Technology has evolved in such a way that these studies and results may be outdated. An example of a study done in 1988 (Oborne & Holton, 1988), says there is no difference between reading from paper and screen, stating that that reading from screens can be as fast and accurate as reading from paper. A newer study done in 1997 (O'Hara & Sellen, 1997), shows however that it is the space the user can use that determines how easy a user can read and work. Working on paper was thus easier than working on a screen. The main point both authors commonly share, is the design of the software: the better the design and the more space you have, the easier the reading, working, and swapping between different documents. With paper, this is very easy, as you just need to physically move it.

Ferris Jabr published some very interesting articles in the Scientific American about this topic as well. Two of these (Jabr, 2013c), (Jabr, 2013b), are about how e-readers with ink-screen technology and tablets with HD screens are becoming more popular for reading, but paper still has the upper hand. An article translated in Dutch by the same author was published in an issue of EOS (Jabr, 2013a), discussing paper versus pixels. The author of these articles not only gives a comparison between both, but also explains why paper is still important, building on the same statements which were explained over the previous paragraphs. These are fresh, recent sources, making it accurate towards today's standards.

3.3 Paperless School

In the above-mentioned book, the authors discuss why people thought work places would become paperless, but why this is not the case. Although they discuss a work environment, the same can be applied to a school environment, indicating the need of pen and paper, instead of just a computer using mouse and keyboard, or a tablet with a capacitive screen, which can deteriorate the read/write learning style of children. This will be discussed in more detail in Chapter 4.

In the article *The Myth of the Paperless School* (Thayer, 2011), the author describes the urge of schools wanting to use e-readers in their school environment as a replacement for printed textbooks, but also warns for the impact it can have on students. It questions what is gained with e-readers, such as a possible decrease of costs, and what is lost when abandoning paper, mentioning again the same points that are highlighted in the previous sections of this chapter.

Attempts to switch to a paperless school have already been made. In an online article (Cargill, 2012), the authors discuss why the United States government wants to gradually replace printed schoolbooks with e-readers, mostly because of the decrease in budget. E-readers can be used for different textbooks, while printed ones are of course separate books. Modern e-readers are also fast and light, making them perfect to carry around. However, these devices are for reading only. In the article, critique is given because students cannot simply make annotations, as they would do on normal paper. The acquisition of these e-readers, in combination with the cost of acquiring the e-versions of the books, might also not make such a significant impact on the budget. It is made clear that schools want an improvement over normal pen/paper textbooks, but even today's technology imposes difficulties when implemented, either being its cost price, functionality, or usability.

While reading on a digital device might have benefits over paper in a school environment, the same cannot be said about the writing aspect. As mentioned in the previous article, e-readers are not a solution when it comes to writing down annotations. The alternate solution would be to switch to tablet devices, where reading and writing at the same time is more efficient. But not only are these devices more expensive, increasing the school's budget compared to paper school books, the discussion about the pros and contras of using paper versus screens can again be discussed, as mentioned in the previous section.

It is clear that there is no easy solution for schools to adapt to a modern environment in such a way that the learning is improved and budget is decreased. Paper is something that cannot simply be replaced by electronic devices. So instead of trying so hard to reduce paper by introducing modern technology, why not combine both? Why not have a platform that still uses paper, but where everything that is written down on that paper can be instantly and automatically digitally processed? This would preserve the advantages of reading and writing on paper, while at the same time allow for the digitalisation and processing of the data that is written down. This is the solution that will be implemented in this thesis, by developing the Smart Study educational platform. Part III of the thesis will discuss the technical and functional aspects in full detail.

Chapter 4

Learning Styles

4.1 Introduction

Researchers have defined many different learning styles that are adopted by children. A learning style is individual's natural or habitual pattern of acquiring and processing information in learning situations, is called a learning style. A core concept is that individuals differ in how they learn (James & Gardner, 1995). The educational platform presented in this thesis is based on reading and writing, and therefore it can be used to stimulate the use of a learning style based on reading and writing.

In this chapter, two theories related to learning styles will be discussed that recognize reading and writing as a separate style, i.e., the VARK model and the theory of Multiple Intelligences. Besides Neil Fleming's VARK model and Multiple Intelligences, there exist other learning models and theories as well. The Dunn and Dunn Model (James & Maher, 2004) describes how information is acquired by looking at the way how people begin to concentrate on, process, internalize and retain this new and difficult information. Another, newer model is the RASI Model (Hawk & Shah, 2007), which stands for Revised Approaches to Studying Inventory. This model describes how people interact with and respond to a learning environment based on cognitive, affective, and psychological factors. It classifies studying in three measures: deep, surface, and strategic, with each person having a preferred approach. These models and theories are not discussed as they are not directly related to the work in this thesis.

4.2 Neil Fleming's VARK Model

The most common and widely used (Leite, Svinicki, & Shi, 2010) categorization of different types of learning styles is Neil Fleming's VARK model (Drago &

Wagner, 2004), (VARK, n.d.). It categorizes the learning styles into four major styles, which are explained in the sections below. In practice, however, children seldom only use one specific learning style, but a mixture of different learning styles, also called *multimodality*. Figure 4.1 gives an overview of all VARK profiles, based on results of the VARK online database in which 20.254 people worldwide participated. This data extract is of May 2014.

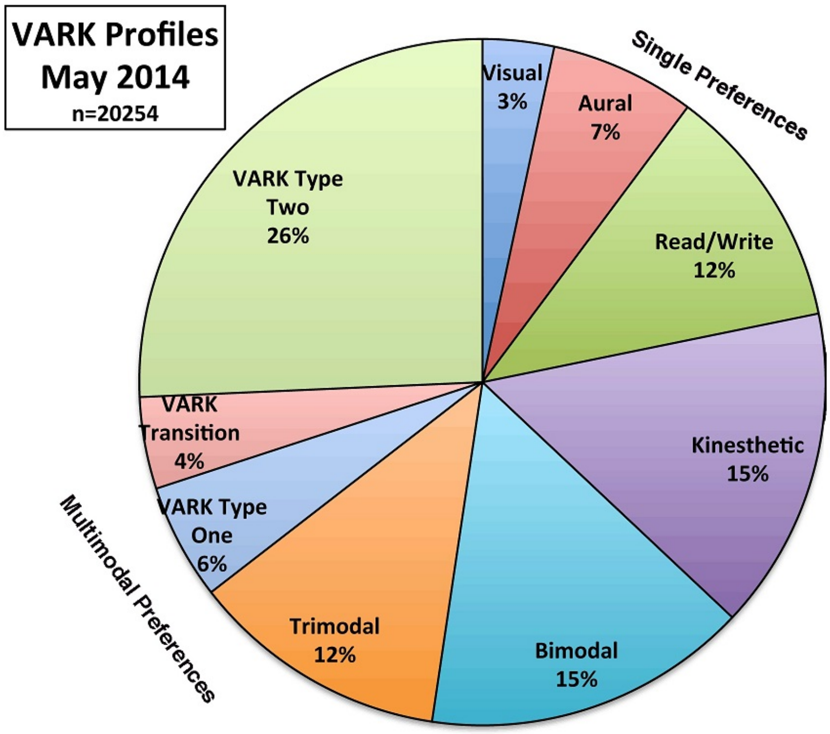


Figure 4.1: Distribution of all VARK profiles

Visual

This preferred style of learning represents information in figures instead of words, such as graphs, maps, designs, shapes, etc. This is not to be confused with real life pictures or videos, as this could match or overlap with another learning style.

Auditory

People with this learning style have a preference for information that is heard or spoken, such as lectures, conversations, group discussions, etc. This also includes talking to oneself. People with this learning style often speak it out first, instead of sorting it out in a different way before speaking.

Read/Write

This preference of learning style represents information as text. This learning style is often used because of the importance of being able to read and write well. Examples of this learning style are reading and writing reports, essays, assignments, and basically anything that has to do with text. The read/write style is of importance here, as this is the learning style that will be applied when using the digital pen/paper, and is part of the pen-based learning methodology discussed in the next section.

Kinesthetic

The kinesthetic learning style is a preferred learning style for people who learn from the experience of doing something, while valuing their own background of experiences. This includes demonstrations, simulations, case studies, practices, etc. The importance here is the connection to reality.

Multimodal

Multimodel is the mixture of multiple VARK learning styles. It is the preference that is most common for all people. Depending on how many different preferences someone has, a distinction can be made between the combination of these preferences. Bi-modal preferences means that a person has two learning style preferences, with tri-modal preferences having three preferred learning styles, and all four preferred meaning that someone uses all four learning styles.

People who comply with all four VARK profiles, can be subdivided in three groups: VARK Type One, VARK Type Two, and VARK Transition. Type One describes people who can easily switch from between styles depending on the situation, having two, three, or four almost-equal preferences in learning styles. Type Two describes people who take more time when using a specific learning style in a situation, resulting in a deeper and broader understanding. VARK Transition describes people who are in between both types. Figure 4.2 gives an overview of these types, showing that most people are characterized by Type Two.

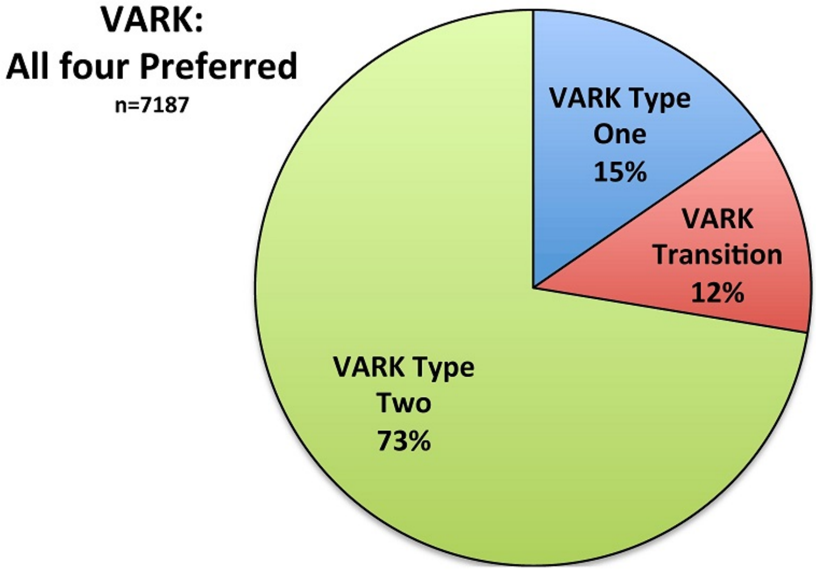


Figure 4.2: Distribution of VARK types when preferring all four learning styles

4.3 Multiple Intelligences

Multiple Intelligences is a theory of intelligence in which distinction is made between different types of intelligences, rather than having a single intelligence being dominated by a single ability. This theory was introduced by Howard Gardner (Gardner, 1985), and has since attracted many people to study this theory further (T. Armstrong, 2009). The original author continued studying and improving his theory, explicitly addressing some of the misunderstandings and missuses, giving an up-to-date version of his multiple intelligences theory in a book released in 2006 (Gardner, 2006).

The multiple intelligences theory emerged from questioning the methods used for determining intelligence. A better way for measuring this is proposed by stating that intelligence has more to do with the capacity for solving problems and forging products in an applicable and naturalistic setting. In order to describe such a person's intelligence, a number of capabilities were grouped into 8 comprehensive categories, also called intelligences. Figure 4.3 (Ostwald-Kowald, 2013) gives an overview of all 8 intelligences, with the following sections describing each intelligence separately.

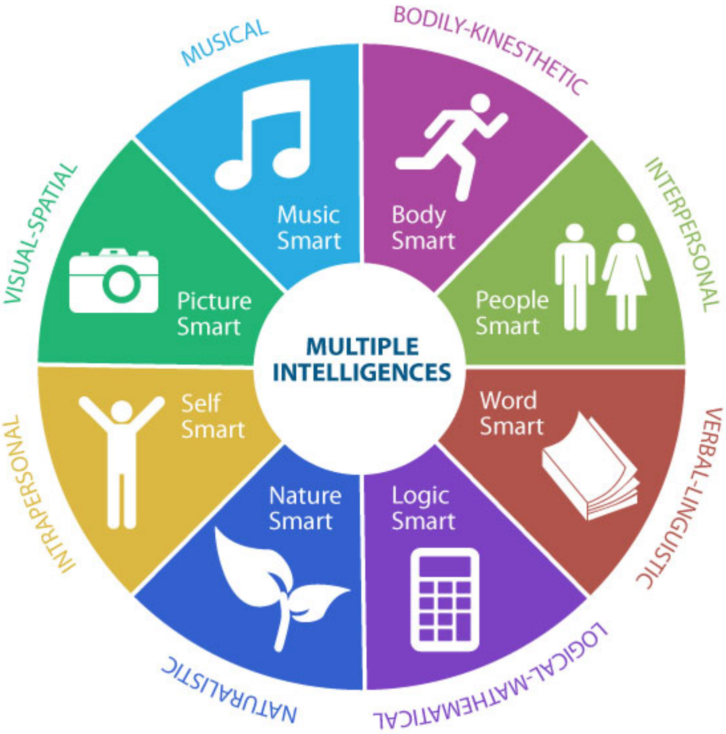


Figure 4.3: Overview of all types of intelligences described by the MI theory

Bodily-Kinesthetic

The whole body is used to express ideas and emotions, while hands are used to produce or manipulate objects in the environment. This type of intelligence needs specific physical skills, such as speed, coordination, flexibility, tactile capacities, etc. This intelligence is usually practised by actors, athletes, craftspeople, etc.

Interpersonal

This intelligence is described by the ability to perceive and distinguish emotions, motivations, and feelings of other people. People with this ability are sensitive to facial expressions, as well as voice and gestures. This intelligence is usually practised by people who can influence, even manipulate, a group of people to do certain actions.

Verbal-Linguistic

This is described by the capacity of effectively using words in an oral or writing way. People with this intelligence are able to manipulate the syntax, structure, phonology, sound, semantics and practical uses of a language. Practical uses include mnemonics, explanation, rhetoric, and metalanguage. This intelligence is usually practised by politicians, journalists, storytellers, etc.

This type of intelligence can be related to the read/write learning style described by the VARK model, with people who use this learning style, also being strong in verbal-linguistic. However, it is possible that in some instances this is not the case. Someone could be strong in logical-mathematical, being able to solve mathematical exercises easily, yet also having a strong read/write learning style, while being weak in verbal-linguistic.

Logical-Mathematical

This intelligence is described by the capacity of effectively using numbers, and the ability to reason well. People with this intelligence are good in classification, generalisation, calculation, categorisation, and hypothesis testing, while being sensitive to logical patters and relationships, functions, abstractions, statements and propositions, etc. This intelligence is usually practised by mathematicians, logicians, computer programmers, scientists, etc.

Naturalistic

Recognition and classification of flora and fauna species of a person's environment are bound to this intelligence. People with this intelligence are sensitive to natural phenomena, such as mountains, cloud formations, etc., and are capable of distinguishing inanimate objects, such as buildings, cars, etc.

Intrapersonal

Having self-knowledge and the ability to handle this kind of knowledge, are bound to this intelligence. People with this intelligence accurately know who they are, meaning they know their strengths and limitations well, and are aware of their emotions, motivations, and desires, while having the capacity for self-esteem, self-understanding, and self-discipline.

Visual-Spatial

This intelligence is described by the ability of being able to perceive the visual-spatial world accurately, performing visual transformations upon those perceptions. People with this intelligence are sensitive to colour, shape, form, space, and the relationships between these elements. They are capable of visually and graphically representing visual and spatial ideas. This intelligence is usually practised by hunters, guides, architects, inventors, etc.

Musical

The final intelligence is described by the capacity of perceiving, discriminating, transforming, and expressing musical forms. People with this intelligence are sensitive to rhythm, pitch, and timbre of a musical piece. Two types of understandings can be differentiated here. People can have a figural, top-down understanding of music, meaning they have a global and intuitive approach, while a formal, bottom-up understanding of music, means they have an analytical and technical approach. A combination of both is also possible. This intelligence is usually practised by music composers, performers, aficionados, etc.

There exists a possible ninth intelligence, namely *existential intelligence*. This intelligence is defined as the concern with ultimate life issues, meaning a person's ability to locate oneself within furthest reaches of the universe, being able to reason about the meaning of life and death, the fate of physical and psychological worlds, etc. This intelligence is thus adopted by people addressing questions such as who we are, where we come from, what everything is about, what the future might be that lies ahead of us, etc. This intelligence not described here, as the original author states it does not perfectly fit the terms defined by the criteria of valid intelligences, but is further being explored by educational researchers (Tupper, 2002).

Chapter 5

Related Work

5.1 Pen-based Learning for Children

Recent studies have been conducted in which pen-based learning with children is observed. Sugihara, Miura, Miura, and Kunifuji (2010) use an Anoto-based digital pen system to observe the learning behaviour of students age 6-7. An evaluation is conducted by means of a questionnaire and an interview. Using this method of learning increased the student's motivation levels. Miura, Sugihara, and Kunifuji (2011) studied how lectures can be improved using digital pen technology. The students observed here were age 7-8. The results show that most students were more motivated, concentrated and enjoyed the lecture more. They also compare their study with their previous work, which was AirTransNote, an ultrasonic digital pen using a Personal Digital Assistant (PDA).

An older study in 2006 was done by Read (2006). In this paper, the usability of digital pens was compared to tablets and laptops having handwritten input. Two groups of students, age 7-8 and 12-13, were observed. Results show that the digital pens were well suited for age 12-13. The remark here was the bad handwriting recognition, but since this is an older paper, and handwriting recognition engines have been improved, this is not relevant any more. A very recent paper (Saad, Razak, & Yasin, 2012), but with a less suitable age group, studies the writing of preschool children. The students observed here were age 3-4, which means they are barely capable of writing understandable text. Courseware that uses handwritten input is used with a stylus and tablet. This paper is relevant however because the authors study how they should design the interface of their courseware to make it suitable for children.

When designing software using pen/paper input, it is important to keep the age group in mind. Since the age group for this thesis will be 10-12, the paper and tablet app has to be designed for this audience. This is important, as a high performing piece of hard- and software is worthless if it has a low usability or is confusing to work with. Siozos, Palaigeorgiou, Triantafyllakos, and Despotakis (2009) present a way to design an app usable with a stylus on a tablet for students age 12-15. They compare this with keyboard input of a computer. Their results show that using the stylus on the tablet is more useful and usable for this age group, combined with their software design. Another paper by Read (2007) studies the usability of text entry by children. The age group here was 7-8. Three input methods are discussed and compared, namely normal pen on paper (non-digital), keyboard input on a computer, and a stylus on a graphics tablet. The authors conclude that the best method of writing is having a pen on paper.

5.2 Educational Software for Children

Designing software for a specific platform asks a different approach when its target audience are children. Many researches have been studying the usability and layout of educational software for children, and how it can effect and increase their motivation and learning ability. However, not just the design of such software for this target group is important, but also its effectiveness, since their is a chance that children are not interested in this approach of learning, even if the software has been designed in a suitable way. A recent study (Lin et al., 2013) examines how computer games for after-school remedial learning could show its effectiveness. The Monopoly game is used to enhance the performance of sixth-grade students when learning mathematics. The effectiveness of the feedback that is given is studied, comparing game-based and video-based instructions. Their results show that both types of feedback effectively enhance the learning of mathematical concepts, with the game being more beneficial to the child's learning mastery. This paper is of interest because this is the same type of feedback that is given to the child through the tablet app. Since their studies have proven that this type of feedback can be effective, it was incorporated into the platform, and later evaluated as well.

Educational software cannot only increase the student's motivation, but by using specific interactive learning tasks it can also increase the deep strategy use as well. A study (Vos, van der Meijden, & Denessen, 2011) was conducted in which both aspects were researched by having two groups of children play a memory game. By having a group of participants play an existing type of this game, while another group created their own, similar game, a significant difference between the intrinsic motivation and deep strategy use of the participants was observed. Based on their results, the authors suggest that constructing a game proves to be better for enhancing the student's motivation and deep learning. This interesting approach shows that students achieve both aspects when they are constructively busy with something, instead of just doing simple interaction and execution. The results of this study show that it is important to design software specifically for this target audience, as it is very important that they use software or a platform that is adapted to them, instead of using something that is dull and uninteresting for them, containing the same type of exercises.

5.3 Using Tablets in a School Environment

With devices such as tablets becoming more available to a larger audience due to a higher usability and lower cost price, implementing them in a school environment could be interesting. A case study (Henderson & Yeow, 2012) looks into the adoption of an Apple iPad in a primary school, being used by the teachers and the students. Strong points of adopting these devices in a school environment are its mobility, ease of use, collaboration, and engagement. In their case study, they evaluated the use of an iPad in a classroom. They found that its mobility was one of the most significant features. Students and teachers both agreed that the device was useful for them. Teachers found its features and design a very useful tool for educating. Student were very eager to use the device, using it intuitively with little instruction. The authors do mention that the management when using this tool in a classroom environment is very important, as the iPad needs to be recharged, updated, if broken repaired, etc., and the apps the teachers and students work with need to be chosen carefully. The results of this paper are important to the realisation of the Smart Study app. Children need to be able to intuitively work with the tablet, while having a fun and easy time working with the app. This aspect is evaluated in the thesis as well.

A similar case study has been conducted in a K-12 education environment (Ali, 2013). In this paper, the challenges and issues in the implementation of tablets for e-learning in this educational environment are studied, while exploring the benefits when successfully implementing this system. One of the most important challenges that have been observed are the social issues, stating that most of the software used on the tablet device is in English, while this could be an issue for students speaking another language. Technological issues imply that there must be a good network infrastructure in the school environment in order for the software to work as expected, which could be a problem in some cases. Benefits of using this technology are that it is a good replacement for physical, printed schoolbooks. Tablets devices allow reading and writing, simulating comparable, yet not the same, behaviour as working with a textbook. Other benefits are efficiency; by letting the teacher simply push information to the student's device, interactivity, making use of the tablet device to do activities, and presentation, making it easier for the students to access information when using the tablet device. As mentioned in this thesis, the paper equally states the importance of enhancing and improving the traditional teaching methodology, making the integration of technology in a school environment useful for better education for the students.

5.4 Master Thesis Map-Based Pen Interaction

In a Master thesis done by Szabolcs Becze (2012), a camera-based digital pen is used to test the usability and performance of map-based interaction and is compared to other input devices. It shows that using a digital pen and paper is faster and more accurate than using a stylus on a touch screen. The technical description can be used to aid this thesis to better understand how the Smartpen works. The digital pen used in this thesis is the Livescribe Echo with an older version of the Livescribe SDK, and is the same one used for this thesis.

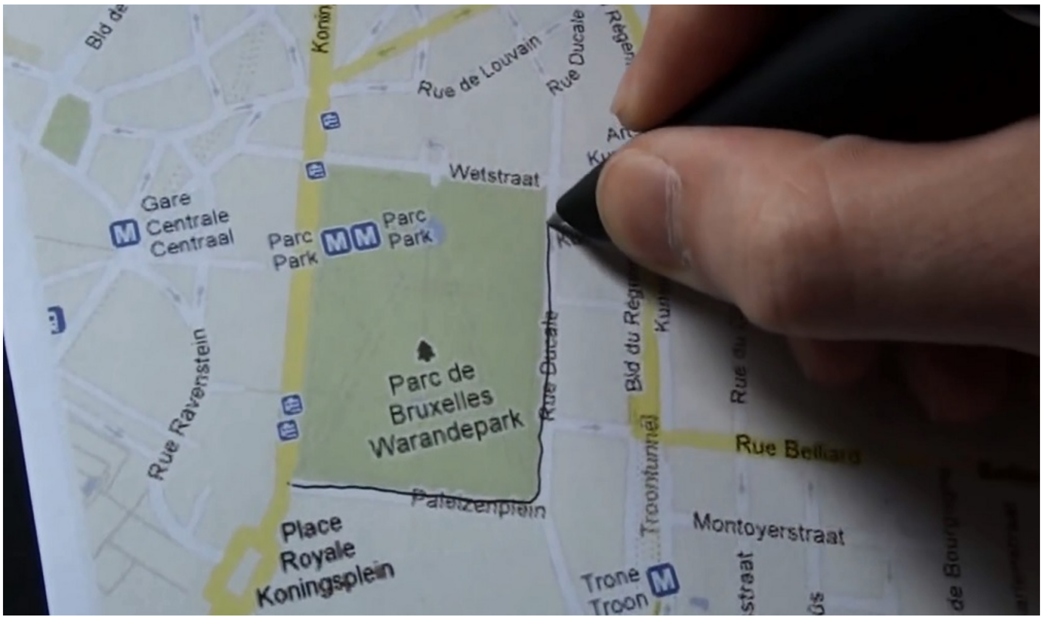


Figure 5.1: Using the Livescribe Echo Smartpen on the printed map

5.5 PhD Thesis HCI Approach Geometry Education

Paper interfaces and their use within classroom environments, are the main subject of a dissertation written by Quentin Bonnard (2012). In this PhD thesis, a project is realised where paper is used as a tangible body, supporting the learning content. It focuses on geometry education at primary schools, letting the students interact by writing formulas and drawing figures, while also being able to move or fold cardboard shapes. The system that lies at the heart of this project is the Metroscope, which incorporates a camera and a projector which is directed to the tabletop surface using a mirror held above the desktop by the system's two metallic arms. Both the camera and projector are connected to a computer which is embedded in the case of the system, making interaction with the hardware as minimal as possible for the end user. Augmented Reality (AR) is realised by projecting an image on the paper, while capturing the student's interaction while solving geometry exercises. The results revealed that the system was not only intuitive to use for the students, but manageable for the teachers as well, by managing the paper interfaces autonomously. The flexibility of paper as a material for building user interfaces supporting pedagogical designs is shown by the variety of collaborative scripts that could be created. This flexibility can be further exploited, enabling the teachers to create their own pedagogical AR applications. Figure 5.2 shows how this system looks like when placed on a desktop, with some geometry tools next to it.

Figure 5.2: The Metroscope, a camera-projector system enabling augmentation on a table

5.6 Symphony

Symphony is a commercial product developed by the Korean company TStudy (2011) that enables a new style of classroom teaching. It uses an Anoto Smartpen and dot patterned paper, with the handwritten data being send to the teacher's computer and displayed on a screen or Interactive WhiteBoard (IWB), so all students in the classroom can see this. Using this system enhances the student's motivation and creativity by letting them participate actively, and share and compare their work in group. By sending all data of each student to the teacher, their results can be evaluated and targeted feedback can be given, which allows the teacher to monitor the progress of each student more easily. A study led by the Hitachi Research Centre and University of Tokyo has shown that the use of Symphony helped propagate logical thinking among students, with exam grades improving by more than 40%.

Symphony, Smart Study, and other comparable systems discussed in this chapter have a similar approach to transporting classrooms into the digital age. The major difference is that data is displayed by projecting it somewhere in the classroom or by showing it on an IWB, while Smart Study gives personal feedback on a tablet device for each student, letting them work more individually. The Symphony system focuses more on collaboration and group discussions, while the Smart Study platform is designed for individual use. While the Symphony system transmits the data to the computer of the teacher, the Smart Study platform stores this data in a live database, which can then be further processed for showing the results on a tablet device, generating grades, creating reports, etc. The handwritten data is also recognised, and is stored in its recognised form. This is not the case for the Symphony system, as this displays the handwritten data, and does no form of recognition that allows converting it to digital text.

Figure 5.3: Collaborative working using the Symphony system

5.7 Golem Arcana

Golem Arcana is a Kick Start funded project (Harebrained Schemes LLC, n.d.). It has reached its funding goal of $500,000 and is being developed by Harebrained Schemes LLC. This is a tabletop game that uses a Tabletop Digital Interface stylus. The stylus can read microcodes that are printed over the icons and values of the figure's bases and over the terrain art of the board's regions. The results are displayed on a tablet that is running the Golem Arcana app. This project is similar to the Smart Study project, in the sense that pen/paper interaction is used and results are displayed on a tablet device.

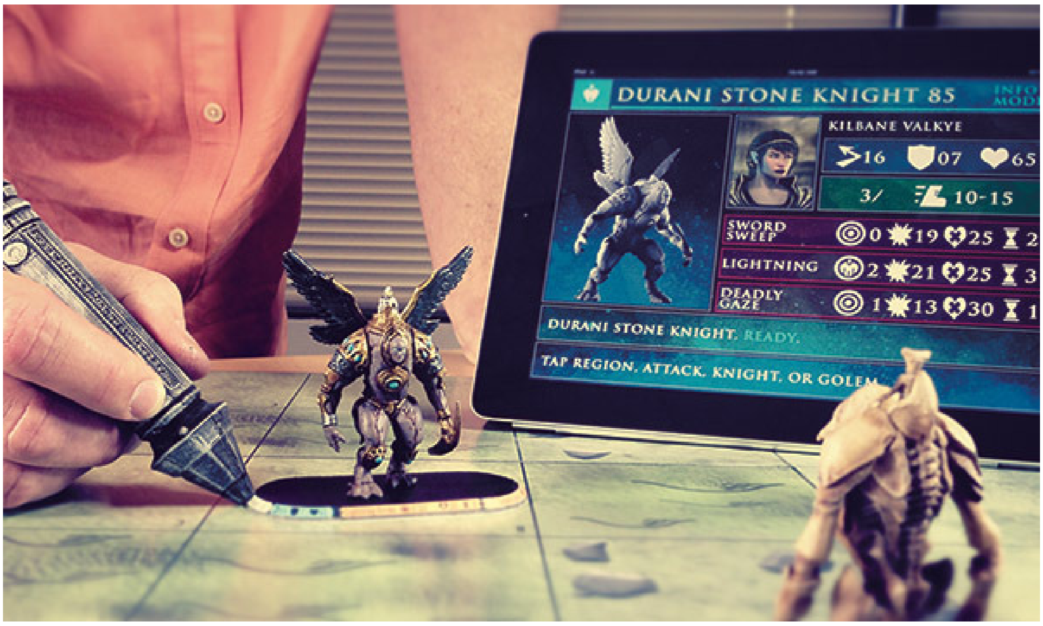


Figure 5.4: Playing Golem Arcana using a digital pen for interaction

Part III

Development

Chapter 6

Analysis

6.1 Introduction

As explained in Chapter 1, the goal was to develop an educational platform that aims at helping primary school children to work more independently, stimulate their read/write learning style, and display the results of their written answers, the corrections, and feedback in a clear way.

For the writing part, the Livescribe Echo digital pen was used. For this pen a free SDK was available, which was not the case for the other Livescribe pens, or for pens of the competitors. Note that Anoto also provides an SDK but not for free. The selected pen writes like a normal pen, but can capture everything written down on a piece of paper. On the paper itself, an Anoto dotted pattern is printed. These are very smalls dots that have unique positions, so the digital pen can determine the exact location of the tip of the pen on the paper. By writing on the paper, and thus not lifting the pen, these coordinates are linked. The ICR engine of the pen can then try to recognize the handwriting.

For the results, corrections, and feedback, an Android tablet was used. Because tablet devices are light, mobile, and easy to use by providing a touch screen, this was the best choice compared to the use of a notebook or a desktop computer. Android tablets were deliberately chosen because of the wide variety of available tablets, where manufacturers are running the Android Operating System (OS) on their hardware. This allows users to buy cheap Android tablets, and still give them the opportunity to seamlessly run the Smart Study app.

Before starting with the design of the platform, the available technologies were first analysed in order to understand them and know possible limitations that could influence the design. First, the Livescribe software available for developing software for the Smartpen is described. Next, the Android environment for developing software is explained.

6.2 Livescribe Platform

To develop software for the Livescribe Smartpen two major components need to be developed: the Penlet, which is short for pen application and is the software running on the Smartpen that performs operations on dot papers it recognizes, and the Paper Design, which is the software deployed onto the Smartpen to know how a paper looks like and which active regions it contains. The following sections explain both parts.

6.2.1 Livescribe SDK

Livescribe provided a Software Development Kit (SDK) in order to create these applications. Unfortunately, the company discontinued support and future updates in 2011 (Livescribe, 2011), meaning that the current platform is designed with their latest version of the SDK in 2011. This also increased the difficulty when stumbling upon errors while creating these applications, as there is no longer active support and the community forums are removed.

The SDK is implemented via plug-ins and libraries in a Java Integrated Development Environment (IDE), preferably Eclipse. The package containing the SDK that Livescribe provided already contained a version of Eclipse where the entire SDK was injected. Because this is an outdated version of Eclipse (Galileo 3.5.1) it was not used. Instead, the newest version of Eclipse at the time of development (Kepler 4.3.1) was used to create all Java related applications. The latest Java platform (version 7 Update 55) was used as well. The 32-bits platform was installed, because the Livescribe SDK does not support the 64-bits Java platform. Note that Java version 8 was available since March 2014, after the initial development of the project, but was not used due to serious compatibility issues. There were also no benefits in using version 8 over 7 for this project, so the latter was used.

Views are added to the Eclipse IDE in order to support the capabilities of the SDK. Figure 6.1 gives an overview of how Eclipse with the integrated Livescribe SDK looks like. The two news views, also called perspectives, can be seen at the right top, framed in red. When designing a Penlet, the developer can switch over to the Penlet view. On the right, a view appears with two tabs. When clicking on the first tab, it gives information about the connected Smartpen. Installed Penlets and Paper Designs can be viewed here. Figure 6.1 also displays the Smart Study Penlet and its Paper Designs, framed in red, which are installed on the connected Smartpen. When clicking on the other tab, the debug of the Smartpen can be read. This is useful when designing Penlets, as logging can be programmed into the Penlet, which can then be read from the debug Random Access Memory (RAM) of the Smartpen. Since no live feedback can be given from the Smartpen to the Eclipse IDE because the pen's event handlers invoking the detachment and reattachment take up to 5 seconds total, the debug from the Smartpen's RAM needs to be read manually. Figure 6.3 shows how this looks like when reading the debug RAM of the Smartpen when using the Smart Study platform, filtered on the Smart Study Penlet. Logging that was programmed into the Penlet can be seen here. There is no need to remove this code, even if the Penlet works and is stable, as this can be useful when adding new features, or if code is given to another developer.

The other view is needed when creating Paper Designs. Figure 6.2 gives an overview of how the Paper Design looks when enabling this view. This view is specifically for designing paper products, and not for programming code. The left side gives an overview of all the papers that have been designed, and will be deployed as one single document to the Smartpen. The middle section shows the current paper product, with next to it the tools the developer can use. The top right side gives an outline of all the regions and other graphical elements on the paper, with below it the properties of each selected element. This will be explained in more detail in Chapter 7 when talking about the Paper Design.

When an application is ready to be used, it needs to be installed onto the Smartpen. This is done by deploying the entire Penlet project or a Paper Design document onto the pen. Any existing Penlet or Paper Design that has the same name is overwritten without any confirmation. The Penlet can be activated by navigating to it using the Smartpen's menu, or by interacting with the printed dot paper right away.

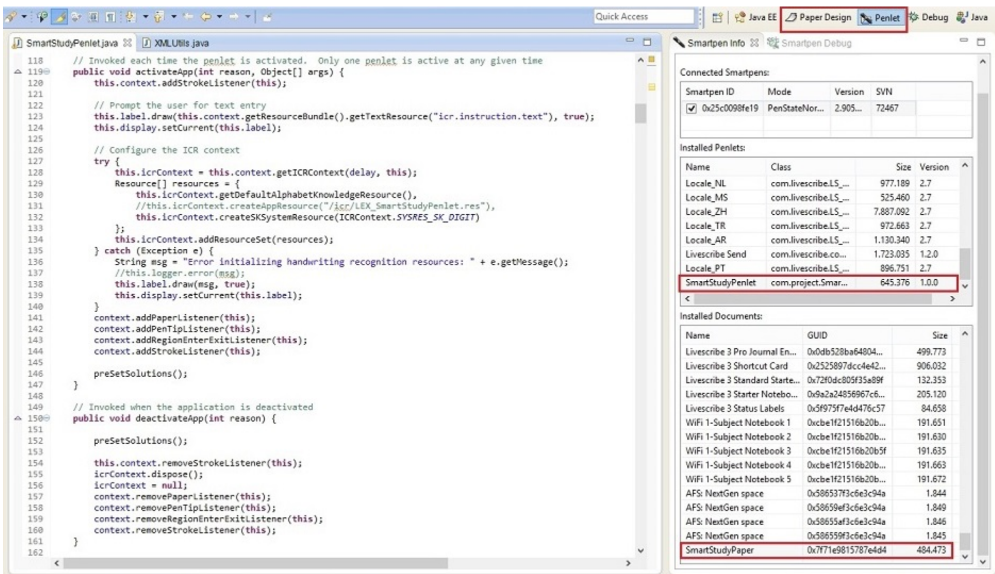


Figure 6.1: Overview of the Eclipse IDE with the Livescribe SDK integrated

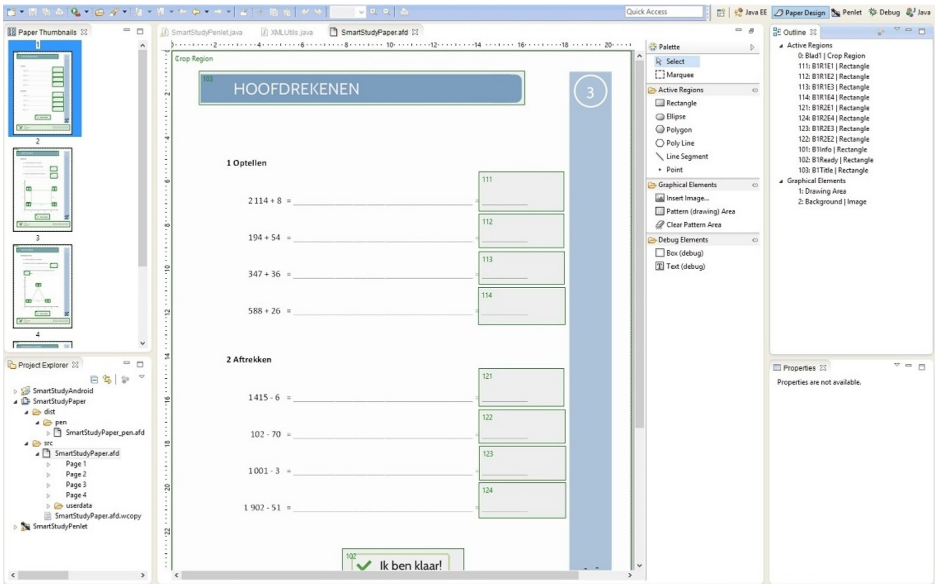


Figure 6.2: Overview of the Eclipse IDE with the Paper Design view active

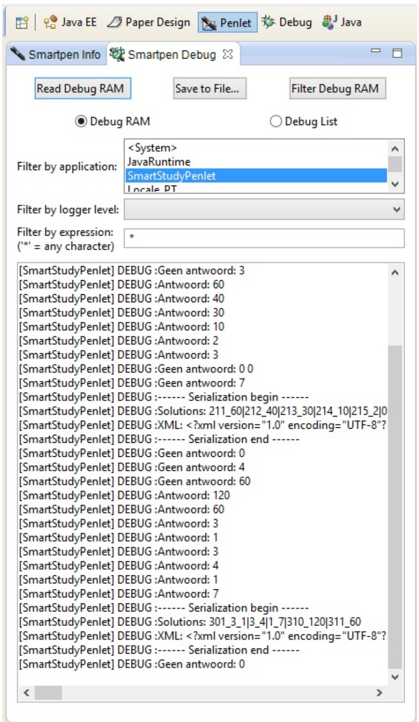


Figure 6.3: Smartpen Debug when activating the Penlet view

6.2.2 Penlet

As introduced in the previous section, a Penlet is a Java application that allows interaction with specific active regions which are defined on a Paper Design. The Penlet can handle certain events and perform actions described by the active regions on the dot paper, such as tapping or writing in this area.

Each Penlet is represented by a main Java class which implements certain interfaces, which are usually event listeners. There can only be one Penlet active at a time, due to the nature of a Penlet's life cycle, which manages objects by the Smartpen runtime. When another Penlet is activated, the current one gets deactivated and destroyed. There are exceptions however. Certain static regions on supported dot paper can call Livescribe system functionality, such as navigation and volume change, without deactivating and destroying a currently running Penlet. The life cycle of a Penlet is described in Figure 6.4 (Livescribe, 2010), with each method being explained in the following sections. These methods are defined as the *Four Life Cycle Callback Methods*. The runtime system calls these methods at the appropriate time.

initApp()

This is the first of the four callback methods that is being called, and is invoked when the application is initialized. This will only be executed once for each application instance, namely at the beginning of the life cycle. When this method is invoked, it leaves the Penlet in the *inactive* state.

activateApp()

After calling the *initApp()* method and the Penlet enters the *active* state, the emphactivateApp() method is called immediately. The Penlet can get activated through the menu of the Smartpen, or when interacting with an active area on the supported dot paper. In the body of this method, event listeners can be added which are accessible when the class implements its interfaces. The event listener *addStrokeListener* can receive events such as *StrokeCreated*, which handles the event whenever strokes are created by the user on the dot paper, which can be a drawing or some text. The event listener *addPenTipListener* can receive events such as *PenDown*, which handles the event whenever the user taps an active area on the dot paper. Another important event listener used in the Smart Study Penlet is *icrContext*, which configures the ICR context, enabling handwriting recognition by using a specified knowledge resource. For the Smart Study Penlet, a knowledge resource supporting numerals was created.

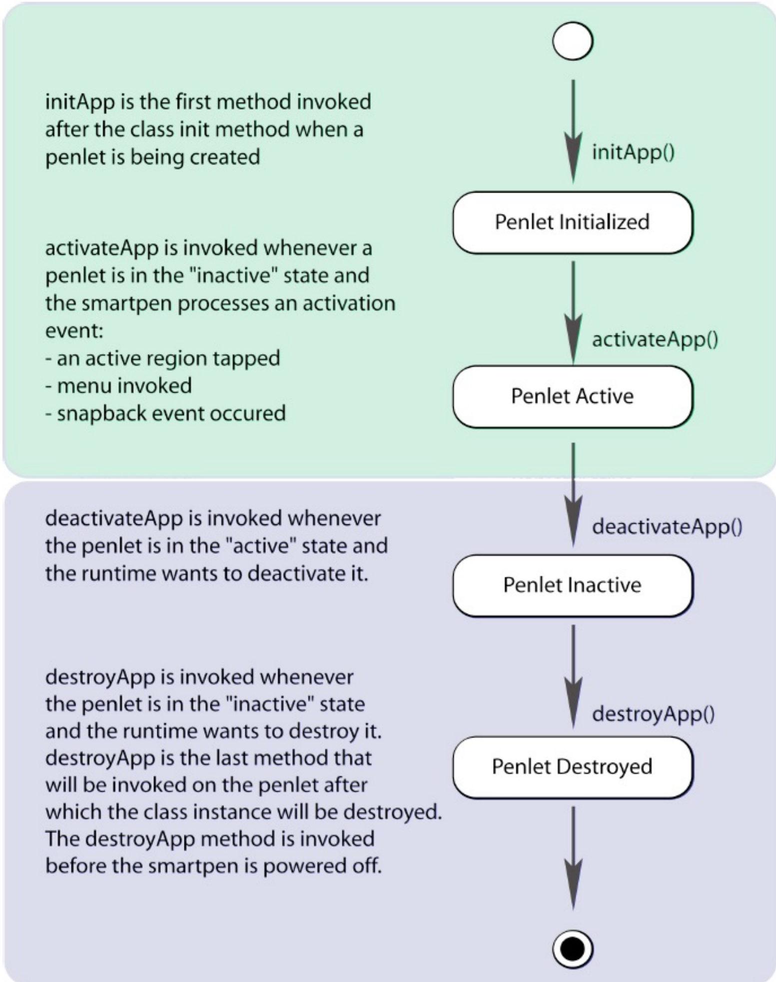


Figure 6.4: State transition diagram of a Penlet life cycle

deactivateApp()

When another Penlet gets activated and the currently running Penlet gets deactivated, the runtime system will call the emphdeactivateApp() method, often immediately followed by the emphdestroyApp() method. The reason why this method is called first instead of calling emphdestroyApp() immediately, is to give the developer the chance to store application data, and release resources so the occupied memory can be freed and used by the next Penlet. The runtime system also passes a constant which describes the deactivation reason, such as a deactivation by turning off the Smartpen, or activating another Penlet. This can prove to be useful when the developer wants to know the reason of deactivation.

destroyApp()

The final callback method is invoked when the Penlet enters the *inactive* state due to calling the emphdeactivateApp() method. This happens once for an application instance. No other methods will be invoked once emphdestroyApp() is called. After this, the runtime system will destroy the Penlet.

Besides these four important methods, there exist other methods that the Penlet can call. Since these other methods are not always present in every Penlet, this will be discussed in Chapter 8 when talking about the implementation of the Smart Study Penlet.

A Paper Design can exist out of multiple active regions, discussed in the next section. While such a region is a physical location on dot paper, an area defines the functionality when a user interacts with a region, triggering one or more event handlers. An area is a subset of a region, meaning that a region contains an area. Each region and area is identified uniquely by providing a 16-bit and 64-bit number, the first one for an Area Id and the other one for a Region Id. An area can be assigned to multiple regions, and will preserve its functionality. These identifiers can be used by the Penlet in order to detect the locations of the areas when the Smartpen interacts with the dot paper, executing specified operations when event handlers are triggered.

6.2.3 Paper Design

In order to create these Paper Designs, the Livescribe SDK provides another handy tool, namely the Paper Design view. This lets the developer create paper products that can work with a Penlet. Such a paper product can contain static regions that have specific functions defined by the developer. The tool allows you to define these static regions, add images and text to your paper, generate the Livescribe dotted overlay so the Smartpen can read the paper, and finally produce the paper product, which will be stored as an Adobe PostScript file. This file can then be printed by a qualified colour LaserJet printer, supporting PostScript and printing at 600dpi or higher. It is important that a supported printer is used, as not every printer can accurately print out the paper with the dotted overlay, which needs to be printed with a high level of precision in order for the Smartpen to be able to read the dots correctly. The file format in which these paper products are being saved is not as a Java file, but as an Anoto Functionality Document (AFD).

Regions can be defined by drawing a shape onto the paper product. Figure 6.5 gives an overview of how such a paper product looks like when designing it. To the right, the tools can be selected. Different types of shapes can be used in order to draw an active region onto the paper product. Figure 6.6 shows how the properties look like when selecting a specific element of the paper product. Here, the name and identifier of an area can be specified. Note that the identifier can only be a 16-bit integer, as mentioned in the previous section. Each area can be linked to a specific Penlet, which can be defined in the Application Id list. This enables the Penlet to recognize the produced paper product and add specific operations when an event has been triggered in this area. A final important feature here is the specification of the event handlers themselves. For the Smart Study project, only two of these were used, namely *PenDown* and *StrokeCreated*. When these boxes get checked, code is automatically generated in the linked Penlet's main class, enabling the event handler, and triggering this when the user does this specified interaction with the Smartpen in the defined area on the dot paper.

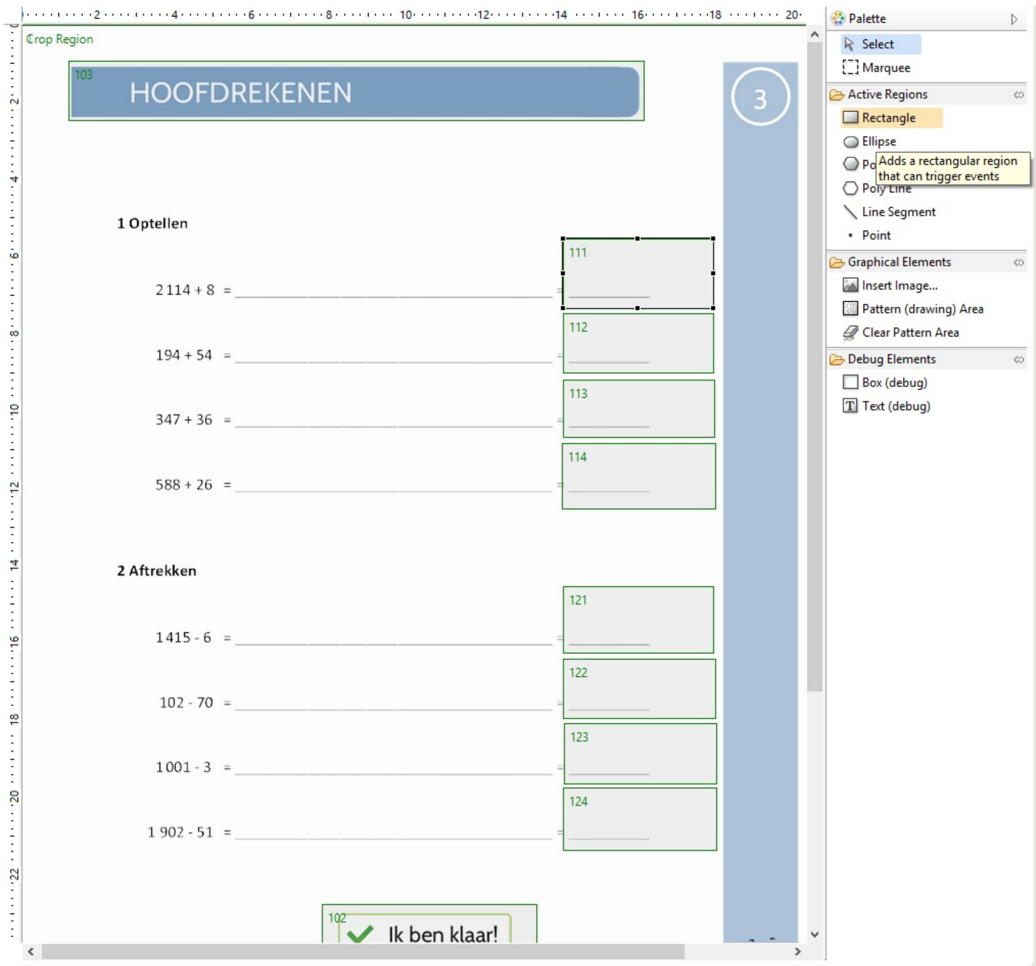


Figure 6.5: Overview of the Paper Design view with the tools to the right

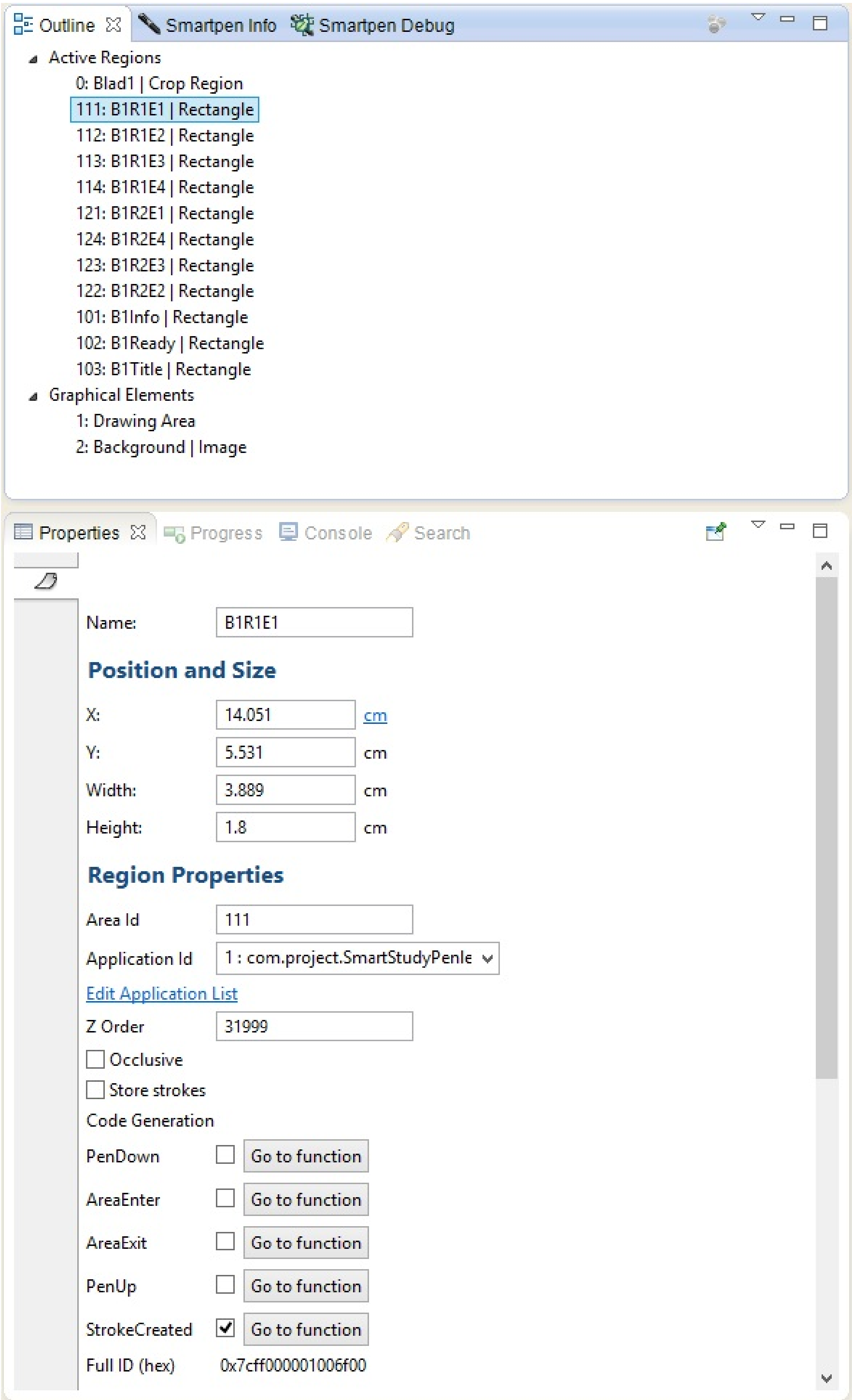


Figure 6.6: Overview of the Paper Design view of an element's properties

6.3 Android Platform

In this section, the Android platform will be discussed. A design choice made in the beginning of the thesis project was to enable the user to have feedback on a tablet screen. In this section, the Android OS and SDK will be introduced.

6.3.1 Android OS

Android is a Linux-based operating system primarily designed for smartphones and tablets using touch interface. It was initially developed by Android Inc., a company that was acquired by Google in 2005 , and later released under the Open Handset Alliance (OHA) (2007). As of March 2014, Android was the most used OS worldwide on smartphones (KWC, 2014) and tablet devices (Gartner, 2014). Since its initial release, Android OS has seen a number of version updates, with Android 4.1, codenamed Jelly Bean, being the most used version as of March 2014 across all supported devices (TechWeek, 2014). Figure 6.7 gives a complete overview of all the versions Android has had so far. At the time of writing, the newest release is version 4.4, codenamed KitKat, which was released on 31 October 2013. Figure 6.8 (Google, 2014) gives an overview of the currently used Android versions worldwide on supported devices, starting with version 2.2. Older versions are not mentioned any more because they do not support the Google Play Store app, and thus would be hard to correctly analyse.

Figure 6.7: Android OS version history

6.3.2 Android SDK

Google provides the Android SDK for developers to create apps for their platform, usually programmed in Java. Their SDK consists out of an array of development tools, which includes software libraries, a debugger, documentation, code samples, tutorials, but also an emulator with which a developed app can be tested by emulating it as an ARM or Intel Atom x86 based device, demonstrating the same behaviour as on a real Android device. The SDK is usually integrated in the Eclipse IDE by using the Android Development Tools (ADT) plugin.

Version	Codename	API	Distribution
2.2	Froyo	8	1.0%
2.3.3 - 2.3.7	Gingerbread	10	16.2%
3.2	Honeycomb	13	0.1%
4.0.3 - 4.0.4	Ice Cream Sandwich	15	13.4%
4.1.x	Jelly Bean	16	33.5%
4.2.x		17	18.8%
4.3		18	8.5%
4.4	KitKat	19	8.5%

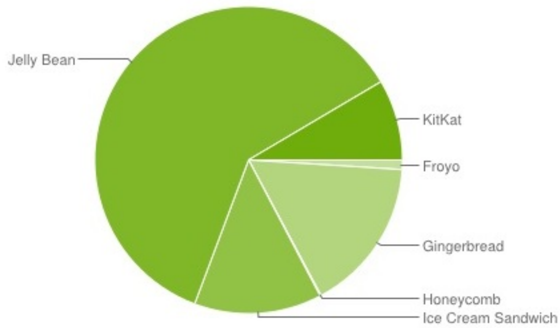


Figure 6.8: Distribution of a relative number of devices running a version of the Android platform. Data collected during a 7-day period ending on May 1, 2014.

In May 2013, Android Studio, an alternative IDE developed by Google, was launched in an *early access* state. This IDE is specifically designed for creating Android applications, and is based on IntelliJ IDEA software. It has the same functionality as Eclipse's ADT, but its IDE offers a different interface, and is faster and lighter compared to Eclipse. Since it is still in very early development, several features are either incomplete or not yet implemented. It is advised not to be used as a replacement of Eclipse's ADT. Figure 8.1 gives a comparison view of how the interface looks like in Eclipse Kepler using the ADT plugin and Android Studio. There also exists Android Native Development Kit (NDK), a toolset developed by Google, that allows implementing parts of an app using native-code languages like C and C++. Using this can useful for reusing code libraries specifically written in that programming language.

Since Android development is starting to become a commonality, no further details about its SDK will be given. A comprehensive overview of the basics of working with the SDK, setting up Eclipse's ADT plugin, and new features of KitKat for Android developers, can be found on their website (Google, n.d.).

Chapter 7

Design

7.1 Introduction

In the previous chapter of the development part, the technologies used to implement the platform were explained. This chapter will explain the overall design of the Smart Study educational platform. The platform has been designed using the Software Engineering approach of loose coupling and high cohesion. Each node is independent, making it easy to replace it with other or newer software or technology, while the other nodes simply keep on working with very little change to their software. This makes them pluggable, which is very interesting when another developer continues working with this platform for making changes or extended it.

First, the requirement elicitation phase is discussed, then the architecture of the platform and how the different components interact with each other is presented, and finally the design of the user interfaces and the database.

7.2 Requirements

Requirements elicitation was done with the GuideaMaps application. GuideaMaps is an iOS-based iPad application. It was created as part of a Master thesis done by Erik Janssens (2012). The tool provides support for the requirement elicitation for serious games, making the collecting of required information easier, and helping in the decision-making process. It visualizes the underlying Decision Model and allows collecting the requirements. Figure 7.1 gives an overview of the entire Smart Study project using the GuideaMaps app.

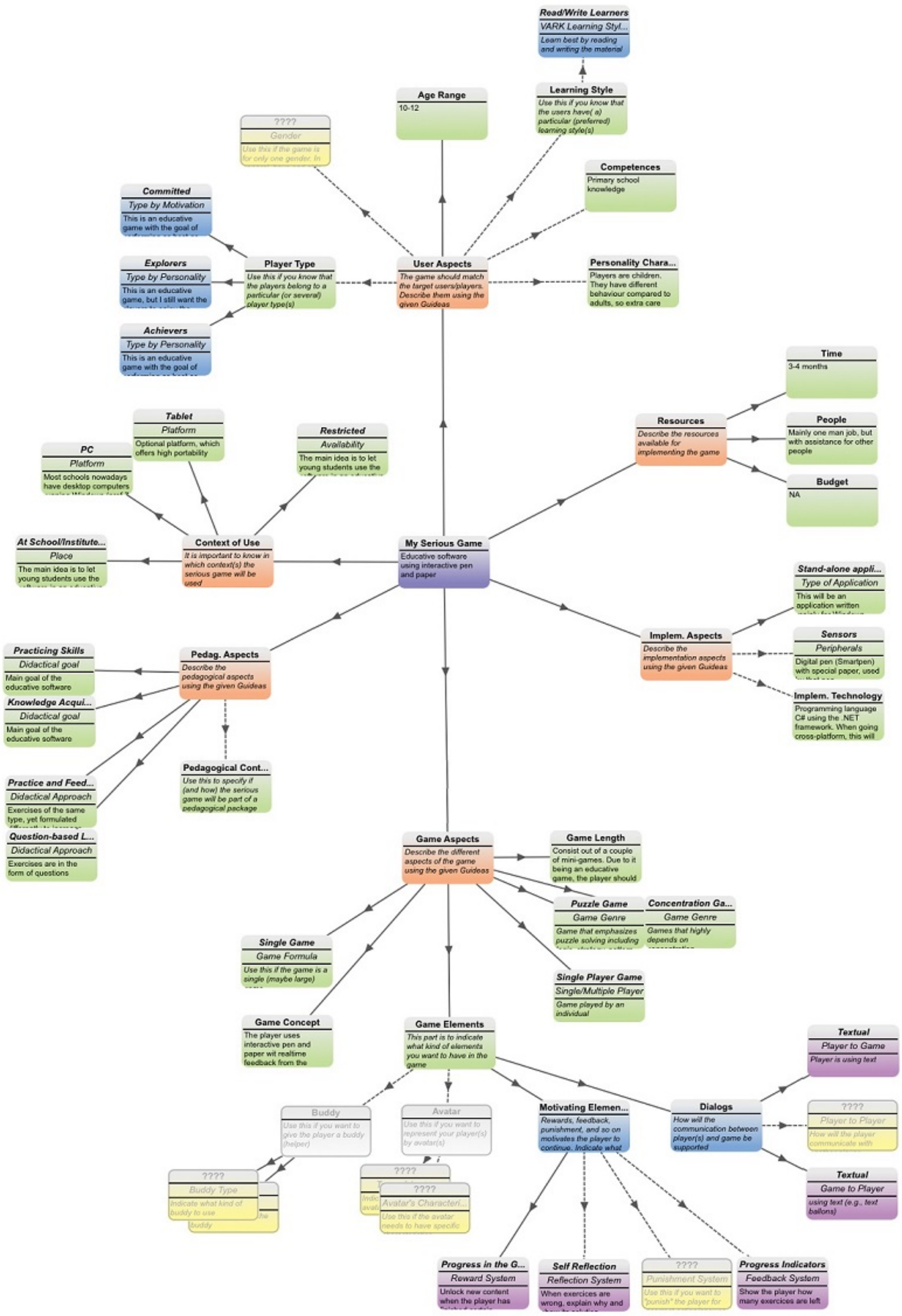


Figure 7.1: Overview of the Smart Study project in GuideaMaps

7.3 Architecture

Figure 7.2 presents the system architecture of the Smart Study platform, while Figure 7.3 shows the information flow and primary operations between the nodes of the platform. Note that not every node is connectible, and that there can be no bidirectional information flow between the Smartpen and the device running the program, due to the limitations of the Smartpen. The interaction between the nodes is described in the next section.

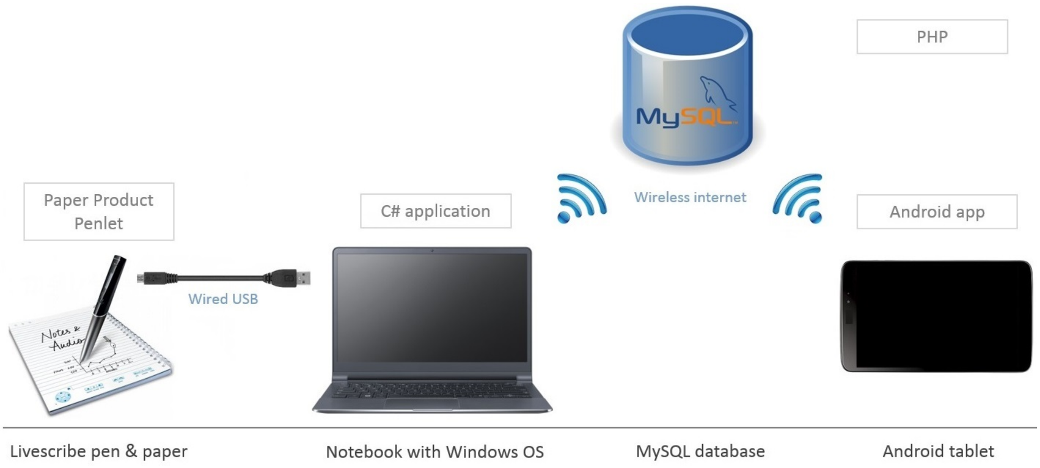


Figure 7.2: System architecture of the Smart Study platform

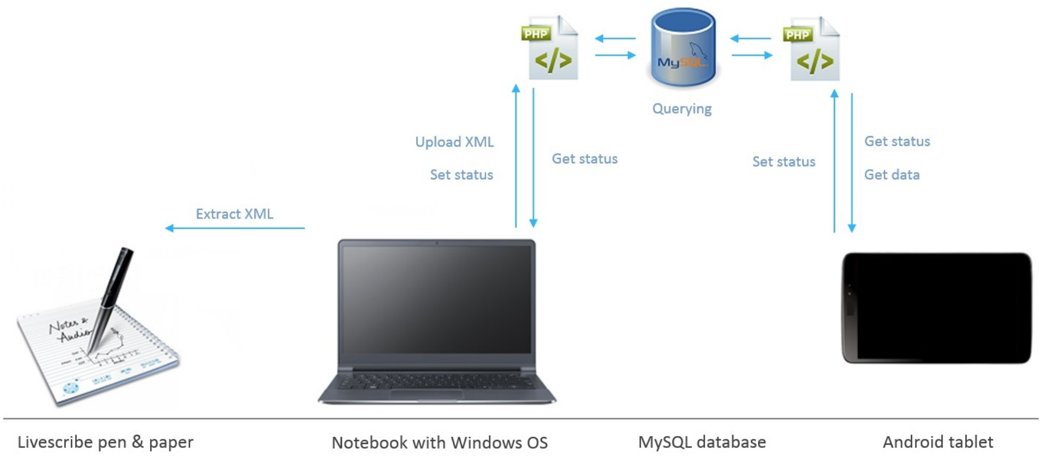


Figure 7.3: Information flow between the nodes of the Smart Study platform

7.4 Interaction Between the Nodes

The following sections will describe the working of the platform. The role of each node and its interactions will be explained. The working is explained by means of a scenario.

7.4.1 Scenario Platform Setup

The first step into making the platform work, is to set everything up. The dot paper of the Smart Study Paper Designs needs to be printed. The Livescribe Echo Smartpen needs to have the Smart Study Penlet and its AFD installed on it. A device (e.g., notebook) running Microsoft Windows, Vista (SP2) or higher, needs to have at least .NET 4.5 installed, with an active internet connection, and the Smart Study Synchronisation program installed. A micro-USB cable needs to be present for connecting the Smartpen to the notebook. Finally, an Android tablet, running at least version 2.3.3, needs to have an active internet connection, with the Smart Study app installed on it.

7.4.2 Scenario Working With the Platform

When everything is set up, the user can start working with the platform. The user picks out an exercise page to solve, and powers on the Smartpen. The Smart Study Penlet is automatically activated when interacting with a recognized exercise page; it does not need to be activated manually. The user fills out the exercise page, writing the answers of each exercise in the corresponding answer regions of the paper. Every time an answer is written in an answer region, it is recognized, stored, and displayed on the screen of the pen. Exercises can be left out if they are too hard to solve. When the user is done filling out the exercise page, the area on the paper with the text *Ik ben klaar! (I am ready!)* is tapped. The screen of the Smartpen displays some text, stating the answers have been saved, and a recording is played through the speakers of the pen, saying that the answers have successfully been saved. The XML file is built and stored on the internal memory of the pen. The user now launches the Smart Study Synchronisation program on the Windows notebook making sure has an active internet connection. The program checks the record in the *Processing* table every 8 seconds by calling the PHP file, which returns the values of the fields of this record. As long as the field *ExtractionStarted* has value 0, the program will keep waiting and checking. As a final procedure, the user connects the Smartpen to the notebook using a micro-USB cable. The user is now ready to perform the second major step, using the Smart Study tablet app.

The user powers on the tablet, and launches the Smart Study app. An active internet connection is required. The app shows the splash screen for a few seconds, afterwards switching to the login screen. The data of all active students is fetched, populating the list on the screen. The user taps this lists to select its name. When there is no active internet connection, the list will be empty and the user cannot proceed until there is an active internet connection. After authentication, the home screen is presented. Since the user just filled out an exercise page, the recognised answers need to be corrected. The sign that says *Oefeningen maken (Make exercises)* is tapped, and on the next screen the sign that says *Controleer mijn antwoorden (Check my answers)* is tapped, in order to correct and display the answers. When this image button is tapped, the process cycle is started. The app calls the PHP file for updating the state of the process cycle, setting the field *ExtractionStarted* to value 1, *ProcessDone* to value 0, and *StudentID* to the value of the student identifier of the currently logged in user. After this, the PHP file for checking all of these fields will again be called, every 6 seconds. The app thus waits on response of the program by constantly checking these fields, before executing further operations on its side. A progress dialogue shows up, asking the user to be patient while the process is being executed, temporarily disabling interaction with the app.

Now that the state of the process cycle is set to *ExtractionStarted*, the program will fetch the data from these fields, and check whether the *ExtractionStarted* field is set to value 1, and the *ProcessDone* field is set to value 0. It is very important that both fields comply to these values at the same time, because if only *ExtractionStarted* would be checked, then it could redo the extraction process again when checking the fields after its 8 seconds delay, but if the app did not yet update the *ProcessDone* field in the next step, then the whole cycle would be suddenly broken. When the if-test is true for both values, the program will now start the extraction process. For each operation that is executed by the program, all possible errors are handled. If the user did not connect the Smartpen to the notebook before tapping the image button for starting the process cycle on the tablet, the program will display an error that no Smartpen could be found. The same can be said about when there is no active internet connection, the Smartpen being detected but extraction failed, the file not being present on the Smartpen, file uploading failed, the database connection failed, the database queries failed, or when there is an unexpected application failure. Even after all possible errors and failures, the program will still respond, and simply restart its status checking loop, hoping that by the next check the errors have been acknowledged by the user, and actions have been taken to solve the issue. If all goes well, the program extracts the XML file from the Smartpen. The file is stored temporarily on the notebook, whereafter it is uploaded to the server using the PHP file. When uploading is successful, the another PHP file reads the uploaded XML file, processes it, compares the answers with the solutions, and stores the data into the database (if that exact exercise page was not filled out yet by the current user). As a final operation, the *ProcessDone* field is set to value 1, and the *CurrentPage* field is set to the page number acquired from the XML file. Note that *ExtractionStarted* is not set to value 0, hence the double check described above. This is because this value is used in an if-test by the app as well, described in the next paragraph.

All data about the filled out exercise page is now stored into the database. The app, still checking the values of the fields every 6 seconds, will proceed when the *ExtractionStarted* field has value 1, and when the *ProcessDone* field has the value 1 as well. By checking whether both fields have value 1, the app knows that the extraction process has just been finished by the program, and the cycle is still busy. If only the *ProcessDone* field was checked, then the app could not know if the process cycle is still busy or not. Normally, there should never be a case where the *ExtractionStarted* field has value 0, while the *ProcessDone* field has value 1 at the same time, as this is programmatically not possible. However, when someone tries to manipulate the data of these database fields manually, for example while doing some testing, the process cycle will not fail since this check is being done. This check is useful during testing when manual data manipulation in the database is required to speed up testing. But since these extra checks have no drawbacks for the platform overall, they can be kept since it is an extra form of security.

When the app has acknowledged that the extraction was successful and the data has been inserted into the database, all that stored data is being fetched. A last operation that is done by this PHP file, is updating the state of the process cycle. Since this has successfully finished now, the fields of the record of the *Processing* table need to be reset to their initial values. The *ExtractionStarted*, *ProcessDone*, *StudentID*, and *CurrentPage* fields are all set to value 0.

This fetched data that was echoed by the PHP file as a JSON string is received by the app and is processed and stored into separate variables. Depending on the group of exercise page that was filled in, a choice is made between which activity will be chosen since the layout of these two screens is different. This is done by reading the *Page* variable stored in the JSON string. A value of 0 or 1 means it belongs to group 1, while a value of 2 or 3 means it belongs to group 2 (geometry). These values correspond to the unique page identifiers that are used by the Penlet and its AFD for recognizing the correct exercise page. The overview of all the exercises of the exercise page is now built per exercise. This consists of the exercise number, the question, the user's recognized answer, and the correct solution in blue when the answer was wrong, in this case changing the user's answers to red instead of green. The user can tap an entire exercise block, which will draw a visible yellow box around the entire selected exercise, and display feedback on the right side of the screen. For group 1 exercise pages this is textual feedback, while for group 2 exercise pages the corresponding figure is shown, with two of those questions having animated feedback in the form of a video. When the user is done analysing its results and possible corrections, the image button at the right bottom of the screen is tapped to return to the home screen.

A full process cycle has now been finished, and the user can choose to solve another exercise page, while still being logged in, with the Smartpen still being powered on, and with the program still running and checking the state of the process cycle. The only thing the user has to do when wanting to fill out a new exercise page, is to disconnect the Smartpen from the micro-USB cable. This invokes the *PenDetach* event handler of the pen, making sure that the program will correctly recognize the pen the next time it is connected to the notebook, while not closing the program, nor turning off the Smartpen. This is not necessary when you close the program and restart the Smartpen every time a user fills out a new exercise page. But since this is a cumbersome way of working, a better way was constructed, so that everything could keep on working while it was still running and powered on.

Finally, the user can check the results of the exercise pages that were filled out. On the home screen, the sign that says *Mijn resultaten (My results)* needs to be tapped. This will display a screen where all of the total results per exercise page can be viewed. A PHP file is called when this activity is started, fetching all the data of the logged in user, for all exercise pages. By making a sum of the exercises that were correct for each exercise page, a score can be displayed, showing the user how many exercises were solved correctly, over the total amount of exercises. When done viewing the results, the user can tap the back button at the bottom left of the screen, returning to the home screen.

7.5 User Interfaces

Before starting the implementation, high-fidelity prototypes of the paper designs, as well as of the screens of the tablet have been made. These are described in the following subsection.

7.5.1 Smart Study Paper Designs

Four papers were created, representing four exercise pages. The designs of these exercise pages can be found on the following pages. These are the original designs created in Adobe Photoshop CS6. As these are prototypes, the dotted pattern overlay is not present.

The layout of the exercise pages has been designed keeping the following principles in mind. Each course has its colour, in this case mathematics is blue. At the top, the title of the exercise page is displayed. The vertical bar at the right side of the paper has the same colour as the current course. On top of this bar, the page number is displayed. These exercise pages are thus designed to be included in an exercise bundle that can have different courses. At the bottom of the bar, a mascot or icon can be seen, each one unique to its course. This right side bar comes in handy when flipping through the pages, with the colours and icons depicting which section the user is currently looking at. The body of the page contains the exercises. The level of these exercises is aimed at primary school children of the fifth grade. A page can have one or more series. The structure of the exercise pages can be divided in two groups, identified by their type of exercises. The exercise pages of addition/subtraction and multiplication have the same structure, namely a total of 8 exercises underneath each other, while the other group has a total of 3 exercises, with the third exercise being a figure to fill in, since it covers geometry. For all the exercises, except the figures, some space is provided to work out the exercise. Next to it, the final solution of the exercise can be written. An area below the last exercise that has the text *Ik ben klaar! (I am ready!)* can be tapped to indicate the user is done filling out the exercise page, and will be explained in more detail in the next paragraph. It has a green check mark left of the text, indicating the finishing of the exercise page more clearly. Finally, at the bottom there is an area where information about the thesis project is displayed. The use of colours and its combinations has been chosen in such a way that they are very readable and usable by people who are colour-blind.

On each of the paper products, active regions are drawn. There are two types of events that can happen in these areas, either a *PenDown* event, or a *StrokeCreated* event. Figure 7.8 and Figure 7.9 show two different groups of exercise pages, where these events have been categorized and labelled in red. Active regions of category 1 are meant to be tapped once. When the user taps in this area on the dot paper, a message will appear on the OLED screen of the Smartpen. The user can tap the title at the top, displaying the text of the title on the screen, tap the area at the bottom, displaying information about the thesis project, and finally tap the area that has the text *Ik ben klaar!* in it, which will play a sound recording and display information on the screen that the solutions have been saved. Active regions indicated as category 2 in the figures can capture strokes that are created inside this area. This is meant to capture the solutions of all the exercises that are written down here. Each region and area has a unique identifier. This enables the developer to program the Penlet in such a way that operations can be executed when interaction takes place inside an area. These identifiers are even used to a further extend, namely as unique identification when inserting data into the database, and correctly displaying the exercises on the Smart Study tablet app.

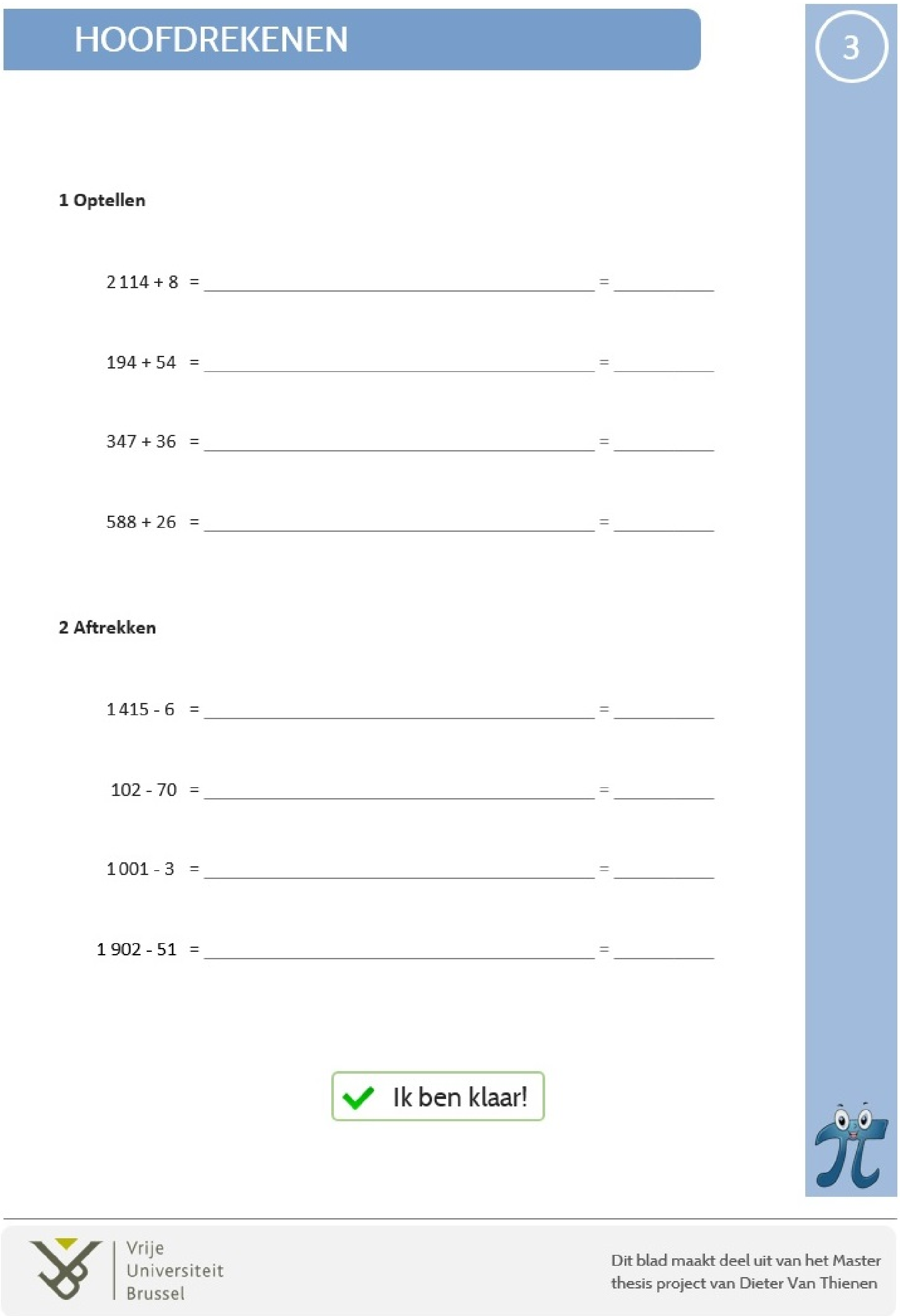


Figure 7.4: Exercise page of addition and subtraction


VERMENIGVULDIGEN

4

1 Los op

300 x 6 = ______________________ = ________

10 x 2,5 = ______________________ = ________

50 x 0,2 = ______________________ = ________

14 x 100 = ______________________ = ________

100 x 3,15 = ______________________ = ________

0,5 x 20 = ______________________ = ________

40 x 7 = ______________________ = ________

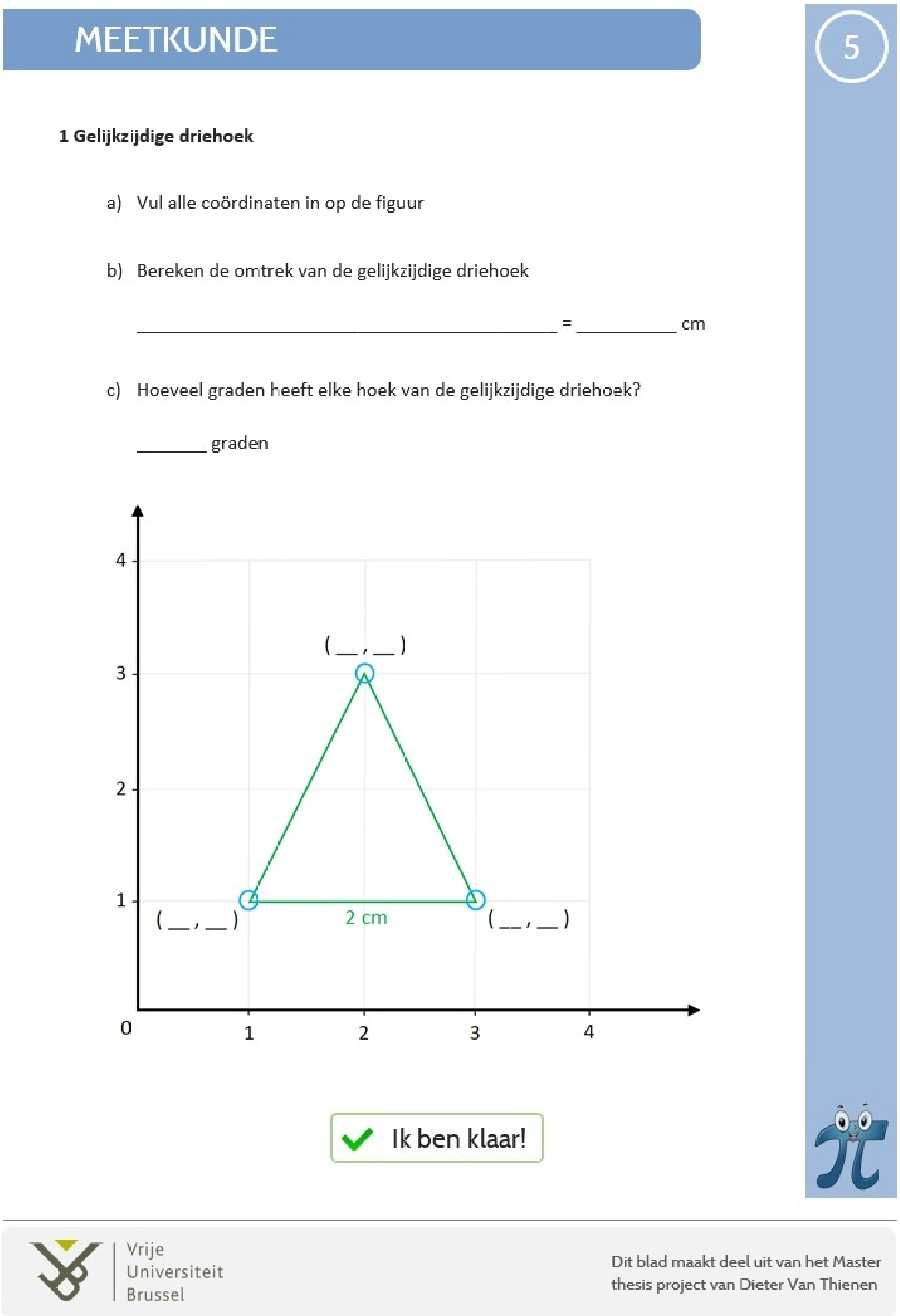
60 x 20 = ______________________ = ________

Ik ben klaar!

Vrije Universiteit Brussel

Dit blad maakt deel uit van het Master thesis project van Dieter Van Thienen

Figure 7.5: Exercise page of multiplications


MEETKUNDE

5

1 Gelijkzijdige driehoek

a) Vul alle coördinaten in op de figuur

b) Bereken de omtrek van de gelijkzijdige driehoek

____ = __________ cm

c) Hoeveel graden heeft elke hoek van de gelijkzijdige driehoek?

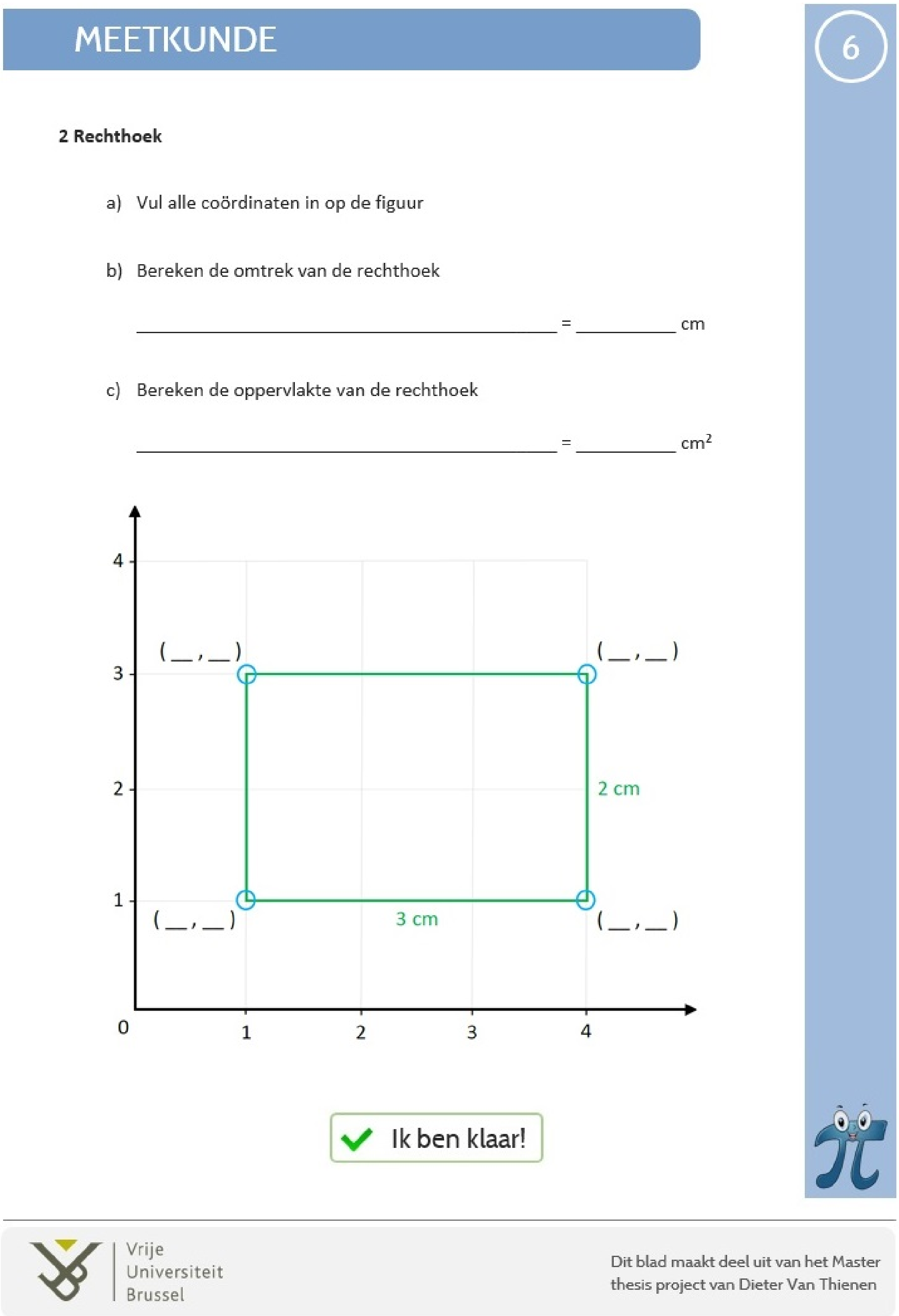
_______ graden

Ik ben klaar!

Vrije Universiteit Brussel

Dit blad maakt deel uit van het Master thesis project van Dieter Van Thienen

Figure 7.6: Exercise page of geometry: triangles



MEETKUNDE

6

2 Rechthoek

a) Vul alle coördinaten in op de figuur

b) Bereken de omtrek van de rechthoek

____ = __________ cm

c) Bereken de oppervlakte van de rechthoek

____ = __________ cm²

Ik ben klaar!

Vrije Universiteit Brussel

Dit blad maakt deel uit van het Master thesis project van Dieter Van Thienen

Figure 7.7: Exercise page of geometry: rectangles

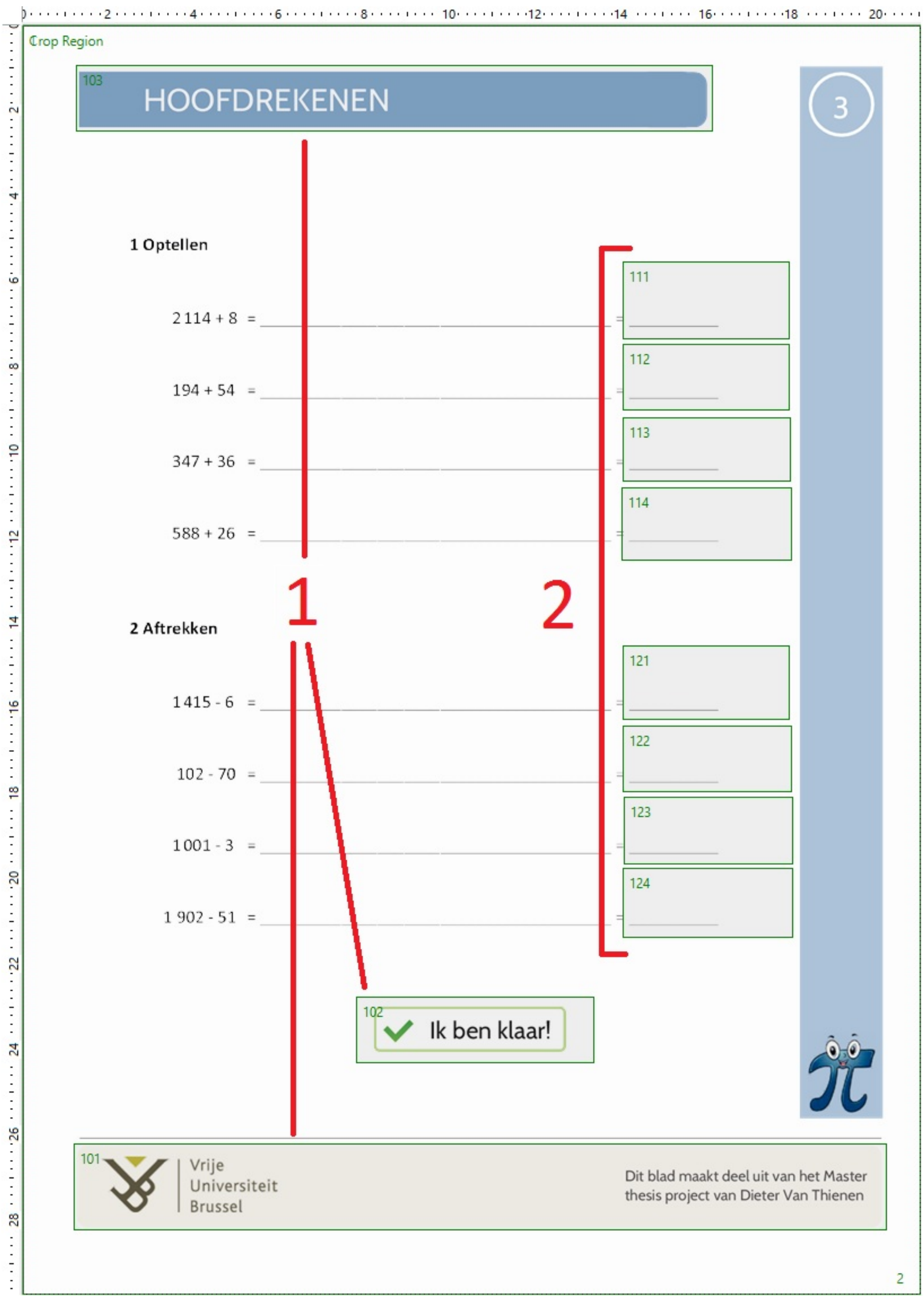


Figure 7.8: Active regions in the Paper Design of the addition and subtraction exercise page. Category 1 indicates *PenDown* events, while category 2 indicates *StrokeCreated* events.

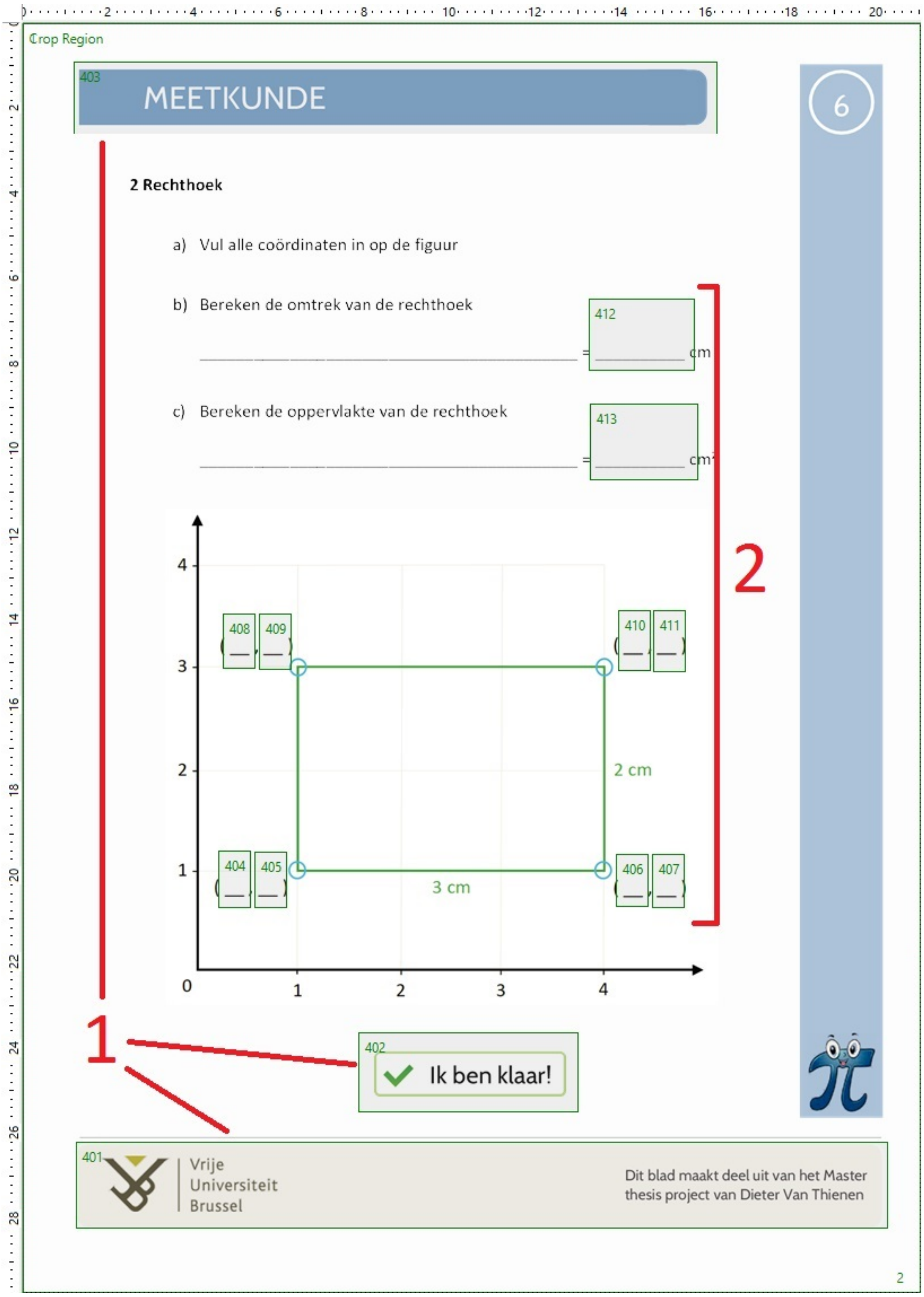


Figure 7.9: Active regions in the Paper Design of the geometry exercise page. Category 1 indicates *PenDown* events, while category 2 indicates *StrokeCreated* events.

7.5.2 Smart Study App Screen Designs

All screens, with the exception of the splash screen, consist of the same layout, using a nature/farm theme designed for children. The background of each screen shows clip art of meadow, used for increasing the concentration of the student by providing this calm background, but increasing their activity level as well by having a rising sun that casts out sun rays. The results of the evaluations, discussed in Chapter 9, confirm that the image and screen layouts indeed have an impact on the behaviour of the child when working with the tablet. Each screen is divided in three parts. The top part, or header, shows current user information, but also the title of the app and its slogan, which are centred and always present. The bottom part, or footer, shows the logo and name of the university at the left, and some personal information to the right. The middle part is where all of the current information is presented. Certain screens also have a back button, located at the left bottom of the main part, or a save button, located at the right bottom of the main part. These locations have been specifically chosen due to the nature of people looking at the left for going back, and at the right for proceeding. The following subsections show and describe the different screens.

Splash Screen

This is the very first screen that will appear when starting the Smart Study app. After 3 seconds it will disappear and the login screen will be shown.

Figure 7.10: Splash screen of the Smart Study app

Login Screen

In this screen, the user can authenticate itself. By using a list, which is put on a wooden sign clip art image, the user can select its name and proceed by tapping the image button *Beginnen (Begin)* underneath the list. This list will be obtained by querying the database in order to fetch the active users. When the activity is loaded, and data was successfully queried, the first name will be selected automatically. Every time a name is selected in the list, a small message will appear at the bottom of the screen for a few seconds, also called *toast*, showing the name of the user that has been selected. This confirms to the user that the name was successfully selected in the list. When there is no internet connection, the toast will mention this as well. The list is not populated and will be empty. Tapping the begin button will do nothing, besides showing this toast again. When the user selects its name and taps the begin button, extended data containing user information will be added to the created intend, so the next activity can work with this data for displaying and further using it.

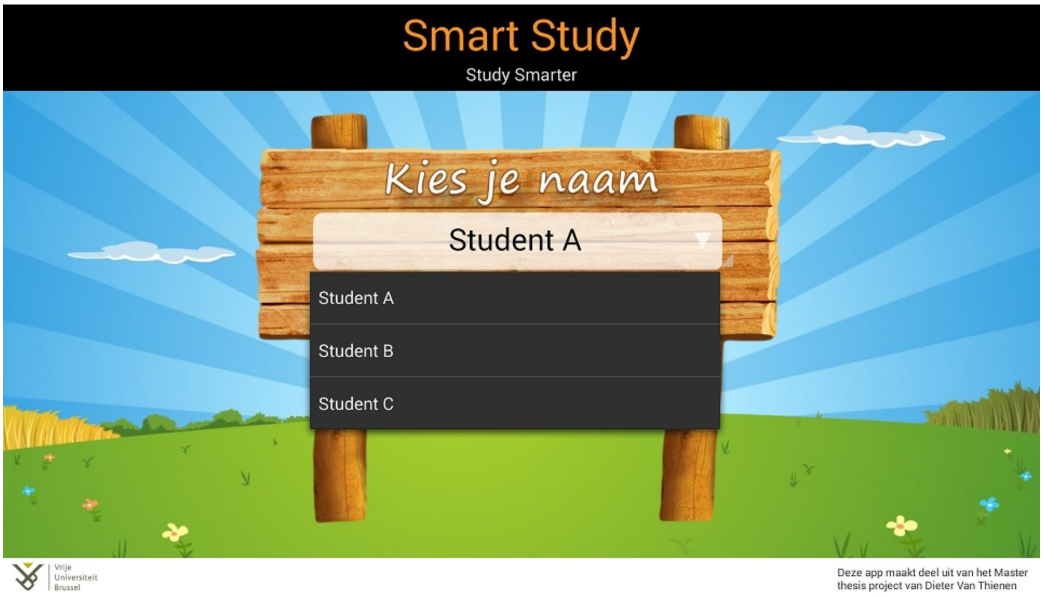


Figure 7.11: Login activity used for user authentication

Home Screen

After authentication, the user is provided with the home screen. On top, information about the current user is displayed. You can chose between two options here. Tapping the wooden sign with the text *Oefeningen maken (Make exercises)* will correct a filled out exercise page. Tapping the other wooden sign with the text *Mijn resultaten (My results)* will give an overview of the results of all the exercise pages. A welcome message with the name of the user is present above the two wooden signs.

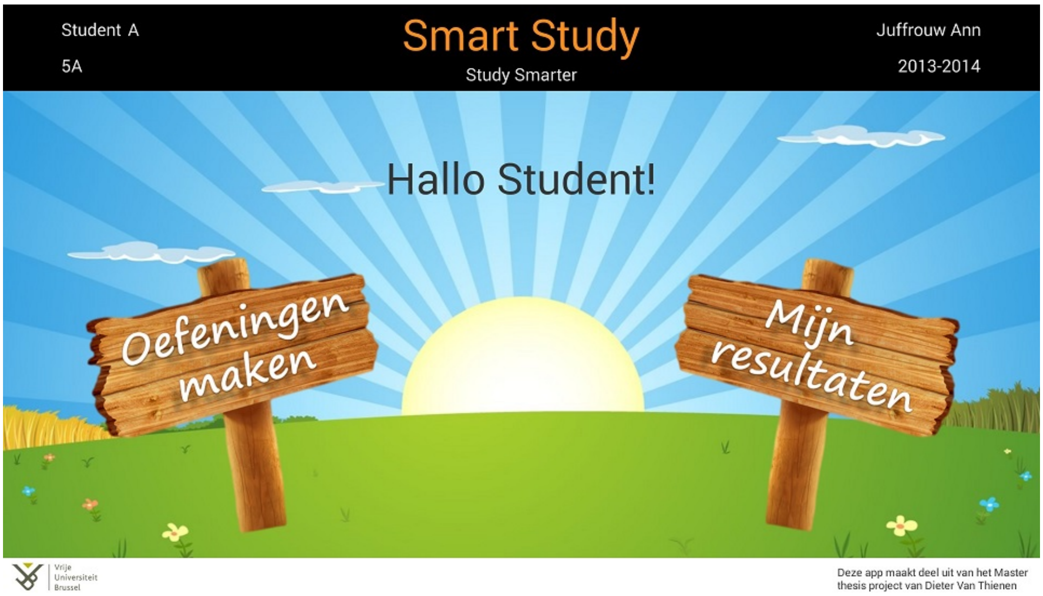


Figure 7.12: Main activity providing the home screen of the app

Check Solutions Screen

When tapping the sign for making exercises, a filled out exercise page will be corrected and information will be displayed. Before this can happen, the user first needs to confirm this by tapping the wooden board with the text *Controleer mijn antwoorden (Check my answers)*. The user can also go back to the home screen by tapping the back button at the bottom left. When tapping the wooden board to check the solutions, a progress dialogue showing a process indicator will appear showing the textual message *Even geduld (Please wait)*. User interaction is then disabled, and the progress dialogue will be dismissed when data has been acquired, or when an error occurs, which will result in going back to the home screen. When all the background processing has been successfully executed, the next activity will be started. Because there are different types of exercise pages, the type of the filled out exercise page will be analysed, and based on this data will start the specific activity bound to that type. As a result, there exist two types of screens, one for addition/subtraction and multiplication (group 1), and one for geometry (group 2). These screens have a different structural representation of data, as geometry uses figures, so separate activities had to be made.

Figure 7.13: Check solutions activity of the Smart Study app

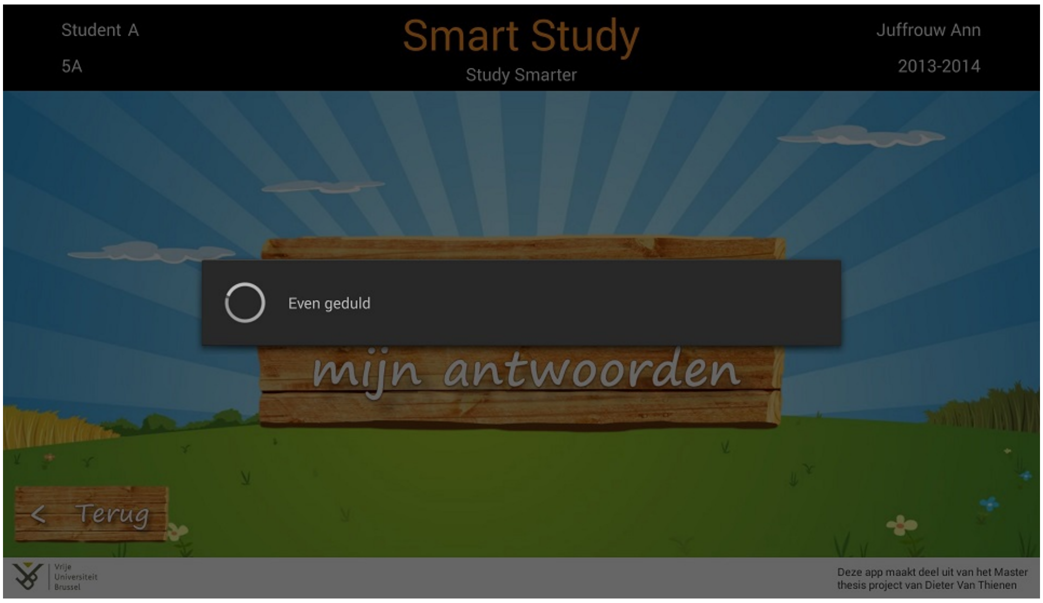


Figure 7.14: Waiting on response from the Smartpen screen

Solutions Exercises (Group 1) Screens

For the first group of exercises, an overview of all 8 exercises, their corrections and feedback is presented. Two exercise pages are present under this group, namely addition/subtraction and multiplication. At the top of the main part of the screen, the title of the exercise page is displayed, with the title bar colour having the same colour code of the course. To the right, the page number is displayed. Underneath the titles, the exercises are displayed to the left. An exercise is built up using its number, the question, the solution, and its correction. When a solution was correct, the text colour changes to green, while an incorrect solution changes its text colour to red, with next to it the correction in blue. Exercises that have not been filled out are displayed as a - sign in red, with its correction next to it. Tapping an exercise will draw a yellow box around it, and displays textual feedback to the right. This feedback shows how to solve the exercise by providing intermediary steps. When done looking at the corrections and results, the user can tap the save button at the right bottom to return to the home screen.

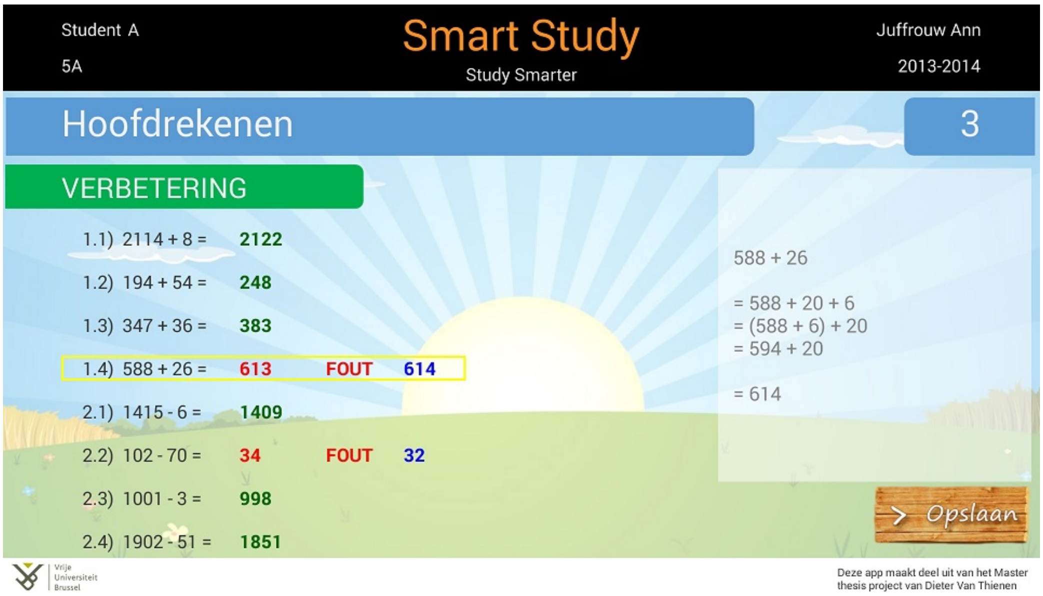


Figure 7.15: Activity giving the overview and corrections of the addition and subtractions exercise page

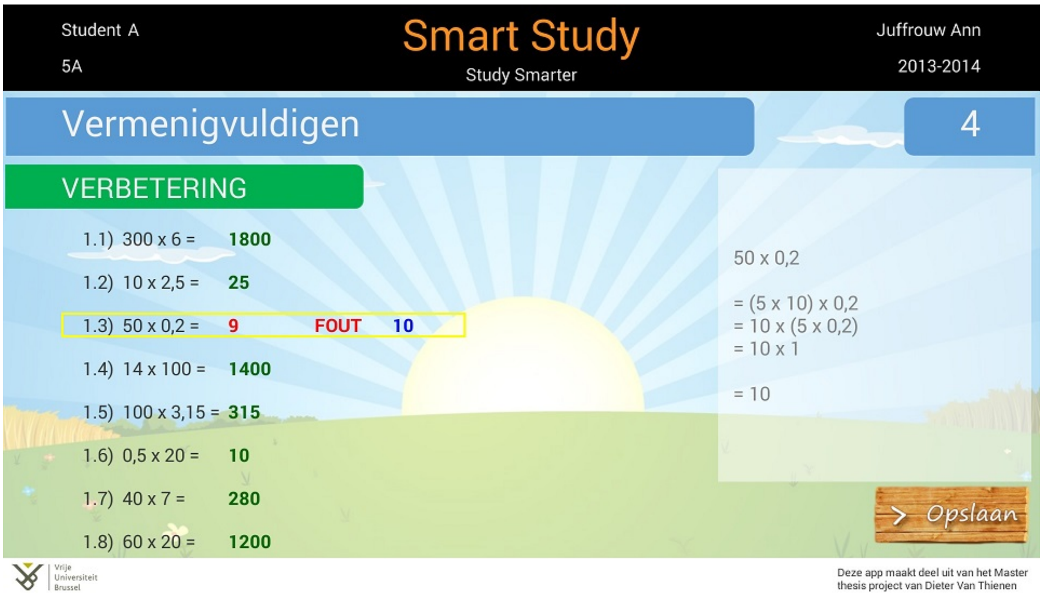


Figure 7.16: Activity giving the overview and corrections of the multiplication exercise page

Solutions Exercises (Group 2) Screens

The screens for the second group have the same basic layout and functionality as the previously described ones. The difference here is that instead of 8 exercises, only 3 exercises are present. Two geometry exercise pages are present under this group, namely triangles and rectangles. Due to the nature of the first exercise, a figure is displayed in which all the coordinates can be seen. Coordinates that were filled out correctly are displayed in a green colour, while corrected ones are displayed in a red colour. The second and third exercise are of the same type of exercises of group 1, but the difference here is that the feedback when tapping an exercise is animated, instead of just text. A video will play when an exercise is tapped, explaining its solution step-by-step by highlighting parts of the figure, while giving textual feedback below the figure, where the formula or definition is applied and the numbers are filled out.

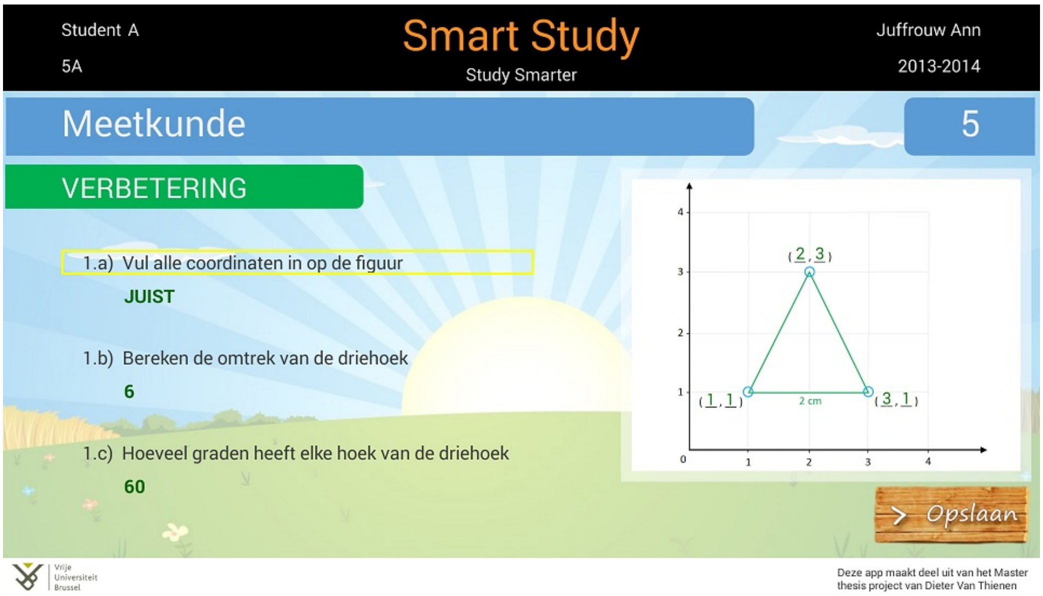


Figure 7.17: Activity giving the overview and corrections of the geometry (triangles) exercise page

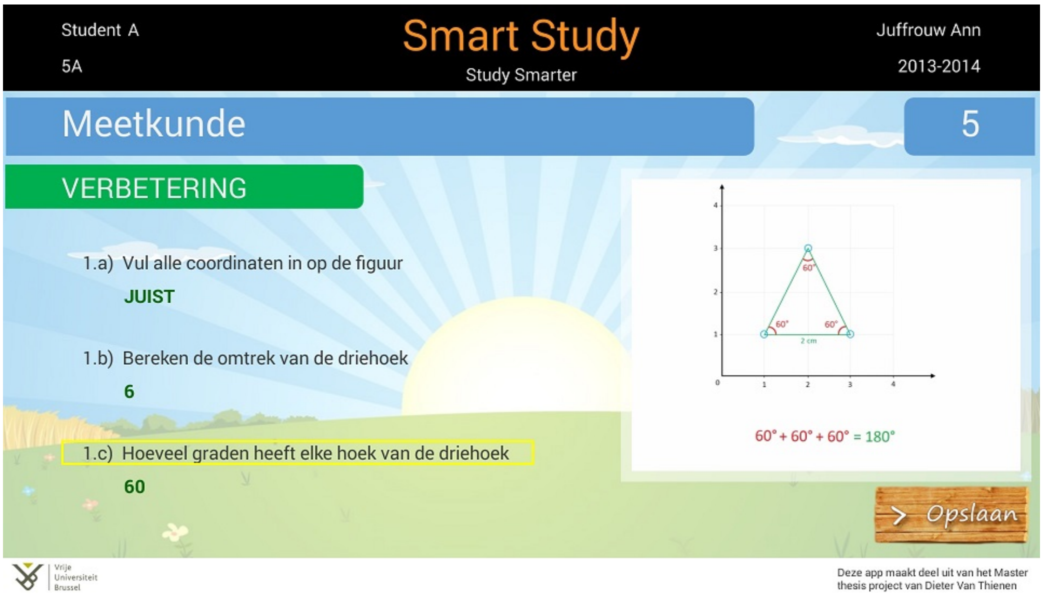


Figure 7.18: When tapping the second or third question, animated feedback appears on the right

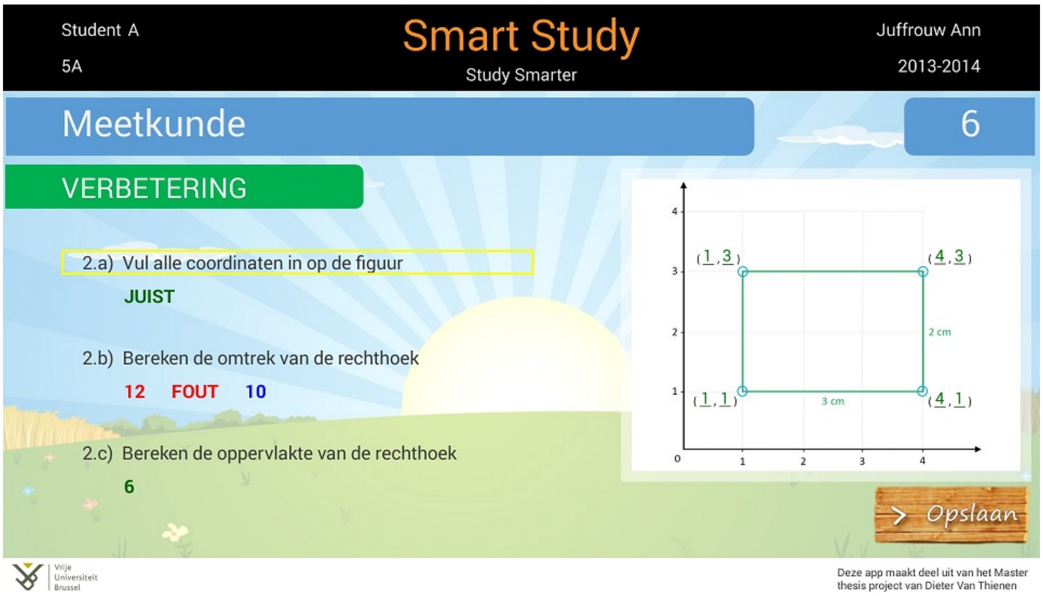


Figure 7.19: Activity giving the overview and corrections of the geometry (rectangles) exercise page

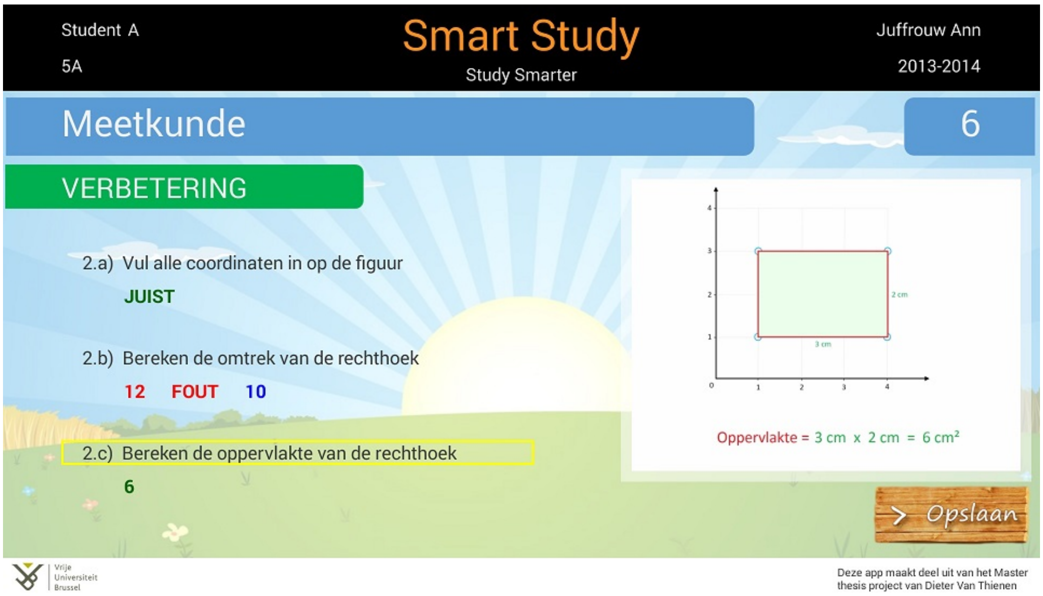


Figure 7.20: When tapping the second or third question, animated feedback appears on the right

Report Screen

The final screen gives an overview of the results of all exercise pages solved. This screen is started when tapping the sign for showing the results. The results are presented in the form of a score, stating how many exercises were filled out correctly per exercise page. When a page has not been filled out yet, some text is displayed stating that no exercises were made. The user can go back to the main screen by tapping the back button at the bottom left.

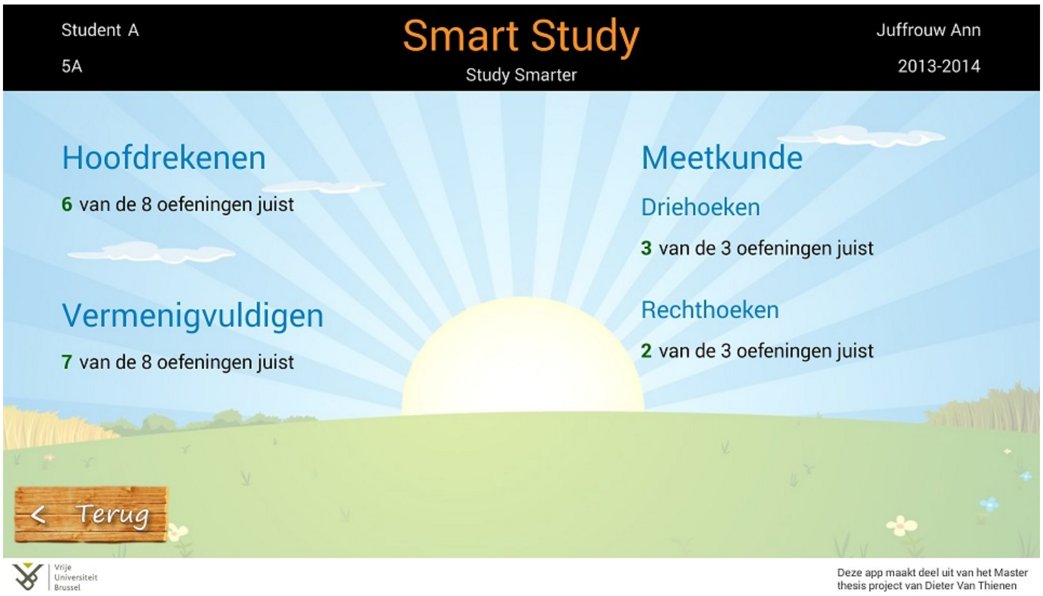


Figure 7.21: Report activity giving an overview of the results of all exercise pages

Overview of the Screen Navigation

Figure 7.22 shows a storyboard of the sequence in which the screens can call each other. Navigation between screens is done by tapping a specific area of the app, with the exception of the splash screen at the start of the app, where the transition happens automatically after 3 seconds.

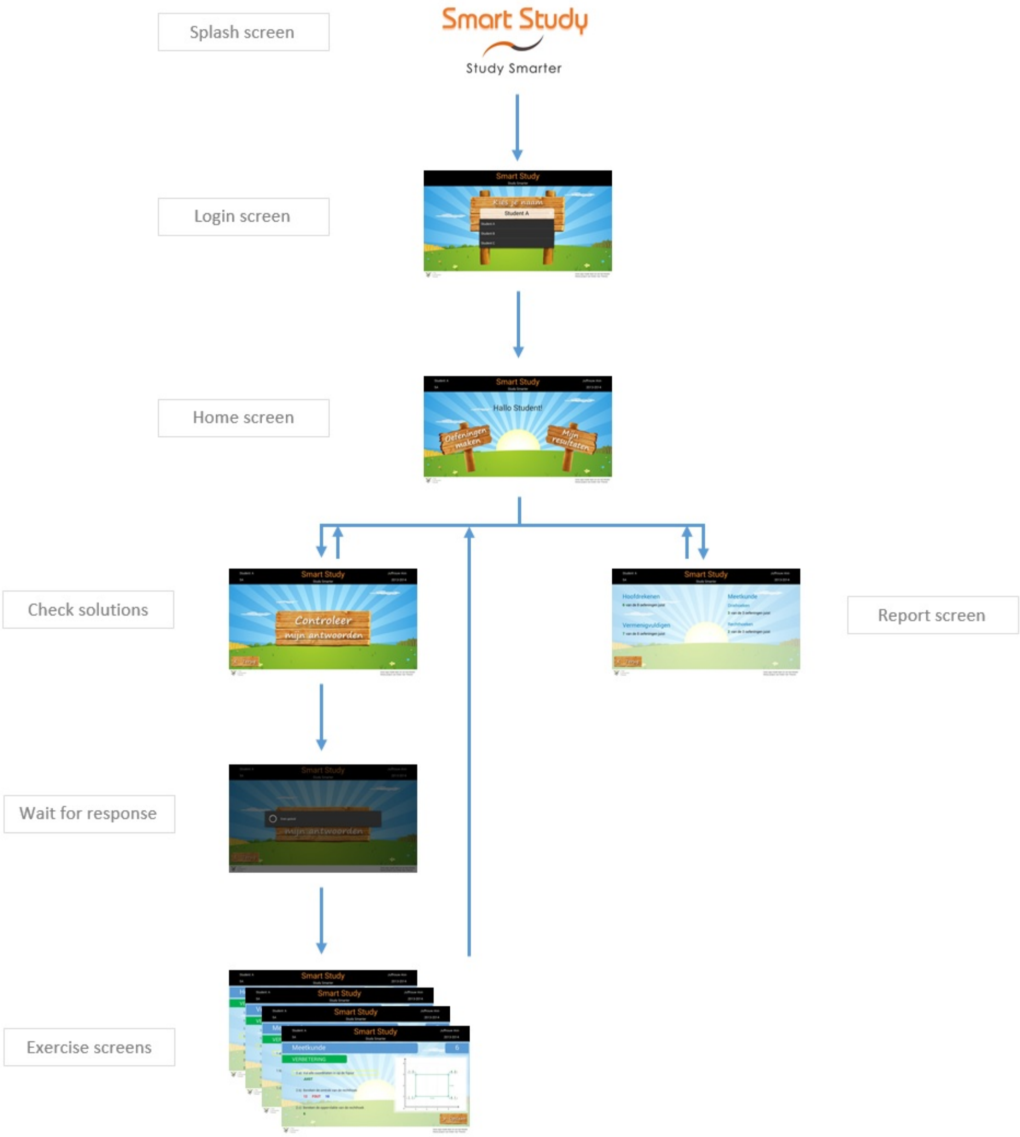


Figure 7.22: Storyboard of the Smart Study app

7.6 Database Design

To store and retrieve the data, a database that is located on a server will be used. This means the database will be accessed over the internet, resulting in the platform working wherever you are, as long if there is an active internet connection.

The database is crucial not only for storing permanent data, but it will also be used to store temporary data used when the platform is running. This data will be read and updated constantly by the Smart Study Synchronisation program and the Smart Study app as a way of exchanging information about the current state of the process.

There are in total 8 tables in the Smart Study database, with 7 tables storing permanent data, and 1 table storing temporary data. Each table has at least one relation with another table, with no circular references present. The database is normalized in Boyce-Codd Normal Form (BCNF). The following sections describe each table of the database, along with its fields and most important aspects. Figure 7.23 shows the database model with all its tables, fields, and relations.

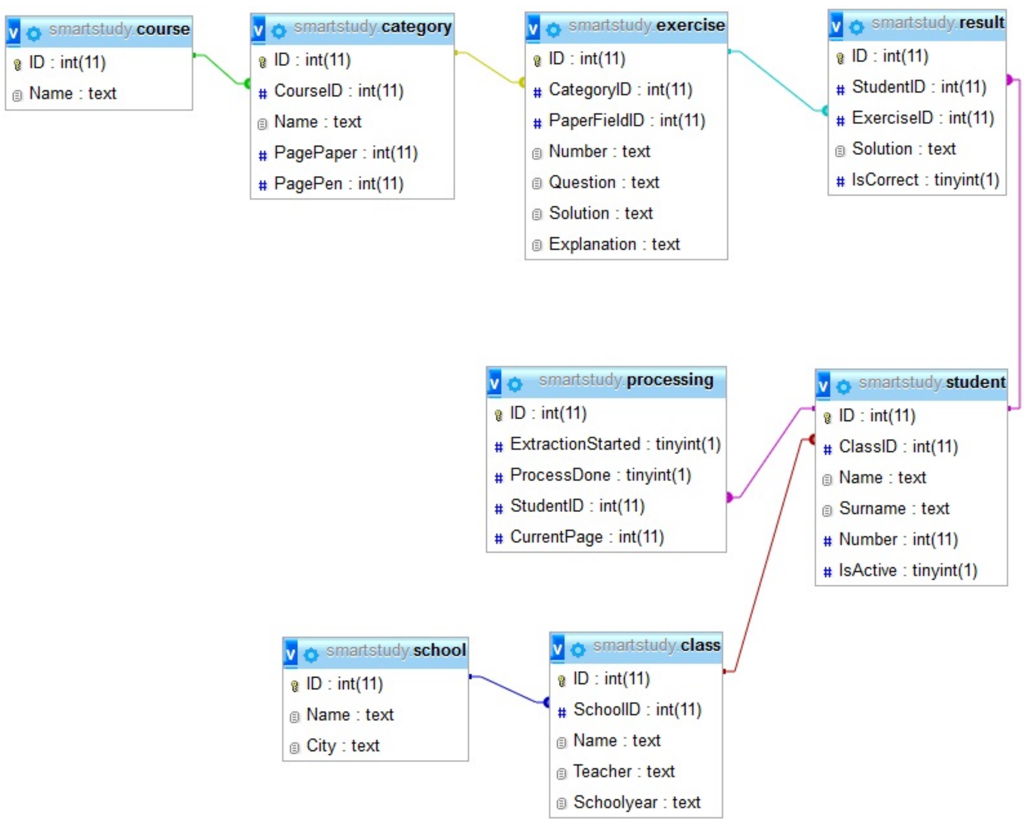


Figure 7.23: Smart Study database model

Course

This table stores all of the courses supported by the platform. It only has 2 fields, simply storing the identifier and name of the course.

Category

Since a single course can have different exercise pages, a separate table needs to store this. Each category corresponds to exactly one exercise page. The name of the category, number of the exercise page, and number of the Paper Design are stored here. The number of the exercise page is the number of the printed page in the exercise bundle, while the number of the Paper Design is its logical number used by the Smartpen for distinguishing each printed paper. A foreign key field makes a relationship to the *Course* table.

Exercise

Each exercise page has a number of exercises. The PaperField identifier, number of the exercise, and its question, solution and explanation are stored in this table. As mentioned in Chapter 6, the PaperField identifier enables the Smart Study app to determine which exercise needs to be positioned where on the screen. Because exercises can be inserted into the database in any order, sorting on the exercise number to get the right order is unreliable. The best way of determining an exercise is by storing its unique PaperField identifier, present in the Smart Study AFD and its Penlet. The tablet app can then retrieve and display each exercise in a reliable order, having the same sequence as the printed exercise paper. A foreign key field makes a relationship to the *Category* table.

Result

When a user has filled out an exercise page, its results need to be stored in the database, which is in this table. The handwritten, recognized and converted solution is stored here. This is done for each exercise individually, by having a foreign key field that makes a relationship to the *Exercise* table. There is a foreign key field to the identifier of the student as well, so the result of each user can be identified uniquely. This foreign key field makes a relationship to the *Student* table, discussed in the next section. A final field that is present stores whether the solution is correct. This correction process is done by a method of a PHP file. The answer correction is thus done server-side, releasing these computations from the client-side, which is the Smart Study app on the tablet. This way, the tablet simply needs to retrieve the data from this field, and check whether it has value 1, meaning the answer is correct, or value 0, meaning it is incorrect and needs to display the corrections.

Student

Each student (or user) is stored in this table. The name, surname and number are stored. There is also a field for storing whether the user is active or not. This was originally a field that was added when doing the evaluations in different schools, so students in one school could not select the names of students of another school. Deactivating a student makes him or her disappear from the list that is shown when logging in to the Smart Study app. This field was later kept, because it can come in handy when a student no longer uses the app, due to moving on to another grade, or not using the Smart Study platform any more. By simply deactivating the student, all data is still present in the database, and can still be retrieved. This is comparable to a delete flag, where data is not deleted from the database, but a specific field is set to determine the record was deleted. A foreign key field also makes a relationship to the *Class* table, discussed in the next section.

Class

Each class of a specific school is stored in this table. The name of the class, name of the teacher, and school year are stored here. This data is simply used for having a unique record that can be linked to multiple students, and is also used by the Smart Study app when display information on top of the screen when a student has been logged in. A foreign key field also makes a relationship to the *School* table, discussed in the next section.

School

This table stores every school that is using the Smart Study platform. It only has 3 fields, storing the identifier, name of the school, and the city it is located in.

Processing

A final, special table stores temporary data in a single record. When the platform is not running, or when a process cycle of the platform is completed, all the data in all fields (except the identifier field) will be set to its initial values, which are all zeroes. It contains 5 fields, where all 4 fields are being constantly read and updated by the Smart Study Synchronisation program and the Smart Study app.

The first field, *ExtractionStarted*, determines whether the process cycle has started, which always starts by the user tapping the image button on the tablet for checking their solutions, followed by the program trying to extract the data from the Smartpen. When this happens, the program updates this field to value 1, while at the end of the process the tablet app will update this field to value 0 again. The seconds field, *ProcessDone*, determines whether the process cycle is finished. Value 0 means it is still busy or has not been started, while value 1 means the cycle is finished. This field will be updated to value 1 by the program when the biggest part of the process cycle has been completed, and updated back to value 0 when the tablet app has successfully received all data. The third field, *StudentID*, is a foreign key field that makes a relationship with the *Student* table, and is set by the tablet app at the beginning of the process cycle, using data of the logged in user. This is set back to value 0 at the end of the process cycle by the tablet app. The fourth and final field, *CurrentPage*, determines the exercise page that is requested for correction, which is data retrieved by the program from the Smartpen. This value is used by the tablet app for determining the number of the Paper Design of the exercise page, so it can choose its activity. Remember there are two choices here because there are two groups of exercise pages, each group having a structurally different exercise page. This is set back to value 0 at the end of the process cycle by the tablet app.

Chapter 8

Implementation

8.1 Introduction

In this chapter, the implementation of the different nodes of the Smart Study Platform are described in more detail. This includes the Smart Study Penlet, tablet app, synchronisation program, and database.

8.2 Smart Study Penlet

Since the fundamentals of a Penlet are already explained in previous sections, only aspects important for the Smart Study platform work will be explained. Code snippets can be found in Appendix A, and will be referenced when described parts of the Smart Study Penlet are better supported with code than just text.

After calling the first callback method of the Penlet's life cycle in order to initialize the application, the second callback method is called when the Penlet is activated. Besides the event handlers that are added to the Penlet's context, the ICR context is configured as well. This enables correct handwriting recognition of the strokes that are created in the answer areas of the paper product. Because the *icrContext()* method is configured, other related methods can be called at specific times and events. This will be mentioned in the next paragraph. A final method that is being called is a custom defined one, namely *preSetSolutions()*. This method resets all variables that are used for retrieving, formatting and storing the values of answer areas to its initial values. For the third callback method, namely when the Penlet is deactivated, the method *preSetSolutions()* is called again to reset all specified variables. All event handlers are removed as well, and the ICR context is disposed. This makes room in the RAM for another Penlet that could get activated after the destruction of the current one. Finally, the last callback method is called, destroying the Penlet. This method is empty, as all ending tasks were performed in the *deactivateApp()* method.

It might seem strange that no other tasks are performed in these callback methods, especially in the most important one, namely *activateApp()*. This is because all the operations necessary to make the Smart Study platform work are dependent on the methods called by the ICR context. Each time a stroke is created in an active area that accepts stroke events, it is added to the ICR context for recognition. Four methods are available here, each representing a specific event described below. The ICR engine here is also known as the Handwriting Recognition (HWR) engine, hence the abbreviation at the start of the method's name.

hwrUserPause()

This method is called when the user pauses writing, indicated by an amount of time that has passed which is specified as a delay in milliseconds. For example, if the delay is 2000 milliseconds, then this method will be called 2 seconds after the user has stopped writing down something on the dot paper. After this, all strokes in the ICR context are cleared, and it is ready for receiving new strokes.

hwrResult()

When the strokes have been received and the ICR engine detects acceptable strokes, it uses its loaded lexicon for recognizing handwriting, which can then be further processed, such as being stored in a variable or displayed onto the OLED screen of the Smartpen.

hwrError()

Whenever an error occurs during handwriting recognition, this method gets called. Programming code here could enable the developer to display an error message on the Smartpen's display, or log all errors that occurred during handwriting recognition.

hwrCrossingOut()

The final available method is called when the user crosses out previously written strokes. When the user does a crossing-out gesture, the developer can program code here, making clear that the user made a mistake and does not want the text that was crossed-out to be saved or processed.

For the Smart Study Penlet, only one of these methods is being used, namely *hwrUserPause()*. This is because of the nature of the project, it does not need the other methods to function well. When the *hwrUserPause()* gets called, which is after a delay of 2200 milliseconds when the user stops writing, all of the code in this method will be executed. A delay of 2,2 seconds might seem high, but keep in mind that children of the fifth grade tend to write slow, so decreasing the delay might result in answers being detected separately. If a child wants to write down the number *1200*, but writes a bit slower after writing down 1 and 2 because it is still thinking, then the ICR will detect the number *12* first, after which it will detect the number *00*, resulting in the number *00* being saved as a final answer. Evaluations, discussed in Chapter 9, have shown that a delay between 2000 and 3000 milliseconds is ideal for children of the fifth grade.

A difference can be made between writing inside and outside of an active region where a stroke event handler is present. The ICR context can still trigger all its methods even when writing outside active regions, so it is important to know when the user is writing inside an active region, which region this is, and what is being written down. To do this, a switch-case is programmed that can recognize when, where and what the user is writing on the dot paper. This accounts for every active region supporting stroke creation event handlers on every paper, but since the structure is the same per group of exercise pages, this only needs to be programmed once per group. When writing in such an active region, the strokes and area identifier are saved into its resembling variables. When strokes are created in such a region, they are recognized and displayed on the screen of the Smartpen as well. This enables the user to see whether the ICR has correctly recognized the answer that was written down, and if not, allows the user to rewrite the answer. Writing outside of an answer region will no operations, besides logging this activity and the recognized handwriting in the debug RAM of the Smartpen.

The final, most important feature of the Penlet is processing all recognized and stored solutions, to prepare the data for the next phase in the life cycle of the Smart Study platform. This process is triggered when the user taps the area with the text *Ik ben klaar!*, stating that the user is ready filling out the exercise page, and wants to move on to the next step, showing it on the tablet. But before that can happens, a large amount of processing needs to happen. The first thing to happen when the user taps this area, is to get the current page the user has been working on, and store this in a variable. The screen of the Smartpen now displays the text *Antwoorden opgeslagen! (The answers have been saved!)*, after which a sound is being played through the Smartpen's speakers, which is a recording saying that the answers have been saved (in Dutch). An important method is being called after this, namely *serialize()*, which stores the data into a format that can be reconstructed later on.

The first thing this method does is creating a valid XML structure that contains all stored data of the variables described in the paragraph above. To keep the code clean and structured, a method of a separate Java class is being called. This Java class is called *XMLUtils*, and has two versions, one for each group, representing the type of exercise page. Both classes are more or less the same, the only difference is that the first group has 8 solution fields, while the seconds group (geometry) has 3 solution fields. The code of the *XMLUtils2* Java class, used for the second group of exercise pages, can be found in Appendix A.1.1. The entire generated XML structure is saved into a variable. The string of this variable is then read as an XML file and stored as a text file on the internal memory of the Smartpen. This file is stored temporarily though, turning off the Smartpen will result in losing this file. This is done deliberately, because this way the file can no longer be present when turning on the Smartpen. If the file should already exist, for example when using the Smartpen to fill out a series of exercise pages without turning it off, it will completely overwrite the existing file.

Some final code, which is never being called internally, is important to mention as well. The method *executeCommand()* is used to handle the information transfer from the Smartpen to an external application, which will be the custom designed C# application. This is made possible by implementing the *Remote* interface, allowing an external application to access the Smartpen's infrastructure. This method is crucial, because it allows the extraction of the text file that is stored on the internal memory of the Smartpen.

8.3 Smart Study App

The Smart Study app was developed using the latest version of the Android SDK at the time of writing. The targeted Application Programming Interface (API) level is 19, meaning it is designed for devices running Android 4.4 KitKat. The minimum version is set to API level 10, which is Android 2.3.3 Ginger Bread. This is to ensure that older devices running old versions of Android that cannot be further updated, can be used as well. No exclusive features of Android 4.x have been used, making them fully compatible with older versions. Testing was not done using the provided emulator, but by pushing and installing the Android Application Package (APK) to a connected device each time a version of the app was being run for testing. The tablet device that was used for testing and doing the evaluations is the LG G Pad 8.3, updated to Android 4.4.2.

The screens of the app, also called activities, that define the layout of the user interface. Since these are layout files, they are saved in XML format. Each such file is used by a Java class to make it interactive and execute operations when certain events are triggered. Navigation between these activities is made possible in a specific sequential way. When switching between activities, in order to navigate to another screen, an *intent* is created that contains the current and next activity. This intent allows activities to be started, and current ones to be closed by finishing them. An intent also allows extended data to be added, which can

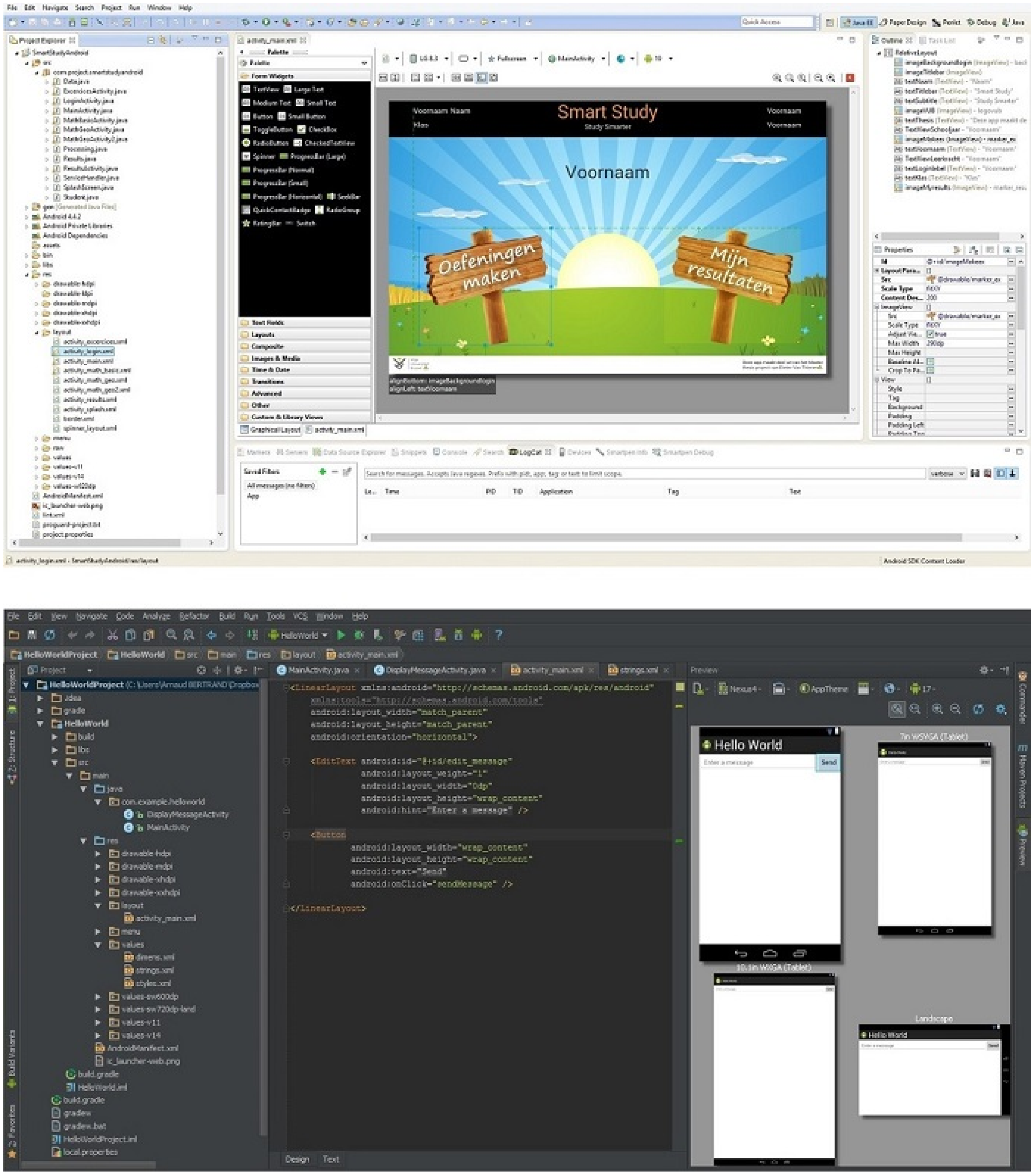


Figure 8.1: Comparison between Eclipse with the ADT plugin and Android Studio

then be used in the next activity and stored into local variables of that class.

The transition effect that is used when switching between activities, is a faded zoom-in effect of the called activity, masking this over the existing activity before it gets closed. This is the standard transitional effect of activities when developing Android applications. A sliding transition was not chosen because this effect took too long and was disturbing. A quick fading transition was more appealing for this app.

8.4 Smart Study Synchronisation Program

Because of the inability of the Livescribe SDK to push data to external programs, a program needed to be written that extracts the data from the Smartpen whenever this extraction process is triggered. A Microsoft Windows program is written in C# programming language, using the .NET 4.5 framework. It was created using the Microsoft Visual Studio 2013 IDE, which uses the latest version of the .NET framework, which was at the time of writing version 4.5.2. The target platform it is designed for is Microsoft Windows 8.1, but is compatible with previous version of Windows, starting from Windows Vista (SP2), with at least .NET 4.5 installed.

The main purpose of this program is to connect to the Smartpen, extract the text file which resides on its internal memory, read this file as XML, and finally insert data into the database. The program has extended error handling, and does extensive logging of the current state of the platform while the program is actively used. Interacting with the program is made impossible, since all operations are automated. The program should simply be running in the background while using the platform, executing its operations and displaying every logged event. A final important notion is that the program supports multi-threading, allowing methods and controls to be on different threads, while providing safe cross-thread calling.

The form of the program is specifically created for a developer or someone who likes to keep track of all the background events that are happening while using the platform. The top part of the form has some text for developers, with a button underneath it. The button has been disabled since an external device, in this case the Android tablet, triggers the synchronisation. It should only be enabled for testing purposes when this device is unavailable or not configured properly. The part underneath this displays the current state of the process cycle, with below it a list that logs all the states and events that have occurred so far. The text of the current state is coloured based on the event type. Errors are coloured red, while successful events are green, and waiting events are blue. Figure 8.2 gives an overview of how the program looks like after successfully extracting the data from the Smartpen, and then processing, uploading, and storing it into the database.

When the program starts, it is checked whether there is an active internet connection. If not, an error will be displayed. If there is an active internet connection, the program attempts to connect to the MySQL database through a PHP file by doing an HTTP web request to this file. The status is now set to *Waiting for status*. When the connection to the database was successful, a specific table and record is checked to see whether the extraction process needs to be started. A timer is now started, and will check the values of these database fields every 8 seconds. When the program receives response that it can start its extraction process, the delay of the timer is set to 20 seconds, and is frozen as long as the process is busy. When

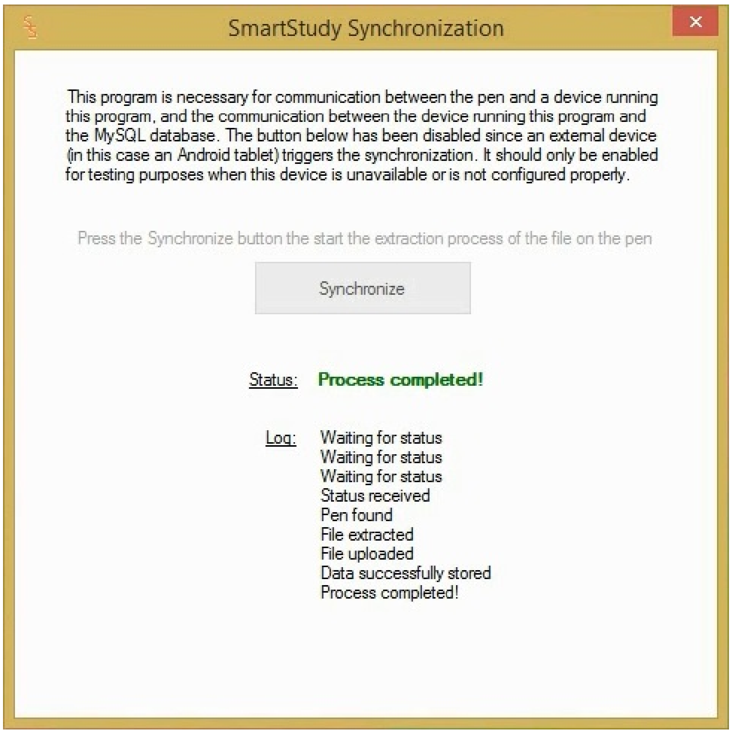


Figure 8.2: Smart Study Synchronisation program

an error should occur, the timer is resumed again, preventing any locks. Since the response for continuing the process cycle has been received, the status is set to *Status received*. A method is now called, in which the Smartpen gets hooked to the program. When the pen has been found, the process continues, and the status changes to *Pen found*. The file can now be extracted from the Smartpen. In order to do this, a data command needs to be send by the program to the pen. This command is received by the method *executeCommand()*, present on the Penlet of the Smartpen.

When the command is received successfully by the Smartpen, it will return a Boolean value. When this is false, it means the specified file is not present on the internal memory of the pen. When the value is true, the file will be extracted and written to the temporary folder of the device running the program. The status will now be set to *File extracted*. Since the file has now been successfully extracted, it will be uploaded to a folder on the server where the PHP files and the database resides. Uploading happens over HTTPS using the POST method through a PHP file. A custom content-type file header is defined here as well, typed *safe/XML*, as a safety measure to ensure that only Smart Study XML files can be uploaded to the server. When the program gets a response that the file has been successfully uploaded, the status will now be set to *File uploaded*. The final step is to store the data inside of the XML file into the database. Since the file is already present on the server, an HTTP request to a specific PHP file is done, which will read this XML data and correctly insert this into the database. If the response of this request was successful, the status will now be set to *Data successfully stored*, whereafter it changes to *Process completed!*, successfully ending this part of the process cycle. The program now waits 20 seconds, whereafter it will start checking the values of the database fields again, waiting on a response for starting a new process cycle. The timer is again set to 8 seconds, after these 20 seconds have passed, returning to its casual checking routine.

The complete *PenAttachEvent()* method, which execute all the operation after the connection to the database was successful, can be found in Appendix A.2. This code could be interesting for developers creating a program that can access the Smartpen directly. The exact link to the PHP files is replaced out of security concerns.

8.5 Database Implementation

The design of the database has been described in section . The database is located on the server of the university. The Relational Database Management System (RDBMS) that is being used is MySQL, an open-source and very popular RDBMS, that supports Structured Query Language (SQL) for database operations. For handling the administration of MySQL, phpMyAdmin is used. This is a free and open source tool used in a web browser. Since May 2014, its latest stable version is 4.2.1, but this is not the version that was used. The installed version of phpMyAdmin on the server was 3.3.x, an older version that still has the classic user interface, compared to the newer, overhauled one since version 4 (phpMyAdmin, n.d.).

Database operations are executed by PHP files that are located on the same server as the database. An amount of files has been programmed in PHP for treating the communication between the Smart Study Synchronisation program and the database, and the Smart Study tablet app and the database. The PHP files mostly contain queries written in SQL performing Create Read Update Delete (CRUD) operations. The following sections describe the most important PHP files used by the program and the app.

8.5.1 PHP Files Used By the Windows Program

programCheckProcess

The very first PHP file is called by the program to check if the process cycle has started. This file is called every 8 seconds. It does a SELECT query on the *Processing* table, and fetches the data of all fields of the record. The data is stored into XML format, which is then received and processed by the program.

programUpload

When the file has been extracted from the Smartpen by using the program, it needs to be uploaded to the server. This PHP file not only does this, but also ensures this happens in a safe way. As mentioned in this chapter on page 81, a custom content-type file header is used in the program, which is checked in this PHP file, to see whether the content-type header matches. It then uploads the file to the server, and returns a confirmation whether the upload was successful or not.

programDoProcess

This important PHP file is called after the upload of the XML file was successful. It reads the XML file that was just uploaded to the server, processes its data, inserts this data in the database (if necessary), and updates the state of the process cycle. The first step is thus loading the XML file. The file is read, and each type of data, defined by the XML tags <page>, <solution_field[x]>, and <solution_data[x]>, is stored into separate variables. The single page tag contains data of the exercise page that is being processed, while the other two tags contain the field and answer of each exercise. Since it is possible that an exercise page has already been solved and its results are already present in the database, a check is done to see whether this data is already present. This is done by doing a SELECT query on the *Result* table, where the identifier of the current student and the first exercise identifier are being fetched. If a record is returned, it means data is already present and the exercise page has already been filled in. Nothing will be inserted, and the program will instantly end the process cycle by updating the process state, which is then received by the tablet app, which in its turn will fetch the already present data in the database. This thus means that the first time this exercise page was solved, this data will always be fetched. This is logical, as it is not allowed to solve an exercise page that a user has already fill out. If the SELECT query returns empty, it means the data is not present and the exercise page has not yet been solved. The answers of the user are checked here as well. A SELECT query fetches all solutions of the exercises of the current exercise page. This is then compared exercise-per-exercise to see whether an answer matches its solution. After checking all answers, all of the processed data will be inserted into the *Result* table. As a final operation, the state of the process cycle is set by updating the field *ProcessDone* of the table *Processing* to value 1, and updating the field *CurrentPage* to the page number retrieved from the XML file.

Since the code of this PHP file gives an interesting look at how the data of the XML file is being read, processed and stored, it is added in Appendix A.3.1.

8.5.2 PHP Files Used By the Tablet App

tabletGetStudents

The first PHP file that is being called by the tablet app, is to populate the list of students presented on the login screen. This is done by executing a SELECT query which will fetch all active students, and store this is an array. This array is then encoded as JavaScript Object Notation (JSON) and echoed, so the tablet app will receive and process a JSON string.

tabletCheckProcess

When the process cycle is started by tapping the image button of the activity for checking the answers, this PHP file will be called every 6 seconds. Note the difference in delay compared to the program, which is 8 seconds. Different delays have been deliberately chosen to prevent a lock due to time synchronisation. The state of the process cycle is checked by executing a SELECT query on the *Processing* table, fetching all data of the single record. The resulting data is simply put into an array, encoded to JSON, and echoed. The app uses this data, and will execute further operations.

tabletUpdateProcess

When the app has read from the previously fetched data that the process cycle has moved on, meaning that the program has extracted the file from the Smartpen and has successfully been inserted into the database (if necessary), this PHP file is called. The tablet app does not just call this file, but sends a single parameter along as well, which contains the identifier of the student that is currently logged in. If the parameter passing was unsuccessful, the student identifier is set to 0. Both the program and app have been programmed in such a way that when this happens, the process cycle is finished instantly, with the process field values being updated to their initial values. Normally, parameter passing should always work, it is very hard to create a scenario where this would fail. But if it should occur, none of the nodes of the platform will crash by catching this anomaly. When the parameter passing was successful, the record in the *Processing* table is being updated, with the *ExtractionStarted* field set to value 1, the *ProcessDone* field set to value 0, and the *StudentID* field set to the value of the passed parameter.

tabletGetData

When the process cycle has reached its final stage, the data of the current user and exercise page are being fetched from the database. A large SELECT query is executed, which will fetch all this data and store it in an array. The array is again encoded to JSON, and is echoed. As a final operation, the end of the process cycle is marked by updating the record in the *Processing* table, with all of its fields (except the identifier field) being set to value 0.

tabletGetResults

The final PHP file is called when the user wants to get an overview of all the results of the exercise pages made. A parameter is again passed along, because this needs to be added in the query for correctly retrieving the results of the logged in user. Should parameter passing fail, the student identifier is again set to 0 and no data will be retrieved. If the parameter passing is successful, a SELECT query will be executed, retrieving the results from the user per exercise page, by making the sum of the value of the *IsCorrect* field for all exercises of one category. Since these values are either 0 or 1, the total sum will result in having a score on the total amount of exercises of that exercise page. The resulting data is again stored into an array, which is encoded to JSON, and echoed.

Chapter 9

Evaluation and Results

9.1 Introduction

In this chapter of this thesis, the evaluations and its results will be given. The evaluation was done by means of a case study consisting of a use-case scenario, and intended to evaluate different aspects of the platform. The setup, the methodology used for the evaluation, as well as the results, will be discussed.

9.2 Setup

The Smart Study platform was evaluated by letting primary school children of the fifth grade use the platform, using different evaluation methods. The evaluation per student consists of three phases, with an additional evaluation involving the teacher after all the evaluations with all students of a school were done. Questionnaires were used for the evaluations with the student and teacher. The questionnaires used for the children and teachers, are based on a PhD thesis (Donker, 2005), in which research is done towards finding the human factors in educational software for children, and what questions are appropriate for them when performing evaluations.

The evaluations were conducted in three different primary schools, having 5 students participating per school. Different schools were chosen because of an expected difference in the student's behaviour, which was also evaluated and is discussed later. In each school prepared to participate, a letter was given to the parents of the children of a fifth grade class. This document explains the experiment their child could participate in. Parents who agreed needed to sign this document, granting permission that their child could participate in the experiment.

A total amount of 15 participants participated in the experiment, all being between the age 10 and 11. 7 boys (47%) and 8 girls (53%) participated. The evaluations were conducted in an oral way; each question of the questionnaire was posed to the participant orally, and the evaluator noted the answers. The participants did not have to write down anything on the evaluation forms. This made it easier for the children to answer the questions, as they could add some additional information, making the results more detailed. All the evaluation forms can be found in Appendix B. Note that these are in Dutch.

9.3 Methodology

Each student evaluation consisted of three phases, each having their respective evaluation methods. After the evaluations with all students at one school were finished, an additional evaluation with the teacher of that class was done through a questionnaire. The following sections describe each method used in order to evaluate the Smart Study platform.

Phase I: Pre-experiment

When the platform and evaluation tools were set up, each participating student came individually into the classroom where the evaluation took place. No video or audio recording was used; only the observation technique was used.

Knowledge of Mathematics

By contacting the teacher before doing the experiment, the knowledge of mathematics of each participating student was acquired. This knowledge is represented by an average of each student's score on the mathematics course. The score was categorized in three groups: strong (>90%), good (80-90%), and average (<80%). This data was also confirmed by the student itself, before the experiment. The results of the evaluations of using the Smart Study platform will be matched with the skill level.

Experience With Computer Devices

The next step consisted of determining the computer skills of the student. Questions were asked about the familiarity with computer devices, such as desktop computers and notebooks, and how many hours per week these devices were used. The familiarity of working with tablet devices was questioned as well, again including how many hours per week this device was used. As an additional question, the student was asked for what purposes the device was being used. The results of the evaluations will be match with this skill level.

Experience With Educational Software

A final question before doing the experiment was asked to find out if the student has any experience with educational software. If so, the software or platform that was used was questioned, and also on which device or devices this was used.

Phase II: Experiment

Before the student could do the experiment, the platform was explained, but only the essentials. This was done to ensure that the students could figure out everything by themselves, evaluating the ease and usability. Children who had no experience with tablets got the same explanation to see how easy they could work with the tablet app, even without ever having worked with a tablet device. The aim of this phase was to evaluate the technical aspects of the platform, and the performance of the student. Technical aspects include: is the pen working, is the ICR detecting handwriting well enough, is the app working, is the program correctly executing the synchronisation process, etc.

ICR Accuracy

Since children tend to have different handwriting compared to adults, because it is still developing, it is important to know that the written answers are recognized correctly. The ICR accuracy of the Smartpen was evaluated by comparing the answers the student wrote, with the recognized answer appearing on the display of the pen. This was analysed for each answer. When an answer was recognised incorrectly, this was written down in the comment section of the evaluation form, described in a later section. The reason why this was already checked when the student was filling out the exercise page, was to give the student another chance of writing the answer once more. It would not be fair to indicate the answer on the tablet as incorrect if the student had given a correct answer, but the pen recognized it incorrectly. By letting the student retry when misrecognition occurred, the overall accuracy of the ICR could be calculated based on the amount of retries that were necessary. These results will also describe the gravity of the recognition, namely how many characters were recognized incorrectly.

Pen Grip

Another important aspect that was considered during the evaluation was the pen grip the students used. By analysing this, poor recognition of the ICR could be related to poor or inefficient grip of the Smartpen. The quality of the pen grip was categorized as *good pen grip* or *bad pen grip*. A good pen grip is when the student use the traditional tripod grip (Kao, Hoosain, & Van Galen, 1986), usually resulting in fluent and legible handwriting (Selin, 2003). A bad pen grip is when the student's grip is tight and compensatory, making writing more difficult, usually resulting in inarticulate handwriting. The pen grip was constantly observed when the student was filling out the exercise page, classifying the pen grip as either good or bad, based on the types of grips.

Performance of the Student

The performance of the student while and after filling out an exercise page was noted. The results would be compared with the mathematical skill of the student, to see whether the students performed better or worse than usual. The performance was evaluated by looking at how the students filled out the exercises, such as crossing out answers, rewriting answers, thinking aloud, and stopping to write down parts of an answer while thinking. The score of both exercise pages was noted when the student used the tablet app, where possible corrections were applied. This score was categorized in the same three groups in which the mathematical skills were divided: strong (every answer correct), good (at most two mistakes), and average (more than two mistakes). These results were matched with the student's mathematical skill, to see whether there was an improvement, which could be related to an increased concentration and motivation when using the platform.

Synchronisation Time

When the students presses the image button of the Smart Study app to check their answers, the whole process cycle is started. The time this process takes was recorded, to investigate how long it takes before the student can see an overview of the corrected answers on the tablet. The internet connection used by the tablet device and notebook was tethered to the smartphone, which used the 3G mobile network to connect to the internet. This means that the signal strength determines the speed of the internet. Note that a slow internet connection increases the total synchronisation time, as it plays a major roll since a lot of requests to the server are being done. Since every participant filled out two exercise pages, the average of both times is taken; the results are grouped per participant.

Additional Notes

Any additional information was noted in a specific part of the evaluation form. This could include the overall performance of the platform, misrecognition of handwriting, the behaviour of the student (uninterested, motivated, hyperactive, etc.), questions posed by the student, and any additional comments made by the student while doing the experiment. The motivation level of the student was noted as well to see whether the student found it good that the answers written down could be directly seen on the display of the pen, making it a potentially fun gadget for students when filling out an exercise page.

Phase III: Post-experiment

After the platform was used by the student and the technical aspects had been evaluated, it was time to evaluate the platform by asking some questions to the student using a questionnaire. Since the participants are children, the questions have been specially designed to make them easy to understand, yet still provide enough feedback.

Evaluate Opinion Through Questionnaire

By using a custom questionnaire, the student's opinion was questioned. For the Smart Study app, the student's opinion about the difficulty, usability, effectiveness, clarity, and layout were questioned. The student's motivation while using the educational platform was questioned, and whether this platform could be useful for the student, compared to the traditional pen/paper method and manual corrections by the teacher. The questions that were posed to the student can be found in the list below.

- Was it fun for you to solve exercises like this?
- Was it clear what you had to do?
- Was it hard for you to work with the app on the tablet?
- Did you find the app nice and clear?
- Did you find it good that you could see your corrected answers?
- Did you find the explanation of the exercises clear?
- Would you want to use the platform in the future, at school or at home?
- Do you think you would be able to work with the platform by yourself?
- Is there something you did not like about the platform, and would like to change?
- Would this be a better way for you to make your homework or tests?

Evaluate the Teacher's Opinion Through Questionnaire

When all students of a class had performed the evaluation, also the opinion of the teacher of that class was questioned. Since this happens after the evaluation by the students, the teacher could be notified about the results of the evaluations, allowing discussing the positive and negative contributions towards learning for the students when using the platform. Possible improvements were discussed as well, and the possibility of implementing the platform in the school was questioned. The questions that were posed to the teacher can be found in the list below.

- How many hours per week do you spent on using devices such as a computer, tablet, etc.?
- Have you ever used educational software?
- What is your opinion on introducing educative software or platforms in a school environment? Would this increase the motivation of the students and increase their learning outcome?
- What is your opinion about the Smart Study platform?
- Do you find it good that answers are corrected automatically, and that reports can be generated from the results?
- Would you like to see your students use the Smart Study platform? Do you think it would increase their motivation and learning ability?
- What would you like to change to the Smart Study platform?
- If this platform would be made commercially available, possibly subsidised by the government, do you think it would be successful and realisable within a school environment?

9.4 Results

Phase I: Pre-experiment

Knowledge of Mathematics

Based on each participant's average score, the group of participants showed a balanced knowledge of mathematics. 5 students had very high grades, while 6 students had good grades, and 4 students had average grades. The bar chart in Figure 9.1 represents this graphically.

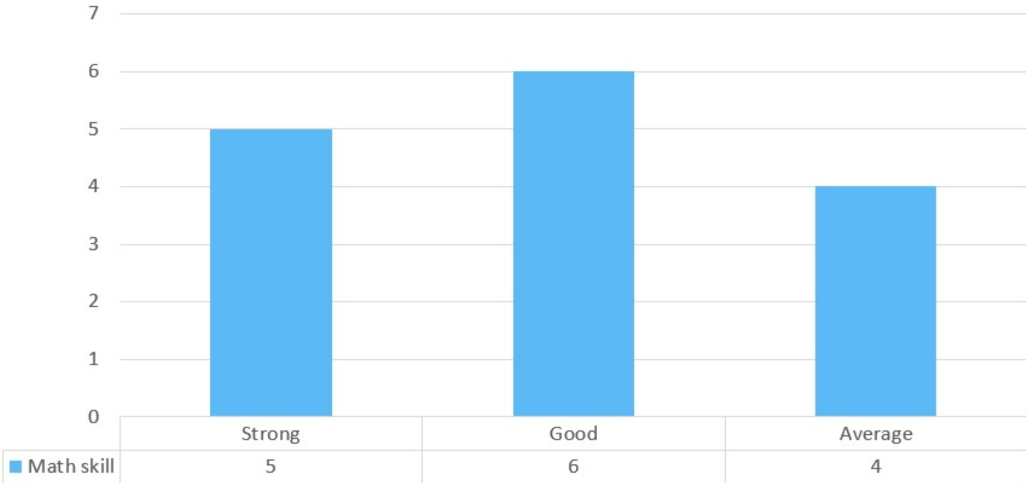
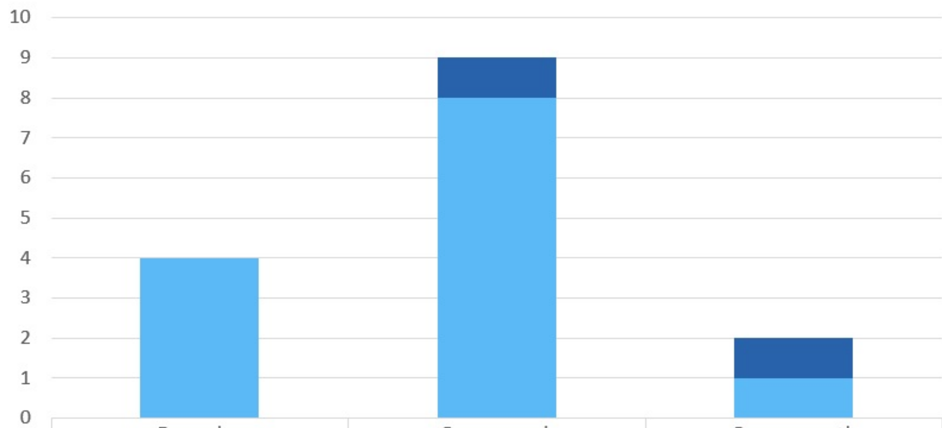


Figure 9.1: Bar chart of the mathematical knowledge

Experience With Computer Devices

Every participant used a computer, desktop or notebook, at least once a month, while most participants used a computer at least once a week. Besides using a computer, nearly every participant had experience with tablet devices, and used this type of devices at least once a week. 4 participants use a computer and tablet every day. 9 participants use a computer at least once a week, with 8 of those participants using a tablet device as well. 2 participants use a computer at least once a month, with 1 of those participants using a tablet device as well. Overall, only 2 out of 15 participants had never used a tablet device. The stacked bar chart in Figure 9.2 represents this graphically. The participants who had experience with computer devices, either desktops, notebooks, or tablets, mostly used this to play non-educational games, browse the internet, and use educational software.



	Every day	Once a week	Once a month
Tablet	4	8	1
No tablet	0	1	1

Figure 9.2: Stacked bar chart of the experience with computer devices

Experience With Educational Software

Most of the participants had experience with educational software. In two schools, this was even stimulated by using a specific educational platform, called Bingel (Van In, n.d.). In one of these two schools, the students were obliged to make exercises using the platform. As a result, most students that had experience with educational software, used this platform. The other school did not stimulate the use of educational software, which resulted in 3 students of that school not having any experience with educational software, and the other 2 students making exercises on-line, but not using the Bingel platform. The stacked bar chart of Figure 9.3 represents this graphically.

A combinational overview of the experience with computer devices and educational software can been seen in Figure 9.4, representing a stacked bar chart with a line. This graph makes it apparent that most students, who had experience with computer devices, were also experienced with educational software. It must be noted however, that the use of educational software was stimulated in 2 out of 3 schools, yet 2 out of 5 participants of that school had experience with educational software and computer devices, without being stimulated by the school. 2 out of 3 participants, who had no experience with educational software, had never used a tablet device.

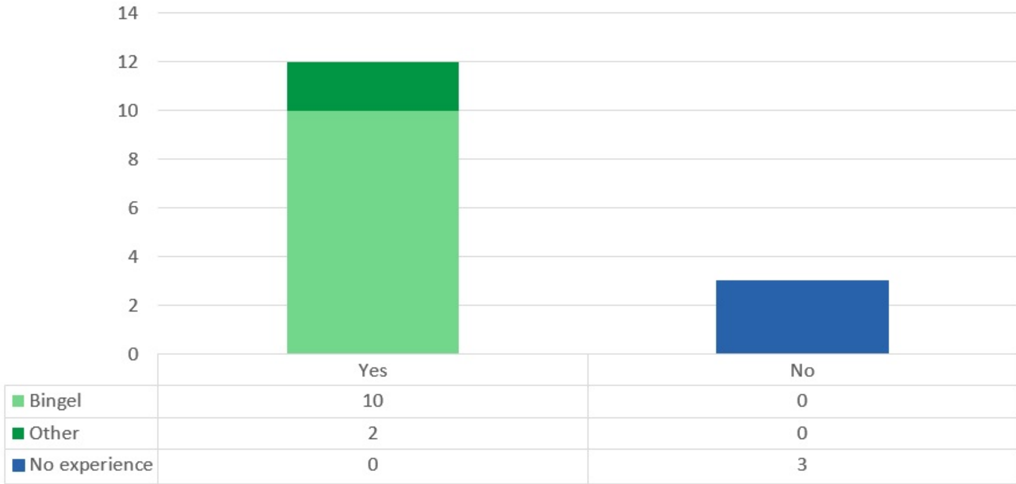


Figure 9.3: Stacked bar chart of the experience with educational software

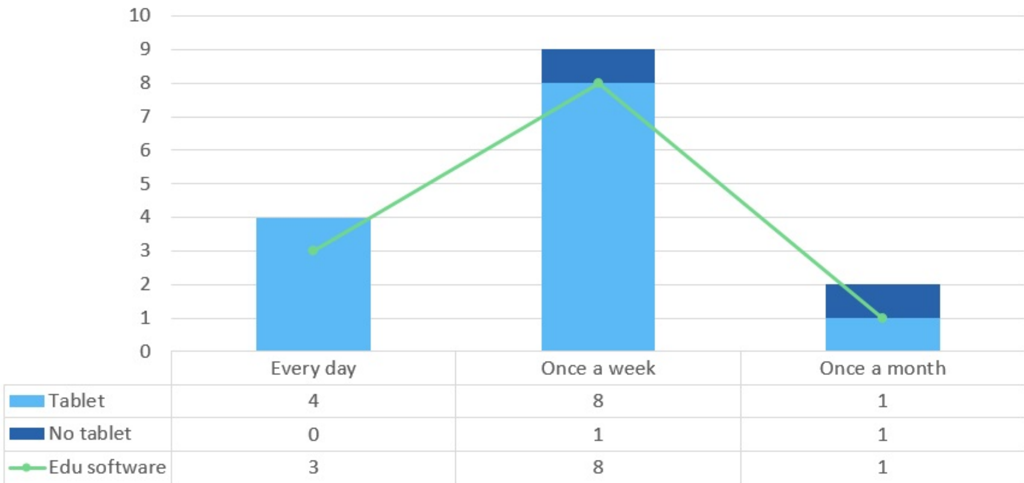


Figure 9.4: Stacked bar chart with line, combining the experience of computer devices with educational software

Phase II: Experiment

ICR Accuracy

The results of the accuracy of the ICR were surprisingly high. It was expected that the recognition of a child's handwriting would be worse than an adult's handwriting, but it clearly was not. The ICR resulted in 100% accuracy for all 15 students when filling out the geometry exercise page. 11 out of 15 students were able to fill out the mental calculation exercise page without any recognition failures, resulting in an accuracy of 100%. 4 out of 15 students had at least 1 recognition failure. After their second attempt, the ICR was able to correctly detect the answer for all 4 students. Of those 4 students, misrecognition occurred once for an answer of 1 student, and twice for the answers of the other 3 students. The pie chart in Figure 9.5 represent the amount of attempts per exercise page graphically.

Figure 9.5: Pie charts of the amount of recognition attempts per exercise page

Each student had to solve a total of 11 exercises, 8 for the first exercise page, and 3 for the other exercise page, totalling 165 exercises for all 15 students. Note that the first question of the geometry exercise page has 8 separate fields, as the XY coordinates needed to be filled out. This resulted in having a total of 18 fields to be filled out by each student. When an answer was not been filled out, meaning the exercise was left open, this was not counted, as nothing was written down and thus no recognition took place. A total of 270 fields were present on 30 pages, out of which 268 fields were filled out. Handwriting in 261 out of 268 fields was recognised correctly on the first attempt. The overall accuracy can thus be calculated based on the first recognition attempt of all fields, since the second recognition attempt was always successful. An accuracy of **97%** (97,39%) was achieved, which is visualised by the left pie chart of Figure 9.6. This very high accuracy results in the ICR of the Smartpen being a trustworthy tool for correctly recognizing handwriting of children of that age group. The accuracy per student is visualised by the right pie chart of Figure 9.6. The accuracy here is calculated for each student individually. For 11 students, 100% recognition accuracy was achieved. For 1 student, an accuracy of 94% was achieved, because of a misrecognition for one exercise. For 3 students, an accuracy of 88% was achieved, because of a misrecognition for two exercises.

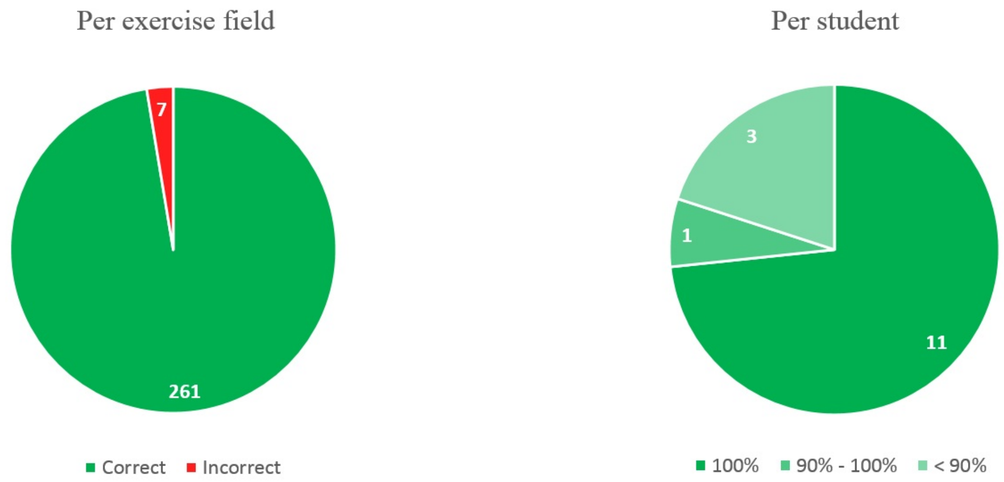


Figure 9.6: Pie charts of the overall accuracy of the ICR based on the fields of the exercises (left), and per student (right)

The recognition failed for at most one single digit of the answer. This had two observed reasons: either the digit was written incorrectly, making it hard to read even for the human eye, or it was written too curly, making the recognition engine interpret it as a different number. The following sections describe all of the misinterpreted handwriting.

1 recognised as 4

The most common misinterpretation was the digit 1 being recognized as the digit 4. This occurred for the following answers: 614 (644), 1419 (4419), 1851 (4851). The underlined number 1 in the original answers was always recognized as the digit 4. This is due to left tip of the number 1 having an exaggerated upwards curl, making it look like a number 4 but without the vertical stripe. Students, for which this exact misinterpretation occurred, all had the same style of writing the digit 1. It is interesting to see that when an answer containing more than one digit 1, the second digit 1 is always recognised correctly. This is due to the writing of the first 1 being exaggerated, while the second 1 always looks more readable and is written in a more accurate way.

1 recognised as 7

For one particular student, the following answer was misinterpreted: 7851 (4851). The underlined digit 1 in the original answer, was recognized as the digit 7. This is because the digit 1 was written in such a skewed way, that it even looked like a legible digit 7. Since this answer reads like 7851, instead of 1851, it is no surprise that the recognition engine recognised this as a digit 7, instead of a digit 1.

3 recognised as 6

One student had a particular curly writing style. Every answer of this student was recognized correctly, with the exception of one: 32 (62). The underlined digit 3 was recognized as a digit 6, due to the lower part of the digit 3 being too curly, making it look like the digit 6. Because this looked remarkably similar to the digit 6, the recognition engine approximated this as this digit, due to the heavy curl at the lower part of the digit.

6 recognised as 8

Another student with a curly handwriting, but not as heavy as the student described above, had the following answer misinterpreted: 614 (814). The underlined digit 6 was recognized as a digit 8, due to the upper part of the digit 6 being too curly, making it look like the digit 8. The curl at the top extended inwards, making to look similar to the digit 8. It was also observed that this student had a reverse way of writing digit. Normally, when starting to write the digit 6, you start at the top, and then work your way to the middle. This student did it the other way around, starting from the middle, and working its way to the top, ending with a heavy inward curl. Digits such as 1, 3, 7 and 9 were also written this way, but with no effect on misinterpretation.

Pen Grip

Most of the students used a good pen grip, usually a mature dynamic tripod grip, while some students had a similar grip, but with the fingers places wrongly and using too much force. Out of all 15 students, 10 had a good pen grip, while 5 had a bad pen grip. 3 out of 5 of these students had bad handwriting, while the other 2 students had a good handwriting, despite using a cramped pen grip. The stacked bar chart of Figure 9.7 gives an overview of the effect of the pen grip on the handwriting recognition. 9 out of 11 students, whose handwriting recognition was at 100% accuracy, had a good pen grip, with most of those students having a neat and clear handwriting. The other 2 students did not have a good pen grip, yet this still resulted in the recognition engine recognising all the handwriting correctly.

This is because their handwriting was neat and clean, despite their bad pen grip. Both students also wrote very big, making it easier for the recognition engine to clearly distinct the pattern of a digit from another. 2 out of 3 students, whose handwriting recognition was below 90% accuracy, had a bad pen grip, resulting in bad handwriting and misrecognition. The other student had a good pen grip, but wrote the digit 1 in such a way that the recognition engine interpreted this as the digit 4.

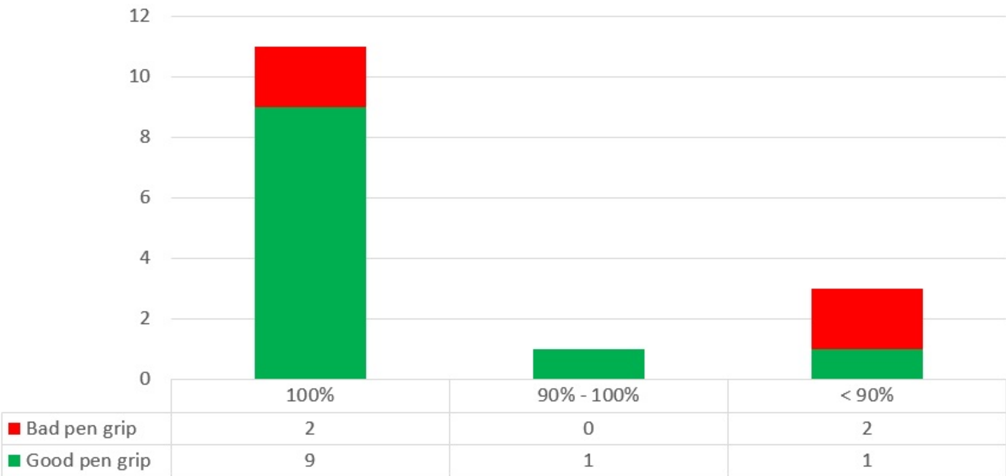


Figure 9.7: Stacked bar chart matching pen grip with the handwriting recognition accuracy

Performance of the Student

The graph of Figure 9.8 shows the relation between the mathematical skills of the students and the results of both exercise pages. All 5 strong students equally performed on the exercise pages, making no mistakes. Out of the 6 students that had good mathematical skills, 3 performed better on the exercise pages, making no mistakes, and as a result shifted to the group of strong students (indicated by the green part of the first bar). Out of the 4 students that had average mathematical skills, one student performed better on the exercise pages, making only one mistake, and transferred to the group of good skilled students. One possible explanation for the increase of the performance of the students could be that the use of the platform motivated them in being more concentrated and eager to perform well. The students were already aware about the platform being able to correct their answers automatically, the tablet app being able to show their handwritten answers and possible corrections. This made most of the students excited, increasing their overall motivation. This is further discusses when giving the results of the questionnaire.

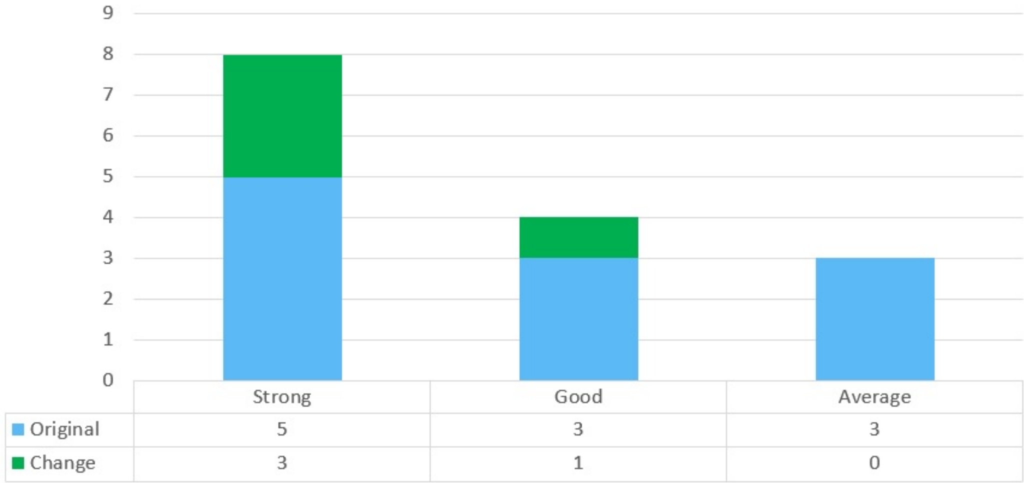


Figure 9.8: Stacked bar chart matching the mathematical skill with the results of both exercise pages

Synchronisation Time

The results of the synchronisation time for all participants were all in the range of 6 and 8 seconds, which is a surprisingly good result for having a slow internet connection. There was one exception due to a problem with the internet connection, resulting in a peak of 18,1 seconds. Overall, it can be said that this is a satisfying result, as the average amount of time (without the exception) the student needed to wait for the answers to appear on the tablet screen is **7,01 seconds**. The graph in Figure 9.9 gives a graphical overview of the synchronisation time for all participants, with the clearly noticeable peek for one participant. Also note that the results are sorted per school, meaning that the first 5 results are of the first school, results 6 to 10 are of the second school, and results 11 to 15 are of the third school. It can be seen that the average synchronisation time is below 7 seconds for the first school, due to having a better internet connection in that area, while the internet connection at the second and third school was slightly lower, resulting in an average above 7 seconds. When testing the platform with a fast internet connection outside of the evaluation environment, synchronisation times between 2 and 4 seconds could be achieved.

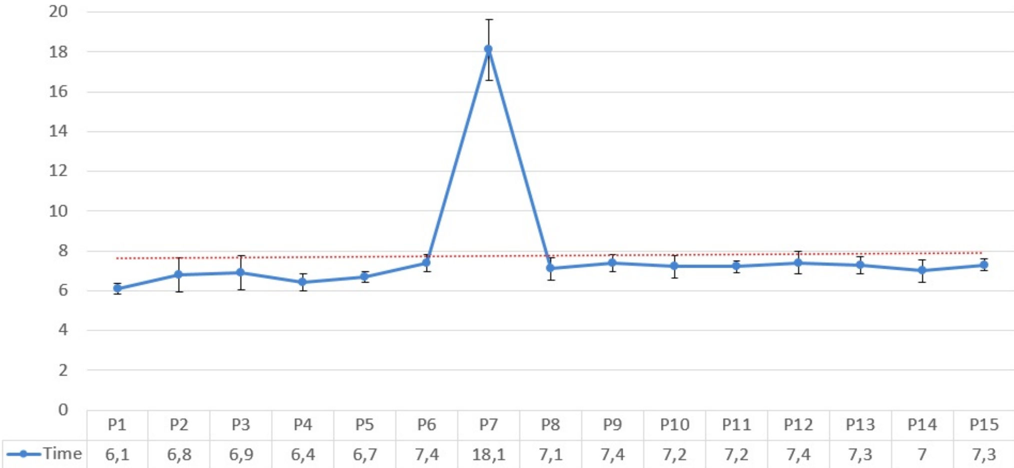


Figure 9.9: Line chart giving an overview of the synchronisation time per participant

Additional Notes

The most common observation that was made for all students is that they did not write their answers down in one go. They usually pause after writing a part of the answer to think, and after a few seconds continued writing down the other part of the same answer. This had as a result that the pen already stored a part of the answer, followed by storing the other part of the answer separately, thus considering it as two different answers because the delay allowed was not big enough. Students of the first school had to rewrite their first answers, but once they were aware of this, they first constructed the full answer in their head, afterwards writing the complete answer down in one go. To avoid this problem, the delay was adjusted to 3000ms after the evaluations in the first school, which resulted in solving this problem, aside from a few exceptions where students paused for more than 5 seconds in between writing parts of a single answer.

Another observation is that 3 out of 15 students showed impatient behaviour, resulting in already using the platform before everything was explained. When this happened, the explanation was stopped, and the student was asked whether everything was already clear without the full explanation. All 3 impatient students could work with the platform without any hassle. It must be noted however that these 3 students had experience with tablet devices, of which 1 student used this device daily. A minor issue with these students was that instead of the answers being stored in parts (like in the previous case), some answers were now stored together because they wrote them down too quickly. This occurred only for the geometry exercise page, because for this page it was easier to give the answers fast. Once the student was told that they needed to wait for their answer to be displayed on the display of the Smartpen, the answers were registered correctly.

A final observation is that most students realised that they needed to tap the *I am ready* text area on the paper. This was not explained before the students started the experiment, to see what action they would perform after filling out the exercise page. 8 out of 15 students pressed this area without having explained to them that tapping this area with the pen stores their answers. When these students were asked why they pressed this, every student answered that they did it to indicate to the pen that they were ready with the exercises. It was unexpected that more than half of the participants did this spontaneously, indicating a good intuitive usability of the Smartpen and Paper Design.

Phase III: Post-experiment

Evaluate Opinion Through Questionnaire

Since the participants were children, most of the questions have yes/no answers, sometimes with an additional question for getting some more detailed information. An overview of all the answers can be found in Figure 9.10. Every student enjoyed working with the platform, and found it easy to work with. This thus proves a high usability, which was already observed when evaluating the students while they were working with the platform. Every student liked the layout of app, however 1 student did have a comment about the theme that was used, finding the nature/farm theme too childish. It was observed that this student was already very mature for its age, and gave some interesting feedback as well when asking about possible improvements. Every student found it good that they could see their answers, corrections, and explanations on the tablet app. Every student would like to use the platform at school or at home, however 1 student did not show interest in the platform. When asked whether they would be able to work with the platform independently, most students immediately said yes, while 2 students hesitated, saying that they would probably need some help, but overall it was clear to them what needed to be done. It was also asked whether they would like something to be changed to the platform. Most students of the first school were a bit shy, and nodded no, while most of the participants of the other 2 schools nodded no in a confident way. Out of those 10 students, 3 students did have some remarks about the platform. A common remark was that they found the Smartpen a bit too thick, making it harder to write with it, and making them changing their pen grip. This was observed during the experiment as well. Another remark was about a different theme for the app. A final remark by a single student was that he did not like to rewrite its answer when misrecognition occurred. The student asked whether this was necessary for every answer, not understanding the underlying problem. A final, important question was whether they would find the platform a better way for making homework or doing tests. Every student confidently nodded yes, except for 1 student, who found that making it with normal pen/paper and waiting for the corrections from the teacher, was better. The student did not dislike the platform or did not find it hard to use, but was not interested in using it.

Question	Yes	Neutral	No	Comments
Was it fun for you to solve exercises like this?	15			
Was it clear what you had to do?	15			
Was it hard for you to work with the app on the tablet?			15	
Did you find the app nice and clear?	14	1		Found the nature/farm theme too childish
Did you find it good that you could see your corrected answers?	15			
Did you find the explanation of the exercises clear?	15			
Would you want to use the platform in the future, at school or at home?	14	1		Was not interested in the use of the platform
Do you think you would be able to work with the platform by yourself?	13	2		Maybe, with some help
Is there something you did not like about the platform, and would like to change?	3		12	Thinner pen, other app theme, one participant had misrecognition twice and didn't like to rewrite
Would this be a better way for you to make your homework or tests?	14		1	Participant that was not interested in the platform, preferred the use of normal pen/paper and correction by the teacher

Figure 9.10: Results of the questionnaire for all participants

Evaluate the Teacher's Opinion Through Questionnaire

The final part of the evaluation was done using a questionnaire for the teacher of the participants' class. The questions of this questionnaire had no simple yes/no answers. The combined results of all teachers will be discussed per question.

How many hours per week do you spent on using devices, such as a computer, tablet, etc.?

All 3 teachers worked with a computer device daily, including tablet devices.

Have you ever used educational software?

2 out of 3 teachers used an IWB for teaching (V. Armstrong et al., 2005) and the Bingel software for exercises and homework for their students. The other

teacher did not use an IWB, but did have experience with Bingel.

What is your opinion on introducing educational software or platforms in a school environment? Would this increase the motivation of the students and increase their learning outcomes?

All teachers agreed that the use of educational software or platforms could be encouraged. They all agreed that using this would increase the student's motivation in learning and doing homework.

What is your opinion about the Smart Study platform?

All teachers were very positive about the platform, saying that it is a good stimulant for the students to perform better. One teacher stated that it would be good for students to use this while doing tests or tasks, as the teacher then would not have to help each student individually. Interestingly enough, all teachers also noted that this platform would be ideal for students with learning problems, as the platform would better accompany and help them at their pace.

Do you find it good that answers are corrected automatically, and that reports can be automatically generated from the results?

All teachers were satisfied that the platform could do this, as they all mentioned that correcting homework could be tedious and time-consuming. They all noted that by using the platform, results could be given to the students right away, instead of the day after.

Would you like to see your students use the Smart Study platform? Do you think it would increase their motivation and learning ability?

All teachers confidently answered yes, saying that the Smart Study platform would definitely have a high addition educational value, increasing the student's motivation and learning ability.

What changes would you like to see to the Smart Study platform?

Most of the teachers noted some of the restrictions of the platform, such as the Smartpen being connected to a computer device in a wired way, the pen being a bit too thick, and the additional use of a computer device for the data extraction of the pen. Since this platform is just a prototype, these are things that can absolutely be changed or improved without much hassle. None of the teachers had any remarks on the usability of the platform, or the layout of the app; they were very satisfied about it.

If this platform would be made commercially available, possibly subsidised by the government, do you think it would be successful and realisable within a school environment?

All teachers noted that the platform could be too expensive to effectively be realised within a school environment. If not every student in their class could afford it then the group would be divided in students who work with the platform, and students who have to work in the traditional way with normal pen/paper and the teacher's corrections. However, what all teachers did mention is that this platform should be subsidised by the government, to make it available at schools, as they are sure that it would provide an effective increase in the learning outcome, and motivation of their students. A final important note made by 2 of the 3 teachers, is that the learning time for using the platform is low learning curve and that it is very accessible to the students. They said that the current platforms they use are sometimes too hard to work with for children, making them less motivated when using it. From the teacher's point of view, the Smart Study platform does not have this issue, making it a perfect candidate for using it in a school or home environment.

9.5 Discussion

The results of the evaluation were very positive. Furthermore, no problems occurred in neither of the 3 schools while the participants were using the platform indicating that the software is already very stable. The ICR accuracy of the Smartpen was very high, and the synchronisation time of the platform was short, even with a slow internet connection. All of the participants were excited when using the platform and satisfied about the functionality and usability. The children found it very fascinating that a normal looking pen can capture their handwriting, and even show and correct their answers on a tablet device. Probably because of this fascination, the students performed better than usual. They were more motivated when filling out the exercise pages, because every time they solved an exercise, they knew that their handwritten answer would appear on the display of the Smartpen. Every student found it fun and easy to work with the app, and was also actively working with the app, closely studying the explanation of an exercise they filled in wrongly. No major comments were made by the participants when asked for improvements of the platform. However, it should noted that the participants were children and could have been too shy to mention what they did not like or what could be done better.

The teachers were asked more constructive and in-depth questions about the platform, giving a perspective on whether the platform would be useful and acceptable or not, and what elements of the platform could be improved. All of the teachers were enthusiastic with the current state of the platform, and found its workings fascinating. They also noted that this platform would be beneficial for children with learning problems. Common remarks on the technical aspects of the platform were usually on the hardware configuration, i.e., the use of a wired pen and a computer between the Smartpen and the tablet. This is however a prototype, and these components can easily be replaced or improved. By using a newer version or a pen of another brand, wireless connectivity can be achieved, even directly to a tablet device, making a computer for the data extraction process unnecessary. All of the teachers questioned whether this would be affordable in a school environment, as giving a digital pen and tablet to each student would become expensive. However, they also mentioned that it could be most beneficial for children with learning problems. Therefore a possibility would be to only provide the platform to students with learning problems during hours of remediation, which is usually done outside the class environment. However, next to the financial issue, they mentioned that it would be the best type of digital learning platform that would be used in their school so far, because it provides a motivating and stimulation environment for children to work independently, releases the teachers of some time-consuming correcting work, and requires a short learning time and has a high usability.

Chapter 10

Conclusion

10.1 Introduction

This final chapter concludes thesis by reflecting upon the work done for the development of the Smart Study educational platform, and how the digital evolution in education is important for a child's future. Limitations and future work are discussed as well.

10.2 Summary

This thesis was opened with a quote by one of the most profound philosophers of the 20th century, John Dewey. In his quote, he stated that *"If we teach today as we taught yesterday, we rob our children of tomorrow"*. This quote still holds today. If the way in which children are educated does not evolve and adapt with the technological and digital evolution, those children will not only miss unique opportunities to help them developing their intellectual skills, but also miss the opportunities to develop the technological and digital skills that they will need in the society of tomorrow.

Education holds the key to a child's future. It builds the foundations a child relies on, in order to grow up in a strong and successful way. The way upon which education is brought to children is therefore very import, as even average students need to get a good chance of having a successful future. In order to go along with this digital and technological evolution, and adapt this to an educational environment, a novel digital platform, composed of a digital pen, interactive paper, and a tablet, was created. This digital platform allows maintaining a child's normal writing behaviour, while introducing modern technology that could increase the child's motivation and learning outcome, while relieving work from the teacher by automating certain processes. The result of this work is that children cannot only keep practising the read/write learning style, but also interact and work with modern devices, capable of individually helping them with learning. Correcting answers and generating reports is no longer the task of the teachers, but is done in a fast and completely autonomous way by the platform. Both the students and their teacher have a motivating and interactive way of participating in the educational activities.

An increasing amount of schools is starting to adopt modern technology that can enrich the teaching abilities for teachers, and the learning abilities for students. Schools are starting to see the benefits of this, and as technology evolves, it gets easier and more accessible for a larger audience. The Smart Study platform presented in this thesis is a good example of how schools could profit from this. There is still a long road ahead before all schools could start adopting this technology, but the technology is there, and the students and teachers are ready to use it.

10.3 Limitations and Future Work

The platform was evaluated in 3 schools and with a total of 15 children. This evaluation showed that the platform performed well in a school environment. There are however some points that could be improved. These will be mentioned here as future work.

Wireless

The Smartpen used for this thesis, required a wired connection to a computer, and could not call external applications. This limitation resulted in the need of a computer, and additional software, in order to establish a communication between the Smartpen and the tablet app. Newer versions of the Livescribe pen or other branded Smartpens have wireless connectivity, using Bluetooth or WiFi, and can even connect directly to a tablet device. For the Livescribe pens, at the time of starting the thesis work, no SDK for the wireless pens were available, making development with those pens not possible. For Anoto Smartpens, SDKs are available, however these are expensive. However, making the Smart Study platform working with a wireless Smartpen and without the use of a computer and additional software would not only reduce the cost of the platform but also ease its use. The only tools necessary for working with the platform would be, in that case, the Smartpen, Paper Designs, and the tablet app.

Lighter and Thinner Pen

Another improvement could be the use of a pen that is lighter and slimmer. A common remark of the participants and teachers after the evaluations was that the pen was a bit too thick to write with, especially for children. Using a thinner Smartpen would result in having an almost similar writing experience than when using a normal pen or pencil. In that case, children would not have to adjust their grip based on the thickness of the pen, resulting in a better pen grip, better handwriting, and higher recognition by the ICR of the Smartpen.

Authoring Tools

Currently, the course supported is *Mathematics*. The platform has been designed and programmed in such a way, that it is possible to add other courses with other types of exercise pages, without much hassle. However, it could be a good idea to develop authoring tools to allow instructional designer to create new courses or assignment pages. Authoring tools could be written for designing new exercise pages. These tools should simply insert data into the database, construct Java files ready to be deployed to the Smartpen, but must also create the Paper Design. Since this tool is integrated in the Livescribe SDK and used as a plugin by an Eclipse IDE, it might be hard to automate this process. Further investigation needs to be done in order to find out whether this would be possible.

Authentication

The authentication process currently happens by the user selecting its name from the list at the login screen. An additional configuration file, put on each tablet device separately, could bind that device to a specific school, class, or student. This way, the app can be used over a multitude of students, classes, and even different schools, without the user being able to authenticate itself as someone else. For the sake of keeping interaction very simple, the authentication is not done by providing a username and password, as a list of names is easier to use.

Web Application

When starting to work on the actual implementation, there was originally the idea of creating a web-based application, instead of a native Android app. This would enable users to use this application on every device supporting a web browser, with every supported type of input, no longer being restricted to using an Android tablet. The question then remains whether this would be an actual improvement over the current use of an Android tablet with a native app, with a tablet offering true mobility, and the app being easily used by touch interaction. The downside of using a web-based application is cross-browser compatibility, making it harder for the developer to support it on most browsers.

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Part IV

Appendix

Appendix A

Code

A.1 Penlet

A.1.1 Java class: XMLUtils2

```
package com.project.SmartStudyPenlet;

public class XMLUtils2 {

      public String toXML2(int page, int solution1_field,
                                     String solution1_data,
                                     int solution2_field,
                                     String solution2_data,
                                     int solution3_field,
                                     String solution3_data)
      {
            // If page is empty
            if (solutions == "")
                  return "<no-data/>";

            // Header of XML file
            String xmlOutput = "<?xml version=\"1.0\"
               encoding=\"UTF-8\"?>";

            // Begin annotation tag
            xmlOutput += "<annotationXML>";

            // Add page
            xmlOutput += "<page>" + page + "</page>";
```

```
        // Open solutions tag
        xmlOutput += "<solutions>";

        // All solutions
        xmlOutput += "<solution>";
        xmlOutput += "<solution_field>" +
           solution1_field + "</solution_field>";
        xmlOutput += "<solution_data>" +
           solution1_data + "</solution_data>";
        xmlOutput += "</solution>";

        xmlOutput += "<solution>";
        xmlOutput += "<solution_field>" +
           solution2_field + "</solution_field>";
        xmlOutput += "<solution_data>" +
           solution2_data + "</solution_data>";
        xmlOutput += "</solution>";

        xmlOutput += "<solution>";
        xmlOutput += "<solution_field>" +
           solution3_field + "</solution_field>";
        xmlOutput += "<solution_data>" +
           solution3_data + "</solution_data>";
        xmlOutput += "</solution>";

        // Close solutions tag
        xmlOutput += "</solutions>";

        // End annotation tag
        xmlOutput += "</annotationXML>";

        return xmlOutput;
    }
}
```

A.2 C# program

A.2.1 Method: PenAttachEvent()

```
private void PenAttachEvent(Smartpen pen)
{

   // Extract file from pen
   try
   {
      // The pen.Hardware property is not valid until it
         is updated
      pen.Hardware.Update();

      String result = "";
      bool test = pen.DataCommand("SmartStudyPenlet",
         "receive/SmartStudyData.txt", out result);
      if (test == false)
      {
         SetTextFNF("File not found");
      }
      else
      {
         SetTextFE("File extracted");
      }

      // Write file to local device
      WriteToFile(result, Directory.GetCurrentDirectory()
         + "/SmartStudyData.xml");
   }
   catch(Exception e)
   {
      SetTextPNF("Pen not found");
   }

   // Upload the file over HTTPS/POST through PHP
   try
   {
      System.Net.WebClient Client = new
         System.Net.WebClient();
      Client.Headers.Add("Content-Type", "safe/XML");
      byte[] res = Client.UploadFile(
            "https://xxx/programUpload.php", "POST",
```

```
            "SmartStudyData.xml");
        String updatedXML =
           System.Text.Encoding.UTF8.GetString(res, 0,
           res.Length);

        SetTextFU("File uploaded");
    }
    catch (Exception e)
    {
        SetTextUF("Upload failed: " + e);
    }

    // Process XML file and store data in database
    try
    {
        HttpWebRequest request =
            (HttpWebRequest)WebRequest.Create(
               "https://xxx/programDoProcess.php");
        HttpWebResponse response =
            (HttpWebResponse)request.GetResponse();

        SetTextDSS("Data successfully stored");
        SetTextDSS("Process completed!");
    }
    catch (Exception e)
    {
        SetTextDSF("Data storage failed: " + e);

    }
}
```

A.3 PHP

A.3.1 PHP file: programDoProcess

```
<?php

// Load XML file
$xml=simplexml_load_file("upload/SmartStudyData.xml");

// Read page from <page> tag
$page = $xml->page;

// In order to match with the exercise numbers,
// the array starts at 1 instead of 0
$i = 1;

// Read the data from the XML file depending on its tags
foreach ($xml->solutions->solution as $solution)
{
      $solution_field[$i]=$solution->solution_field;
      $solution_data[$i]=$solution->solution_data;
      $i++;
}

// Include DB connect class
require_once __DIR__ . '/db_connect.php';

// Connect to DB
$db = new DB_CONNECT();

// Check if the exercise page was already solved by this
   user
$query = "SELECT ID
          FROM Result
          WHERE StudentID =
            (SELECT StudentID FROM Processing)
           AND ExerciseID =
            (SELECT ID FROM Exercise
             WHERE PaperFieldID =" .
               $solution_field[1] . ")";
$result = mysql_query($query);
```

```
if($row = mysql_fetch_array($result))
{
      // Already in database
}
else
{
      // Ready for INSERT

      // Do for each exercise
      for ($i = 1; $i <= 8; $i += 1)
      {
            // Get solutions of the exercises
            $query_select = "SELECT Solution
                             FROM Exercise
                             WHERE PaperFieldID =" .
                              $solution_field[$i];
            $result_select = mysql_query($query_select);
            $check_solution =
               mysql_fetch_array($result_select);

            // Check if answer matches solution
            if($check_solution["Solution"] ==
               $solution_data[$i])
                  $is_correct = 1;
            else
                  $is_correct = 0;

            // Insert record into database
            $query_insert =
                  "INSERT INTO Result (ID, StudentID,
                     ExerciseID, Solution, IsCorrect)
                   VALUES (0,
                          (SELECT StudentID FROM
                             Processing),
                          (SELECT ID FROM Exercise WHERE
                             PaperFieldID = " .
                              $solution_field[$i]."),'" .
                              $solution_data[$i] . "'," .
                              $is_correct . ")";
            mysql_query($query_insert);
      }
}
```

```
// After the answers have been inserted,
// update process state so the tablet app can proceed
mysql_query("UPDATE Processing
            SET ProcessDone = 1, CurrentPage = " . $page);

?>
```

Appendix B

Evaluation forms

B.1 Pre-experiment

EVALUATIE: **PRE-TEST**

STUDENT

Naam: ____________________________ Klas: ____________________________

School: ____________________________ Leerkracht: ______________________

VRAGEN

- Wat is de kennis **Wiskunde** van de student?

____

- Wat zijn de **computervaardigheden** van de student?

____

____

- Heb je ervaring met **educatieve software**?

____

____

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Figure B.1: Evaluation before the test

B.2 Experiment

EVALUATIE: TEST

STUDENT

Naam: ______________________________ Klas: ______________________________

School: ______________________________ Leerkracht: ________________________

RESULTATEN

	Blad 1	Blad 2
Synchronisatietijd		
Score		

- **Pen greep** van de student

  ____

- **ICR nauwkeurigheid** en **opmerkingen**

____

____

____

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Figure B.2: Evaluation during the test

B.3 Post-experiment

EVALUATIE: POST-TEST (1)

STUDENT

Naam: ______________________ Klas: ______________________

School: ______________________ Leerkracht: ______________________

VRAGEN

- Vond je het leuk om op deze manier oefeningen op te lossen?

  ____

- Was het duidelijk wat je moest doen?

  ____

- Vond je het moeilijk om met de app op de tablet te werken?

  ____

- Vond je de app op de tablet mooi en duidelijk?

  ____

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Figure B.3: Evaluation after the test (page 1)

EVALUATIE: **POST-TEST (2)**

VRAGEN

- Vond je het goed om je opgeloste oefeningen te kunnen bekijken?
- Was de uitleg van de oefeningen duidelijk?
- Zou je dit in de toekomst willen gebruiken op school of thuis?
- Denk je zelf hiermee overweg te kunnen als je dit thuis zou gebruiken?
- Is er iets dat voor jou beter kan en dat jij zou veranderen aan het leerplatform?
- Zou dit voor jou een betere manier zijn om je huiswerk of toetsen te maken?

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Figure B.4: Evaluation after the test (page 2)

B.4 Teacher

EVALUATIE: LEERKRACHT (1)

LEERKRACHT

Naam: ____________________ Klas: ____________________

School: ____________________ Evaluatie: ____________________

VRAGEN

- Hoe vaak bent u met computer of dergelijke toestellen bezig per week?

  ____

- Gebruikt u of heeft u al educatieve software gebruikt?

  ____

  ____

- Wat is uw mening over het invoeren van educatieve software of platformen in een schoolomgeving? Zou dit de leerling meer motiveren en helpen tijdens het leren?

  ____

  ____

  ____

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Figure B.5: Evaluation of the teacher after evaluating all children (page 1)

EVALUATIE: LEERKRACHT (2)

VRAGEN

- Wat is uw mening over het Smart Study platform?

- Vind u het goed dat oplossingen van de leerlingen automatisch worden verbeterd, opgeslagen, en er rapporten kunnen worden gegenereerd uit de resultaten?

- Ziet u uw leerlingen dit platform gebruiken? Zou dit de leerlingen meer motiveren en helpen tijdens het leren?

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Figure B.6: Evaluation of the teacher after evaluating all children (page 2)

EVALUATIE: **LEERKRACHT (3)**

VRAGEN

- Wat zouden volgens u verbeteringen kunnen zijn aan dit leerplatform?

  ____

  ____

  ____

  ____

- Indien dit platform commercieel zou gemaakt worden, en eventueel gesubsidieerd door de overheid, denkt u dat dit succes zou hebben en realiseerbaar is binnen de schoolomgeving?

  ____

  ____

  ____

  ____

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Figure B.7: Evaluation of the teacher after evaluating all children (page 3)