DEVELOPING AN EDUCATIONAL APPLICATION
FOR FIRST GRADE STUDENTS
BASED ON HANDWRITING RECOGNITION

by

EMRE INAL

Submitted to the Graduate School of Engineering and Natural Sciences
in partial fulfillment of
the requirements for the degree of
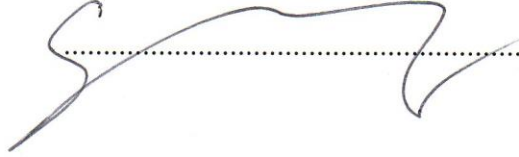Master of Science

Sabancı University

August 2016

DEVELOPING AN EDUCATIONAL APPLICATION FOR FIRST GRADE STUDENTS BASED ON HANDWRITING RECOGNITION

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DATE OF APPROVAL: 08/08/2016

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Computer Science and Engineering, Master Thesis, 2016

Thesis Advisor: Prof. Dr. Berrin Yanıkoğlu

Keywords: Educational application, Child centered design, Handwriting recognition, Tablet computer, Android

Abstract

Tablet computers have become a significant consumer technology by providing a more natural way of interaction via touch sensitive screens, compared to keyboard and mouse input. For this purpose, they are being used increasingly for education purposes, especially aimed for children. In this thesis, an educational application based on handwriting recognition technologies is developed for 1st grade students. The developed application lets teachers prepare online study material directly from text books that students write on and receive back a rich set of information such as timing and writing order, along with a student's completed homework. Arithmetic and linguistic exercises suitable for first grade curriculum are implemented into application.

The thesis covers all aspects about designing and developing such an educational application, including: how to design a friendly and straightforward interface for children; how to prepare study material paralleling a variety of question types (matching, arithmetic, Turkish) found in elementary school education; and what applications would be most beneficial on the tablet platform. Besides the design and user interface issues, technical solutions are developed for how to implement sophisticated applications such as a Hidden Markov Model based recognizer on the Android platform, and how to verify answers.

After the initial design, assessments are collected from first grade students on two separate occasions and the design of the application was iteratively improved to suit the young students' needs who have still-developing motor skills and lesser experience with technology compared to most adults.

BİRİNCİ SINIFLARA YÖNELİK
EL YAZISI TANIMA BAZLI
EĞİTİM UYGULAMASI GELİŞTİRİLMESİ

Emre Inal

Bilgisayar Bilimi ve Mühendisliği, Yüksek Lisans Tezi, 2016

Tez Danışmanı: Prof. Dr. Berrin Yanıkoğlu

Özet

Tablet bilgisayarlar dokunmatik ekranları sayesinde, klavye ve fare kullanımına kıyasla daha doğal bir etkileşim olanağı sağladıklarından tüketiciler için önemli bir teknoloji haline gelmiştir. Bundan dolayı, özellikle çocuklara yönelik olarak eğitim alanında kullanımları artmaktadır. Bu tezde, el yazısı tanıma teknolojilerine dayalı olarak çalışan 1. sınıflara uygun bir eğitim uygulaması geliştirilmiştir. Geliştirilen uygulama, öğretmenlere öğrencilerin kullandığı ders kitapları üzerinden çevrimiçi çalışma materyalleri üretmelerine olanak sağlamakta, aynı zamanda öğrencinin tamamlanmış ödevinin yanı sıra, zamanlama ve yazma sırası gibi çok çeşitli verileri de öğretmenlere sunmaktadır. Uygulamaya birinci sınıf müfredatına uygun aritmetik ve sözel alıştırmalar yerleştirilmiştir.

Bu tez; çocuklar için açık ve anlaşılır bir arayüz tasarlanması, ilkokul eğitimde kullanılan çeşitli soru tiplerine (eşleştirme, aritmetik, Türkçe) denk çalışma materyallerinin hazırlanması, ve hangi uygulamaların tablet platofrmunda en yararlı olacağının belirlenmesi gibi konuları ele alarak bir eğitim uygulamasının tasarlanması ve geliştirilmesi hususunda geniş çaplı bir çalışma gerçekleştirmiştir. Tasarım ve kullanıcı arayüzü ile ilgili hususların yanı sıra, Hidden Markov Modeli'ne dayalı bir tanıyıcının Android platformunda kullanımı ve verilen cevapların doğrulamasının yapılması gibi karmaşık uygulamaların geliştirilmesi ile ilgili teknik çözümler de geliştirilmiştir.

İlk tasarımın ardından iki farklı zamanda birinci sınıf öğrencileri ile değerlendirme yapılmış ve uygulamanın tasarımı, halen motor becerileri gelişmekte olan ve yetişkinlere kıyasla teknoloji ile ilgili deneyimleri kısıtlı olan öğrencilere hitap edecek şekilde, aşamalı olarak iyileştirilmiştir.

Thinking of you, wherever you are.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my thesis advisor Prof. Dr. Berrin Yanıkoğlu. From start to finish, everything I've obtained during my 2 years of graduate education is thanks to her. I could not ask for better opportunities, resources and guidance in my years at Sabancı University.

I would like to thank to my thesis defense committee members Assoc. Prof. Dr. Selim Balcısoy and Assoc. Prof. Aytaç Göğüş, with their valuable comments and their presence.

I also want to thank to Mustafa Berkay Yılmaz for his collobration in the implementation of HTK.

I deem myself very lucky to have my mother and father, with their unrelenting support. My family, Seval and Mehmet, always provided me with the opportunities for the path I've chosen myself to walk on. Over the years we clinched together exceeding the hardships we faced, and I cannot disregard the major role they have played in my life for becoming who I am today.

I identify life as a series of encounters. As my most beloved and precious encounter; in the latter quarter of my life to date, I am very happy to be with my significant other, Ece. Based on her lead I've taken another step in my career. I wouldn't be typing these words if her life were not entwined with mine. Having her support and being able to share everything possible is nothing I would cast aside and I hope to keep her by my side until the end of time.

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LIST OF ABBREVATIONS

FATIH	Fırsatları Arttırma ve Teknolojiyi İyileştirme Hareketi
HMM	Hidden Markov Model
HTK	Hidden Markov Model Toolkit
HWR	Handwriting Recognizer
MTP	Media Transfer Protocol
NDK	Native Development Kit

CHAPTER 1

Introduction

Tablet computers have become one of the most significant consumer technologies over the last decade. Their touch-sensitive screens act as the main source of input and using stylus achieves a more natural way of interaction. While primarily used for gaming, social, media and web based activities, given they could act as an improved replacement for traditional pen and paper, tablet computers are also used in educational settings where their benefits are presented in various studies (BECTA, 2004; Galligan, Loch, McDonald, and Taylor, 2010; Kosheleva, Rusch and Loudina, 2007; Li et al., 2010; Sheehy et al., 2005; Trouche & Drijvers, 2010; Twining & Evans, 2005). With the aim of providing equal opportunities to every student and improving technology for educational settings, FATIH project (FATIH, 2012) in particular equipped each individual student with their own personal tablet computers.

Children in the first two years of elementary school (generally aged 6-8) have still-developing motor skills and lesser experience with technology compared to most adults. Drawing and writing activities in elementary schools have a positive impact on students for developing their fine and gross motor skills. However, it is a challenge to keep young students' attention in such activities.

Computers have been used in educational settings for more than two decades. First generation of educational applications consisted of digitally scanned textbooks and had simple features such as audio tracks and animations for interactivity. With further developments in the area, these applications now lay the foundation for the use of interactive methods in educational settings, allowing students to engage in several exercises and activities. Keyboard and mouse is the primary method for input in

computer-based applications, resulting in a non-natural interaction (Brandl et al., 2008). On the other hand, adding special peripherals such as stylus and writing pads to a computer is costly and not practical.

Given that students in elementary school, especially those in first grade learning, spend a lot of time completing handwriting related exercises (Duran, 2009; Erdoğan & Erdoğan, 2012), it is important to provide a more natural input format. Considering the fact that a tablet computer is an easily obtainable technology compared to a computer, using stylus can be used to achieve this natural interaction. Indeed, use of tablet computers has been observed to assist students that have difficulties in handwriting (Ferrer, Belvis and Pamies, 2011).

Thus, it is significant to provide educational applications that make use of the stylus present in tablet computers in order to benefit from their direct interaction. By having considerable processing power, tablet computers are able to run necessary background processes for more complex educational tasks in order to produce more effective applications.

In this thesis, the aim was to develop an education application running on a tablet, with modules that would most benefit from an underlying handwriting recognizer. Handwriting recognition is a well-developed research area in many languages including Turkish (e.g., Yanikoglu & Sandon, 1998; Vural et al. 2005; Frinken, Fischer, Manmatha, & Bunke, 2012) that has a high potential to significantly affect the ability to keep students interested by giving instant feedback and help teachers collect results and statistics easily about an individual student or the whole classroom, for easy/automatic grading or analysis.

The application developed in this thesis, called *YazÇöz,* is a suite of four modules (handwriting, arithmetic, language and mathematics questions) as illustrated in Figure 1.1. Teachers can easily upload questions and receive handwritten answers from students. The answers can be analyzed for correctness, timing etc., with, as well as giving quicker feedback to students.

During the development of this application, first grade curriculum was studied to determine the question types that can be applied to tablet computer medium and the interface was designed to be capable of representing many different question types. The

interface was developed with an appealing design in mind, which keeps the students' focus on the application; therefore, solidifying their learning experience (Reboli, 2007 and Enriquez, 2010). There were also several supportive applications developed, using same foundation of the main application, that were used for administrative and data collection purposes. For handwriting recognizer, customizations to libraries were developed in order for them to be used on Android. Issues affecting performance on Android were confronted and resolved as well.
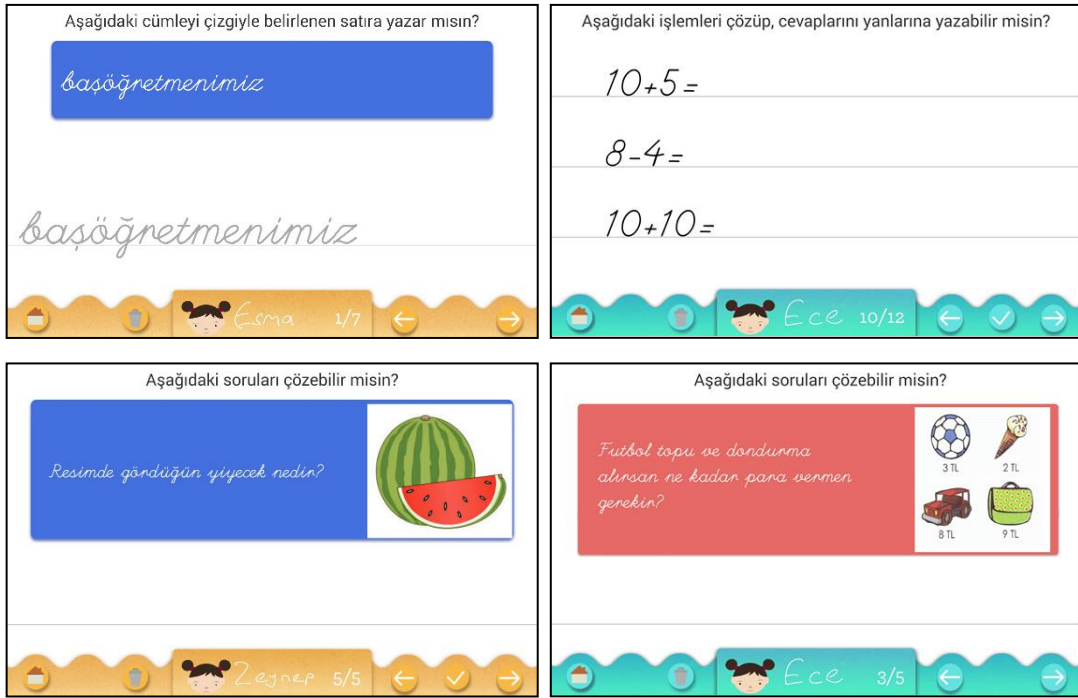
Figure 1.1 Modules of YazÇöz. Clockwise starting top left: Cursive handwriting module, arithmetic operations module, mathematical questions module and language questions module.

The main contribution of this thesis is an overall solution addressing issues encountered in the development of an application specifically aimed towards first grade students. The application was meticulously designed considering the capabilities of first grade students, as observed in two usability assessment tests. Furthermore, the design process is thoroughly documented so as to guide similar applications in the future.

Although the educational technologies are created with the students in mind, the classroom teachers in fact would be the pioneers that will utilize these technologies in their classrooms. This study also incorporated teachers point of view into its design,

particularly about its administrative functions. Steps were taken to introduce an opportunity to utilize older material for today's education.

Chapter 2 includes information about similar applications and research in the area regarding handwriting technologies used in education for younger children. The design and development of the application, including tablet selection and observations from students and how it shaped the final application are explained in Chapter 3. Helper applications that are developed to complement the main system are presented in Chapter 4. Technical details regarding application development process and handwriting recognizer can be found in Chapter 5. Finally, Chapter 6 details the assessments with first grade students and classroom teachers; and concludes with discussion and conclusion sections.

CHAPTER 2

Background Information

Writing skills are not gained by birth, but obtained with education. Besides taking time, obtaining writing skills should follow a planned process, in which it is obligatory to follow the rules of the language. (Kadıoğlu, 2012) These skills can be gained in a favorable environment, with practice and experience. (Güneyli, 2006)

In handwriting, letters are connected together to form syllables, and syllables are connected to form words. While using this technique, in order to write words correctly and clearly, students are required to make the right connections, while paying attention to letters, letter connections and related details. (Balkan 2015) It is crucial to teach angles of the letters, starting and ending points for them, and the right technique that will allow students to write a word without removing their hands. (Güneş, 2016)

In Turkey, starting with 2005-2006 education year, first year students now start learning handwriting by using cursive, and also obligated to use cursive writing when and wherever possible, albeit facing considerable difficulties (e.g. controlling their small muscle groups) (Artut, 2005; Celenk, 2007).

2.1. Literature review for usage of handwriting technologies for children

Handwriting and its impact on children is a widely researched area. On the other hand, in the scope of this thesis, we are interested in the use and impact of handwriting devices and recognition technologies for children.

2.1.1. Valderrama Baham´ondez et al. (2013)

In this study, authors tried to determine the effect of different touch technologies on children's handwriting by comparing four alternatives: Pen and paper, capacitive screen with stylus, capacitive screen with finger, resistive screen with stylus. Assessments are done with 3rd and 6th grade students. Participants were tasked with drawing shapes, writing numbers and sentences. These tasks were evaluated by speed, readability and legibility; in which the authors were aided by classroom teachers.

Evaluations suggest that traditional pen and paper were the most legible writing by a long way compared to other alternatives. It has to be noted that, active styli were not a part of this study. Even with the larger and incommodious nib of a passive styli, capacitive screen with stylus technology were highly preferred and suggested as a highly approachable research area for future studies.

2.1.2. Mann, Hinrichs and Quigley (2014)

The authors in this study compared three relatively new handwriting technologies with traditional pen and paper, for usage in education of children aged 9-10. The technologies used were; a Wacom tablet, a LiveScribe digital pen and an iPad with stylus.

Authors were aware that the comparison has been done enough times in the area, therefore used only novel technology available in the time of study and aimed to evaluate their results with current generation of children, whom the impact of the technology on, varies greatly with each passing year.

The authors also included a self-assessment part for their evaluation, where they asked the students themselves to evaluate their handwritings using the evaluated technologies. Students indicated that their handwriting is either same or worse using tablet technologies, but generally described themselves not affected whilst using digital pen. An interesting fact that, the evaluation of the classroom teachers was also similar, so the feedback from the self-assessment from the students were authentic.

The authors also discuss the topic of feedback, where they discuss that even though handwriting is worse in tablet technologies (which can be explained with students having less to no experience) compared to pen and paper, the ability to give feedback in forms of constructive, haptic, and subtle guidance can be a powerful asset which would result in better learning experience leading into quicker grasp of handwriting.

2.1.3. Falk et al. (2011)

Falk et al (2010) created an innovative computer-based handwriting assessment tool to objectively quantify handwriting proficiency in children, which allows automatic identification of specific difficulties children are facing in handwriting. The aim in their study to diminish idiosyncratic problems the children encounter based on the physical aspects of handling a pen. They have also proposed a measurement system for the handwritten letters in order to evaluate and record numerical discrimination between students.

2.2. Literature review for similar applications

Similar to the topic of this thesis, studies in the context of mobile applications aimed to supplement education are also researched. Truly comparable research or applications could not be found, as expected. One logical inference is the relatively new use of active styli in consumer technology and educational applications.

2.2.1. EasySketch by Kim et al. (2014)

In the work done by Kim et al. (2013, 2014), they've created an application specifically aimed to develop fine motor skills in children. They selected their target users as children preparing to go kindergarten (aged 5-6) or children who are already attending kindergarten but have underdeveloped fine motor skill ability than their peers.

In this application called EasySketch, children are tasked with drawing 16 shapes (numbers 0-9 and letters A-F), and the system checks its user's mastery in each shape individually. This application is created as a Mac application, designed to be used with iPads as input devices, therefore uses non-proprietary stylus. Given the age of its users, they have designed their application to be used with parental guidance. Also, although it uses a fine motor skill classifier and shape recognizer for evaluating children's input, they achieved rather non-successful results in their target age range, therefore decided to provide handwriting information to parents and teachers for evaluation.

2.2.2. Unnamed application by Yılmaz and Durdu (2013)

The application created by Yılmaz and Durdu (2013) uses a heuristic approach for the recognition of handwritten letters. Authors mention that the design should be aimed towards children and states that the experience of the children should also be factored in to evaluate the success of the application. While not addressing these issues explicitly, they developed a default mobile interfaced application to test their heuristic methods.

Authors preferred to do their tests with adults, in spite of targeting children around age 5, stating the reason that tests would be difficult given that the children's verbal skills would not be fully developed yet.

2.2.3. Math Tutor by Masood and Hoda (2014)

Masood and Hoda (2014) created an application for Android tablets, which does not exactly present itself as a mobile application, but uses the touch screen as a replacement for mouse input at most. Math Tutor is designed as a common mobile application and the questions were created as multiple choice questions. A child friendly interface is achieved since the target users were children aged 5-6; yet the application is only evaluated with university students and therefore the success cannot be discussed.

2.2.4. Smart Study by Van Thienen (2014)

Van Thienen in his study developed an educational system that uses LiveScribe digital pen and its corresponding papers, accompanied by a tablet computer. The system is aimed towards students in fifth grade and evaluated with children in target age. The only content supported by the system is mathematics.

The tablet computer in the Smart Study system is not used as an input device, but rather used as the monitoring and evaluation component. When an answer is written wrongly on the paper, the tablet application shows why the answer is wrong; for example, for a mathematic question answered wrong, calculation is shown in detail.

As far as simulating traditional pen and paper goes, smart papers provide a more realistic experience than tablet computers, which is one of the primary reasons smart pens are used in this study, albeit the cost is same as a tablet computer. Evaluation of the experiments show a very positive feedback, but the possibility of using such a system in real life setting is not very favorable due to its cost and accessability.

2.3. Stylus

A stylus is a special pen designed to be used with pressure sensitive devices such as tablets and smart phones. Even though it is possible to encounter problems while using tablet computers resulting from their touch interaction systems, many of these problems can be solved by using a digital counterpart of a pen, a stylus (Annett, 2014). It shares the same functionality with a pen by having a nib, in some cases an eraser and buttons.

A stylus makes use of fine motor controls to provide increased precision and accuracy compared to a finger (Cockburn, Ahlstrom, & Gutwin, 2008; Holzinger et al., 2008; Mackenzie, Sellen, and Buxton, 1990; Tu, Ren, & Zhai, 2012; Zambramski, 2011). The precision allows users to take notes and make sketches. Users can also write equations, create calligraphy, or sign their name in a more natural manner than doing it with a mouse and keyboard, because styli offer direct interaction with content instead of being physically separated (Brandl et al., 2008).

2.3.1. Passive stylus

Passive styli cannot be distinguished from the touch of a finger, by a tablet. In order to emulate a finger touch, they often have large nibs that are made of foam, rubber or plastic. These large nibs result in low precision in turn.

Due to the fact that passive styli do not contain electronic circuitry or sensors, it is not possible to obtain information about the exerted pressure, angle of the barrel or the position of the nib while hovering. (Buxton, 1990) They normally do not have barrel or eraser buttons which prevents the eraser functionality. On the other hand, there is a separate stylus class that make use of auxiliary channels like Bluetooth, which allows to relay button presses or pressure information. However, these styli cannot be distinguished from finger touch either.

2.3.2. Active stylus

It is possible to differentiate finger touch from stylus input using an active stylus. The differentiation is made possible via the signal multiplexing performed by a digitizer or through a separate, dedicated sensing array. The nib of a stylus is very thin; therefore, they allow for much higher resolutions than passive styli and more natural hand positions.

The electronic circuitry used in active styli provides increased input bandwidth and functionality with the inclusion of barrel buttons or force sensors. They can detect different levels of pressure; detect the position of the nib and its distance to the touchscreen while hovering, and the angle of the barrel.

CHAPTER 3

Design and Development of YazÇöz

The design combines what is technologically possible from a computer science perspective and an aesthetically pleasing and easy to use user interface specifically aimed towards children who, given their age, have lesser experience with technology. Design criteria are composed around this principal direction.

The application is developed with feedback obtained in two different hands-on assessments that took place in a medium size public school in Istanbul, with a year between. Twenty 1st grade students and 5 classroom teachers participated in the first assessment and 24 1st grade students and 6 classroom teachers participated in the second assessment. Application design is dramatically influenced by observed behaviors, taken feedback and gained information in these assessments. Results of these assessments are discussed in the Conclusion section.

Most of the 1st grade students are observed to be unfamiliar with rather common concepts such as login screens, menus, keyboard layouts etc. The application design considered these problems and came up with solutions wherever applicable.

The design of the material used by children heavily impacts their learning quality. A clear and fun design would both remove any need for previous technological experience and increase the quality of their study period. Thus, YazÇöz is designed with a beach theme, which is reflected by specially designed characters and its vivid color choices that fits the theme. This design replaced an initially contemplated design based on a classroom setting, which is later deemed as uninspiring and possibly a duplicate design for an educational application.

3.1. Tablet computer selection

For the first assessment, various tablet computers and styli were used for the optimal tablet and stylus selection process, as detailed in Table 3.1. In the first assessment, a non-controlled environment was provided for the students who were then observed while using tablet computers without any restrictions or instructions (e.g. the position they handled the stylus and tablet computers, the way they tried to solve the problems, etc.). Students also filled a questionnaire about what they liked or disliked in the application and the tablets.

For the tablet computer without its own stylus, a 3rd party passive stylus (See Figure 3.1 for an example) was used, which actually simulated hand touches. Therefore, the application couldn't differ the stylus input from hand input opposed to the other tablet computers. A special hand touch unlocked application was installed to this tablet computer.

Figure 3.1 An exemplary 3rd party passive stylus

Tablet Computer	Resolution	Stylus Type
Samsung Galaxy Note 10.1" – 2014 ed.	2560x1600	Built-in Active
Samsung Galaxy Note 10.1" – 2014 ed.	2560x1600	Built-in Active
Samsung Galaxy Note 10.1"	1280x800	Built-in Active
Asus Memopad 10"	1280x800	None (3rd Party Passive)

Table 3.1 Types of tablet computers used in first assessment

According to these observations and feedback, it was very clear that both the resolution of the tablet and its stylus support affected the experience of the users. It was clear that passive stylus was creating very negative experience. Two out of 5 students in fact discarded the pen in favor of finger writing once they figured they can write with their fingers in that particular tablet computer. Also, in order to prevent their hands and wrists touching the tablet, one third of the students handled the tablet computer in an unnatural way (e.g. trying to hold tablet computer with one hand while still based upon

the table and trying to write with other). The other two third laid down the tablet computer as a notebook as expected. Even though a fixed pen size was used in the application, students could still write larger or smaller compared to their classmates.

The resolution also affects both user experience and the handwriting recognizer's success. Lower resolution tablets (e.g. Figure 3.2) decreased the ability for students to do micro movements with the pen and resulted them writing in bigger letters. Furthermore, the recognizer performs worse in lower resolutions.

With the feedback gathered from classroom teachers and students, several design criteria are established. But most importantly, it was decided to use only the tablet computers with the highest resolution and active stylus support (Figure 3.3) for the remainder of the project in which this thesis was conducted.

Figure 3.2 Samsung Galaxy Note 10.1" with first iteration of the application
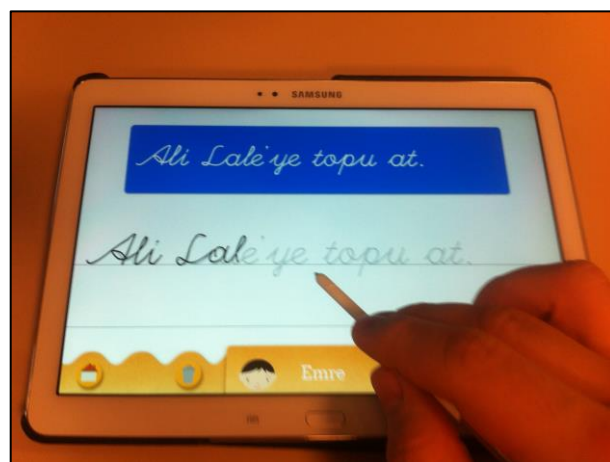

Figure 3.3 Samsung Galaxy Note 10.1" – 2014 ed. with near final iteration of the application

3.2. Login screen

The FATIH project equipped students in the project schools with their own tablet computers, yet for the developed application, two different tablet computer ownership scenarios were assumed, so as not to make an assumption.

In the first scenario, it is assumed that each student had their individual tablet computers. With this setting, each tablet computer could be linked with a student. This scenario also requires a stable internet connection for each student to download new questions and post their answers or results. Or the data exchange can be completed by connecting the tablet computer to a computer that already have this data available – which requires an established guideline to gather answers and distribute new questions. A computer software with the necessary features to be used in this scenario is developed as a side project.

The second scenario assumes that the tablet computers used for this purpose are not personal, but are shared among the classroom or the school. This assumption implies that there could be only one tablet or more, but not enough for every student. In order to accommodate this scenario, an account based identification process is necessary. The main concern in this scenario is the mapping of handwriting data to a particular user.

Given the age of our users, handle names and passwords were not suitable to use as an identification method. Therefore, different mechanisms where a user is identified with ease, were considered. Rather than using passwords, students were asked to write their names or school numbers, but majority of them did not actually had their number memorized. Some of the students tried to enter their full names instead of their first names as well.

When students hold a stylus in their hands, they tried to make every input with stylus, disregarding the fact that the tablet computer is a touch screen device. The developed software actually blocked hand touch input and only allowed stylus input in order to nullify accidental touches whilst holding tablet computer. Some of the students tried to write in the empty spaces in which a keyboard pop up is actually triggered when

touched, common to most applications in tablet computers. Even with a keyboard pop up, there were students that still tried to write in the empty spaces seen on screen.

Half of the test tablet computers were set to English language keyboard by default and this caused confusion. As shown in Figure 3.4, for one of the tablet computers, the Turkish keyboard setting did not have easily understandable buttons for some common words (e.g. For translation of the button with the text "OK", "Tmam" was used in place of "Tamam" because of space constraints of the button). Also, the keyboard was missing Turkish letters. Students that are not accustomed to a keyboard layout, mispronounced their names by using similar looking letters.

Figure 3.4 Turkish keyboard layout in one of the tablet computers

Lastly, a keyboard pops up from the bottom of the screen pushing the current application upwards in order for user to see their current input box, which results in an unfavorable sight shown in Figure 3.5.
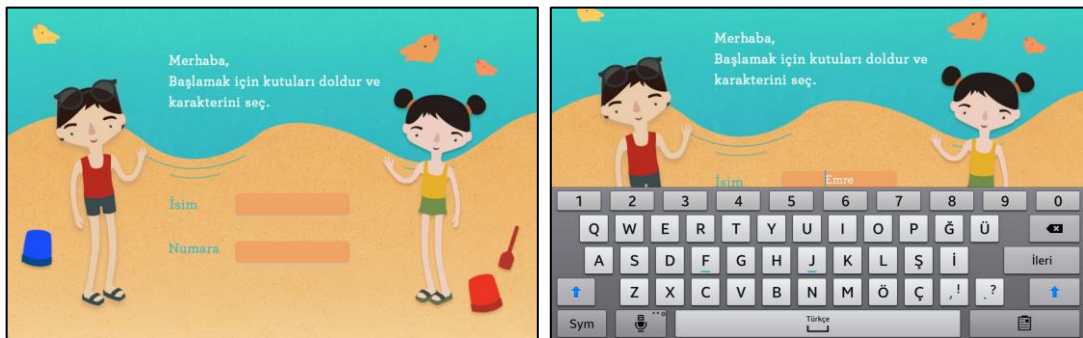

Figure 3.5 Login screen with name and number input. With keyboard popped up, screen is pushed upward, to show the text box on screen

Given all these observations, it was needed to remove any keyboard interaction from the software. On screen keyboard was only used in the login screen, so no other places were changed based on this new criterion.

In the second assessment, a new method for identification was tested. In that case, rather than typing, students were asked to write down their names with the stylus, as shown in Figure 3.6. The name input was also recognized, but it was possible for the recognizer to not successfully recognize the name, which would result in the system not being able to identify students.

Given that the tablet computers used has a front facing camera, we also considered to take a photograph of the student at the time of login operation; but when stylus came into use, students placed their tablet computers on the desk like a notebook as a habit, and therefore photographs could not actually capture the user of the tablet computer.

It is significant to note here that, identification of a student and categorization of the student's answers are necessary for a teacher to inspect the answers of the student and grade them if necessary. Even when the recognition software is incapable of correctly recognizing a student name, a teacher could identify the handwritten name of the students. Therefore, the login screen is finalized as seen in Figure 3.6 with just a request for handwritten first name of the student; and this name is saved as a separate image bundled with data, and placed into all questions in menu bar.

Figure 3.6 Login screen with just handwritten name input

3.3. Question screen

We aimed to devise a common interface that is sufficient to cover a large type of questions and easy to prepare by the teachers. With that purpose, question types in the first year Mathematics and Turkish books used in 2014-15 academic year were studied. Originally divided into 2 areas as language and mathematics (hence the name YazÇöz, meaning WriteSolve), these activity groups are further divided into their own modules. The activities are categorized under 4 different labels, which can be seen in Table 3.2. A screenshot of the module selection screen can be seen in Figure 3.7 and each particular module can be seen in Figure 3.8.

Arithmetic Exercises	Simple addition or subtraction problems
Mathematics Questions	Questions with pictures that is related to mathematical concepts, to be answered with handwritten words or numbers
Language Questions	Questions with pictures that is related to linguistic and common concepts, to be answered with handwritten words
Handwriting Exercises	Word and sentence cursive writing or tracing examples that also requires students to read cursive handwritten sentences

Table 3.2 Description of YazÇöz modules

Figure 3.7 YazÇöz module selection with some completed (green) modules

Figure 3.8 Modules of YazÇöz Clockwise starting top left: Cursive handwriting module, arithmetic operations module, mathematical questions module and Turkish questions module

Generally, for exercises both created in sheet and in applications, students are given boxes to enter their answers. Having the interface design limited with boxes as sole input areas does not have any advantages. Moreover, having answer boxes could result in interruption of input data when the writing goes out of bounds of the box. Furthermore, the recognition system in YazÇöz does not have to take location of the input into consideration. Therefore, we have decided to use the whole screen as the designated area to write the answers. Even though guiding lines are provided in order to give support to students for their handwriting, it is not mandatory to follow these guiding lines.

In all question pages, there is an explanation for the question at the top, followed below by a box where the question is prompted. If there is a picture related to the question, it is also shown in this box, as shown in Figure 3.8.

In order to promote reading cursive text and to parallel handwriting related books, the application uses a cursive font. With this, the question text is also separated from the other texts on the page.

3.3.1. Menu bar

It is aimed for all question screens to have similar usage scenario in order to not disrupt the accustomedness. A menu bar was prepared in order to hold both personal and question related information and buttons for control, which can be seen in Figure 3.9.

Similar to tablet computer's own buttons, these buttons (and also whole application screen) is implemented in such way that only stylus touches are working and hand touches are omitted. As a future design criterion, it is better to have this kind of menu bar above the screen rather than below since hand of the user blocks this area.

Figure 3.9 Menu bars with 2 different styles (Notice the extra button on first one)

When the tablet computer is placed on a table in order to use it like pen and paper, it is possible for a person's wrist to overlap the tablet computer's own buttons. Both in the assessments and over the development stages, it is observed that accidental touches to these buttons indeed happen. Although not suggested by Android, back button is disabled in the application in order to minimize these accidental touches. Therefore, menu bar has a Home button for navigating to the previous screen.

The application initially allowed to traverse freely between questions, but as observed during the first assessment, some students skipped questions accidentally. Therefore, a control mechanism was added for checking that there is input on each screen, before advancing to the next question.

The modules have a recognizer working as the underlying technology. Running a recognizer each time was time consuming, which is detailed in its own section (Chapter 4). Running the recognizer when the previous or next question button pressed locked the screen for a moment, therefore most of the users – not only the children – thought that the button was not pressed. Even though the buttons had suitable

animations in place to show that it was indeed pressed, these indications were not clear enough. Also, when the recognizer run, if the application advanced to another question quickly, the results of the recognition could not be seen as the screen would be iterated to a new question. Therefore, a check button was implemented in order to let the recognizer to do its task irrelevant to screen changing action.

An eraser button was implemented to clear areas by touch or by using stylus; but since the developed application uses online recognition methods, this resulted in handwritten data to be broken down. Therefore, the only option that could be added to question screens was to clear whole screen. Information regarding how students handled their errors will be detailed in the Assessment section.

3.3.2. Tracing and rewriting in cursive writing exercises

Traditional cursive writing exercises is the first module implemented, as it is the first thing that comes into mind when envisioning a handwriting-based application. As seen in Figure 3.10, the sentence to be written is shown on top, printed in cursive font, followed by a semi-transparent copy to trace over if wanted.

Although the users have freedom in where to write their inputs, in order to guide the users, ruling lines are added to the screen.
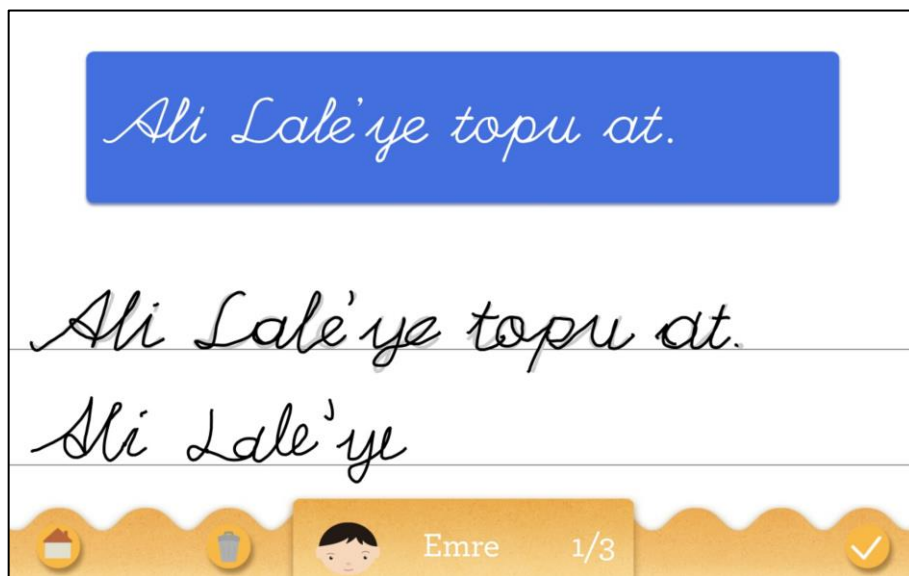

Figure 3.10 Cursive writing exercise design

3.3.3. Arithmetic exercise screen redesign

In the arithmetic exercises module, the students are asked to answer simple addition or subtraction questions. Initially, sticking with a uniform interface principle, this module was designed to have the same look as the other modules, with a box containing the question and lines for students to write their answers to. However, rather than asking the operation as a question, it is much clearer to fill the empty place near the equal sign.
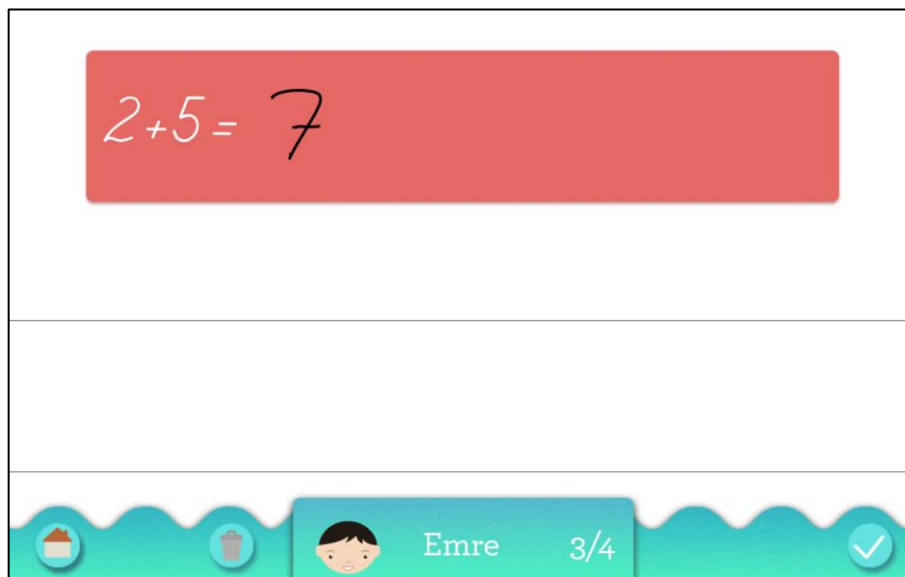

Figure 3.11 Initial design for arithmetic exercise

As seen in Figure 3.11, a lot of the space was wasted for this particular exercise, requiring a lot of page-turning between questions. Therefore, arithmetic exercises are redesigned to include 3 questions in each page, as shown in Figure 3.12, with guided students to write next to the equality sign, rather than entering their answers in random places.

Arithmetic exercise module is one of the modules that use the underlying handwriting recognizer. When the screen contains only one input, the whole handwritten data is sent to the recognizer. In the redesigned arithmetic module, where 3 questions appear on the screen at the same time, the handwriting data is split into three different data sets based on their starting points.

One problem with this particular design is about erasing. Since erasing was not a possibility, the user has to clear the whole screen, resulting in clearing all three inputs. This is especially problematic when only some of the answers are true and the user only wants to erase the wrong answer. A solution for this case is to introduce individual erase buttons for each of the three areas; however, since YazÇöz has a uniform design regarding buttons in all of the modules, this was not explicitly implemented. Adding an eraser may be considered in the future.
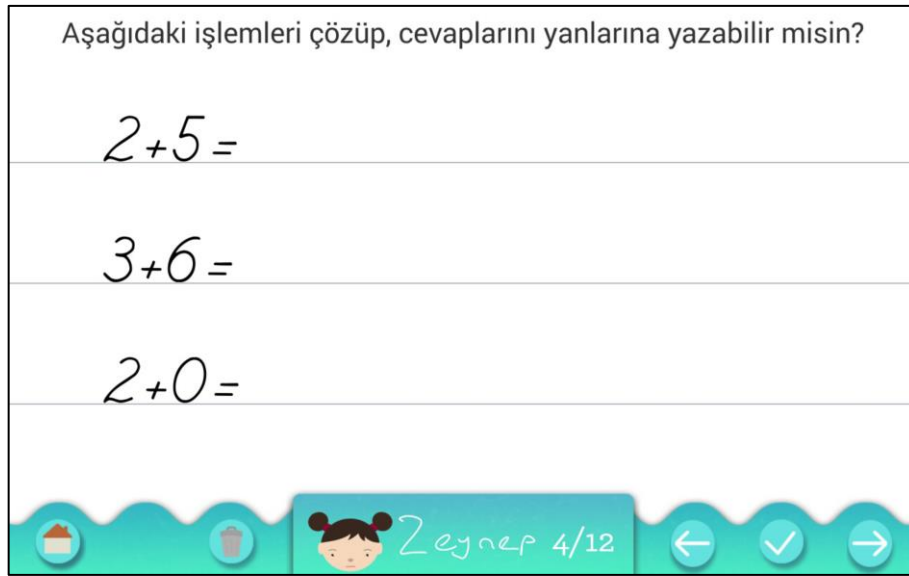

Figure 3.12 Final design for arithmetic exercise

3.3.4. Unexpected answer behaviors

As a design criterion, the application provides the entire screen for the answers to be written, with guiding lines that students can use, but do not have to. As a result of this freedom, some unexpected use cases were observed during the assessments.

Specifically, some questions with pictures may lead students to give their answers by circling an area on the picture, rather than writing the answers (e.g. Figure 3.13). Crossing the wrong answer or drawing arrows to the right answer were also among the observed behaviors. Similarly, some students tried to fit the answer right on the question (e.g. Figure 3.14). To fix this, a task description is placed uniformly on the top row.

Figure 3.13 Circling the answers

Figure 3.14 Fill in the blanks question answered in blank part

It is possible to write different yet correct answers to most of the questions. The most common occurrence observed in students was answering a mathematics question by using digits or words, sometimes with sentences. For the question "How many apples hanging on the tree?", all of the following answers were likely: "16", "Sixteen", "16 apples", "Sixteen apples" and "There are sixteen apples hanging on the tree" (see Figure 3.15 for examples). For such a question, in order for the recognition system to work, all possible answers have to be specified, which is infeasible. For close answers, we calibrated the recognizer to accept the answer, but since all alternatives could not be indicated, we removed the recognizer from the questions with picture modules.

Note that even without a recognizer, the system is at least as useful as filled textbook pages, as currently used in many schools. It can be seen as that the students are participants of an active written communication, where reading comprehension and ability to come up with thoughtful responses are developing. Also, animations can also be used in place of static images, where the questions can be related to occurrences of events that is hard to convey with static images.

Figure 3.15 Types of answers that could be accepted

3.4. Answers and feedback

In our first assessment of the application, a "Wrong Answer..." or "Right Answer!" message popped up when an answer is given, as seen in Figure 3.16. Its impact was more negative than speculated; false negative results (a right answer mistakenly labeled as wrong) resulted in the students doubting themselves and their answers. There were students who tried to erase and enter the same answer again until the recognition is correct. Even though the performance of the recognition engine was fairly high, it is indeed in the nature of using a recognition engine that having errors is possible. Therefore, the feedback messages were dropped from further consideration as alternatives were searched.
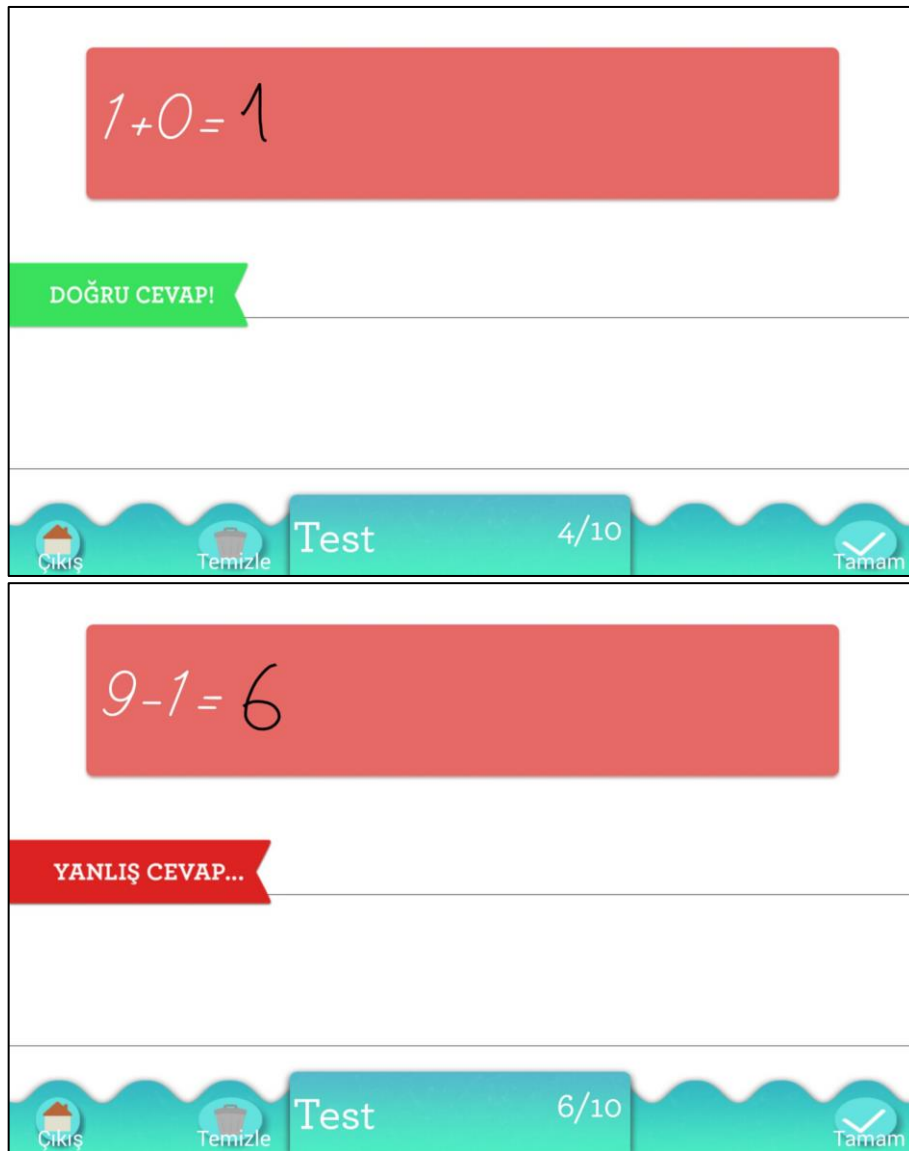
Figure 3.16 Answer feedback with "Right Answer!" and "Wrong Answer…" popups

As an alternative, giving feedback that was *fuzzier* in nature was considered. For this, a character icon showing a kid's face was devised. The icon was inserted next to the name below the screen with a facial emotion representing the confidence of the system about its recognition and correctness of the answer (See Figure 3.17). Four different facial emotion icons were designed and two different approaches for such a feedback were evaluated: per answer or cumulative. In the first one, the feedback was given after each answer, however as this was still error-prone; in the cumulative approach, the emotion was determined by the number of correct answers thus far, however, this method was not very responsive. In the final iteration, the kid icon starts fully smiling immediately after a right answer, and starts to frown with each wrong answer, and displays one of the middle emotions if the system is not confident about the correctness of the answer.

Figure 3.17 Kid icons with different facial expressions

As another alternative, the answers are colored green or red based on the recognition results without giving a clear right/wrong answer, as seen in Figure 3.18. This implementation is particularly essential for the arithmetic exercises module, in which there are 3 different questions and the kid icon's facial expression change cannot be clearly related to any single one of the answers.
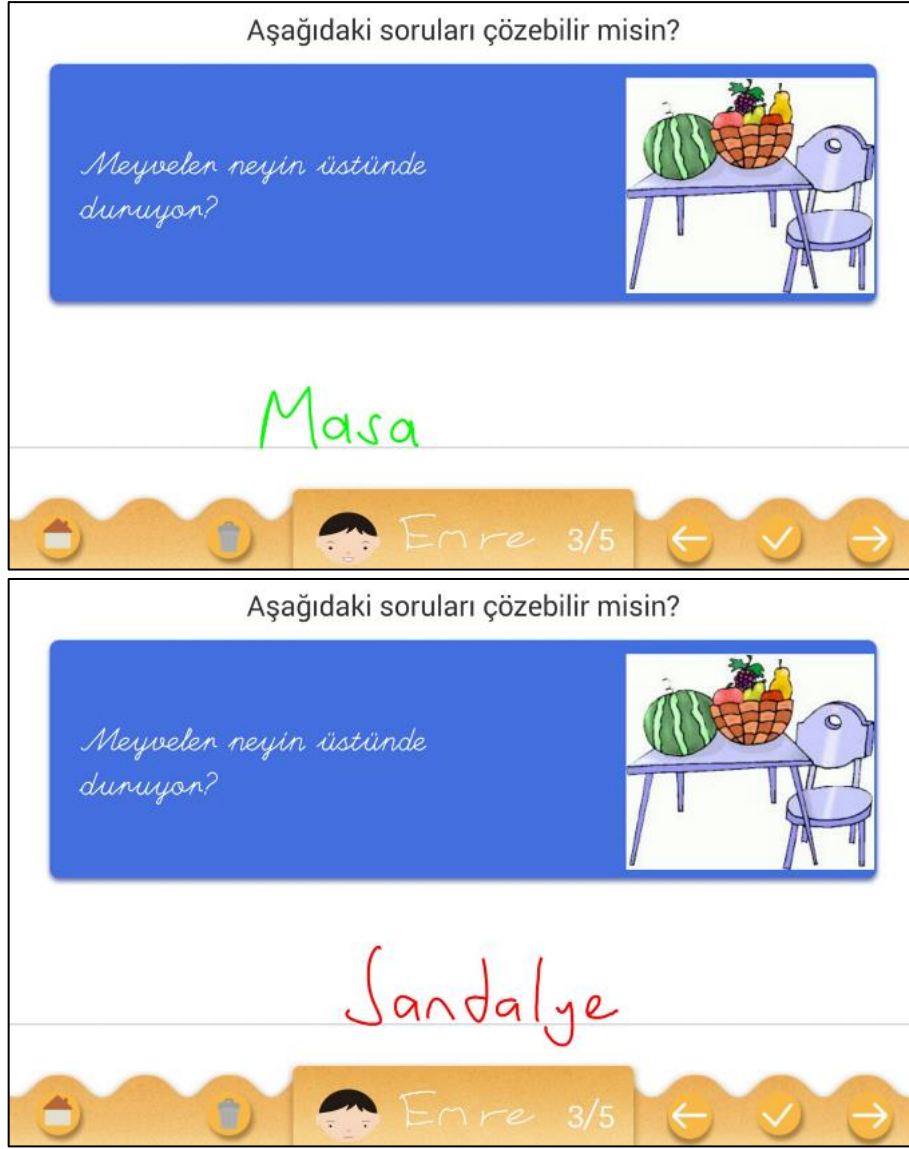
Figure 3.18 Colored inputs giving feedback whether they are right or wrong

An update was developed in order to expand the idea of users completing the missing parts of an arithmetic operation further. When an answer is entered, the input from the user is shifted to the side in order to complete the equation in screen. An already answered screen using this idea with right and wrong answers both colored, can be seen in Figure 3.19.

There are several problems regarding this previous implementation. The input was still erasable and therefore editable, but since the user now sees an either right or wrong completed equation, the design was not clear anymore. The shifting operation in this part was automated, so users are tempted to write their new inputs in the place of already shifted previous inputs (which is possibly erased), since right side of the equal

sign is also occupied. The font that is used for the application also similar to handwriting, therefore when colored like mentioned above, it was easier for an untrained eye to not grasp the situation on screen.
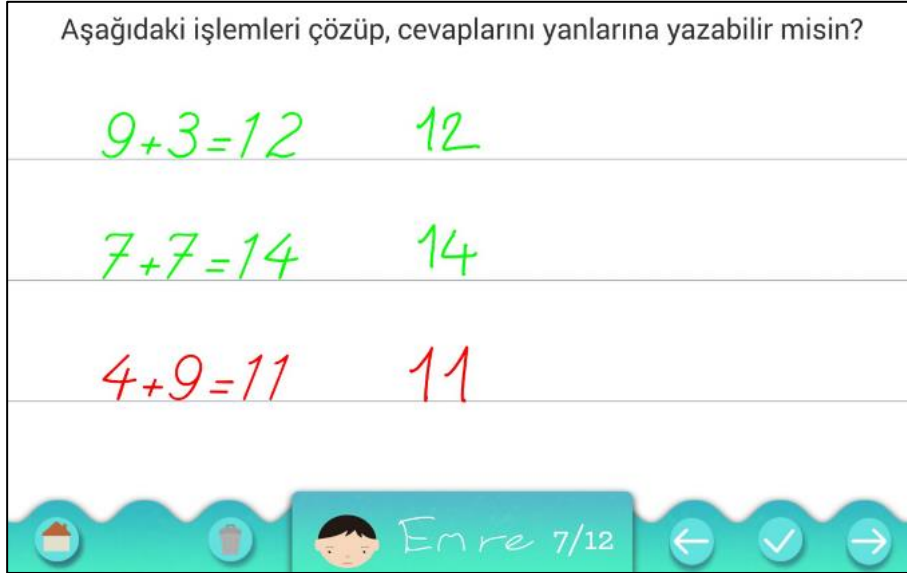
Figure 3.19 First iteration of the feedback in the arithmetic exercises module

One of the faults mentioned for the first iteration, the case where handwritten input and our font is similar, actually helped to form the next iteration. It is possible to complete the equation without any replacement operations and still ensured a satisfying look to the module screen. In the final form, the shifting operation is completely removed, and instead, the right answers are typed in a prompt-like looking font near each equation (See Figure 3.20). The coloring for the right and wrong answers stays the same.
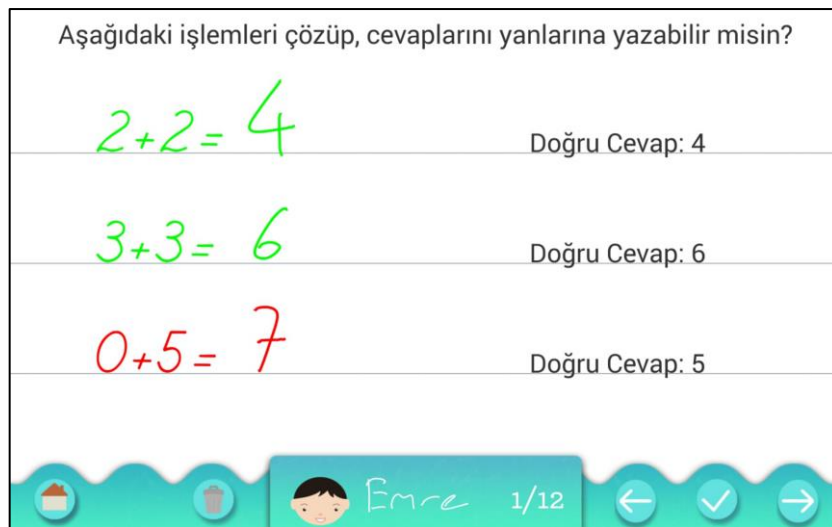
Figure 3.20 Final iteration of the feedback in the arithmetic exercises module

CHAPTER 4

Helper Applications

YazÇöz was developed in multiple iterations obtained from the two assessments, and was aimed to have concise and clear design through design criteria established at the beginning for the whole development process. Given these self-imposed limitations, structurally different helper applications were not implemented within the main application, but they were developed as separate applications. Content creation alternatives and grading are the main focus of these applications.

The applications are created within the capabilities offered by a tablet computer. They are created both as anticipated necessities and based on the received feedback and observations made. The target users are not the students for these application, but mainly teachers.

These helper applications are not thoroughly assessed like the main application, however they do provide some insight into the feasibility and practicality of these complementary actions that go with the main application.

4.1. Data collection application

A simple data gathering application was developed in order to collect handwritten word data from various users. Data obtained in this fashion used to train the classifier. Figure 4.1 shows a screen whilst data collection is in progress. The application also collects some personal information like age, gender, handedness and

previous tablet experience from the users, so as to measure performance of the recognizer on different user groups.

Figure 4.1 Data gathering application

4.2. Collecting exercises from textbooks

The modules in YazÇöz were designed by looking at activity books belonging to first grade curriculum. Content creation for the application was one of the main issues classroom teachers have voiced their opinions on. Some of the teachers had archives of printed out activities that is ready to be used, and indicated that they prefer using those rather than both getting used to tablet computers and making content available for them. Therefore, possibilities of digitalization these activity sheets by just using the tablet computer for quick preparation were analyzed.

A secondary application that takes a photo of the sheet to prepare it as an activity was developed. In detail, the sheet was first located inside the photo. To achieve this, camera of the OpenCV for Android library (OpenCV, 2016) is used. When a photograph is taken, the photograph is analyzed to find the biggest rectangular shape possible. Then, this rectangle is cropped and transformed into a single image that is in A4 size. Slight rotations and angular photos are also fixed with this transform, but the text may become blurry in that case. In the screenshots shown in Figure 4.2, the top part belongs to currently active camera; and when a photo is taken, contours surrounding the

largest found rectangle was shown in the left and generated final image is shown in the right for the below part.

Figure 4.2 Screenshots from the photograph part of the content creation application

This operation is most successful when the sheet and the surface it is residing upon had contrary colors. The algorithm itself is not automated, so the results had to be verified by human eye. Sometimes the rectangle could not be found or a much smaller part of the picture is labeled as the biggest rectangle. Different sheets and surfaces change the success rate dramatically, therefore it is not possible to come up with a general success rate. Changing the background surface for a particular sheet is generally the most plausible solution for successful rectangle search.

It is actually possible to skip the aforementioned step in this content creation application. Pictures found online or sheets that has been scanned can also be used for the later part of this application.

4.3. Specifying expected answers

The second step of this content creation application was to specify expected answers, if automatic grading is to be performed. It is aimed that this process can be used by a classroom teacher without any special training.

For some question types (e.g. arithmetic questions), specifying an answer is straightforward; however, for language related questions, sometimes the answer may include viable alternatives (synonyms etc.). After considering giving all possible answers as valid answers, it is concluded that specifying answers should be done only in straightforward cases.

Specifying the correct answer can be done most naturally by a teacher who solves the exercise on the tablet and record his/her recognized answers (See Figure 4.3). Alternatively, it can be entered using the keyboard.

Another difficulty is if the question page contains multiple questions. In that case, it is necessary to know which answer goes with which question. After considering bounding boxes for expected answer locations, we concluded that the best alternative is to match all the answers (separate handwritten parts) to questions by proximity. This can be implemented in relatively straightforward fashion, and may provide the best and most flexible solutions when the answers are not too close to each other.
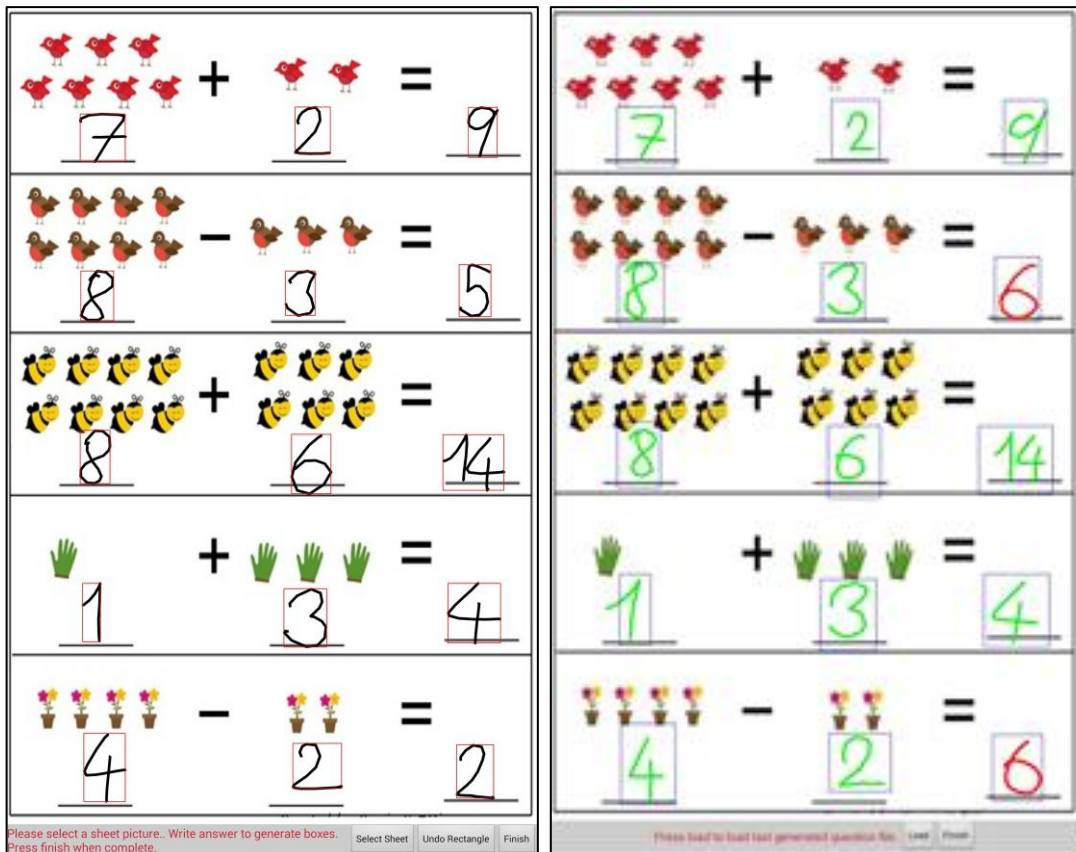
Figure 4.3 Answer specification with working recognizer

4.4. Content creation in tablet computer

In this application, the idea that an authorized user (e.g. a teacher, a parent) having ability to create content just with the tablet computer is evaluated. A simple interface for entering the questions is generated. Text in these interfaces follow a particular pattern in order to generate multiple questions.

These content is aimed to be used in writing exercises mostly. In one variation, each line consists of three words, where these 3 words would be separated for tracing and writing exercises. A single letter generating exercises for the whole page and automatically generated number writing examples are also experimented. Screenshots regarding these exercises can be seen in Figure 4.4.

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Figure 4.4 Content creation with tablet computer

Creating questions with pictures was more challenging compared to preparing this type of questions on a computer. Some pictures found online needed simple edits to become suitable. With having more experience in computer, it was more user-friendly to be able to prepare content on a computer rather than in tablet computer.

In the curriculum research, it has been observed that first grade students start with a couple of letters to structure their words, and then increase the letter count they are capable of reading and writing as they continue their schoolyear. For such an approach, to generate meaningful sentences, some examples include shapes or pictures. Finding and using pictures in question design was also possible, but required more workload as these shapes had to be clearly readable on text while being small. Creating content on tablet computer allowed an opportunity to experiment using emoji for this approach. There are thousands of custom created emoji and inclusion of those were not any different from using images. Hundreds of emoji was included in Unicode Standard in version 6.0 (ISO/IEC 10646:2010), which meant these could be stored as text and applicable in nearly all mobile platforms.

Figure 4.5 Using emoji in question text

A screenshot for using emoji in text can be seen in Figure 4.5. This experiment was done while the underlying recognizer hadn't been implemented yet. In order to use such a system; the system should be able to either bypass shapes in the sentences or be able to recognize these drawings and label them for the emoji counterparts.

4.5. Grading in tablet computer

An interface to check the exercises completed by the users on that specific tablet computer was added to YazÇöz. The design was for the answers would be directly plotted into question screens, and the buttons would be used for grading. As seen in Figure 4.6, each user's data is stored under their name they log on with; and also the answers are categorized by module.
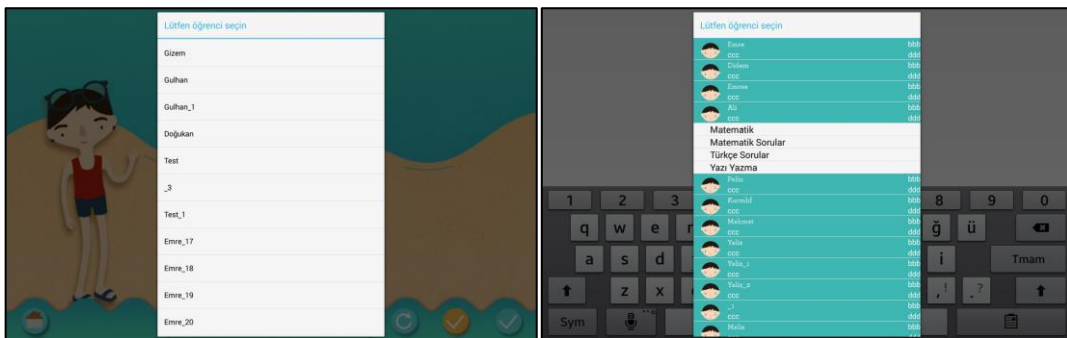
Figure 4.6 Categorization of current data for grading interface

Rather than selecting the answers one by one, a module is selected to bring up all answers in that module. Figure 4.7 shows a screenshot whilst grading in progress. Information regarding current question and owner of the answer is found below of the screen in menu bar, which is shown in detail in. By using buttons on the right, a question is noted as correct or wrong. Also, if the handwriting recognizer was implemented for the module, the recognition for the current question can be also shown in the menu bar.
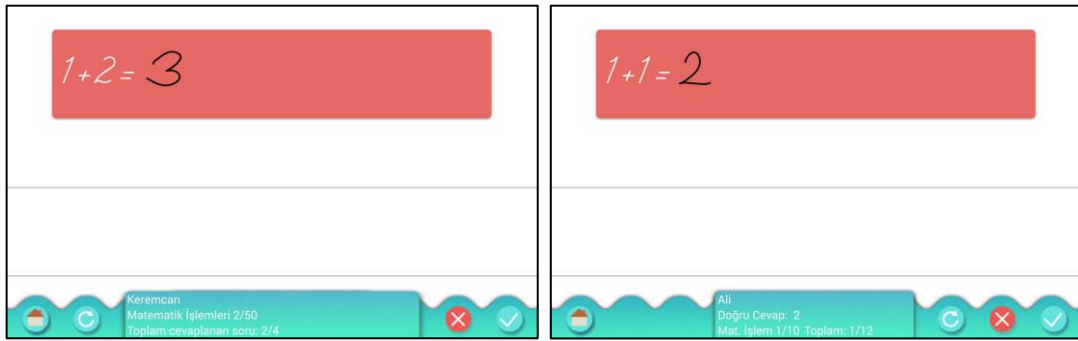
Figure 4.7 Grading an arithmetic question on tablet computer

After the grading is complete, it was devised to create a spreadsheet containing the grading information. But in order to handle the spreadsheets in this scenario, a computer becomes mandatory contradicting the need for this interface. Sending an email including both the questions and grades were also devised.

4.6. Teacher administration tool

Although both content creation and grading can be done on tablet computer only, both applications showed that an administration tool on computer were to be more practical and also more user friendly for the authorized users who are not technologically adept.

The software, dubbed as YazÇöz Öğretmen, requires a tablet computer to be connected to computer to work. After a connection is established, the software reads the currently available questions and answer data on tablet computer. For preparing questions; adding new ones, deleting older ones and editing them is possible. Since Android does not allow file editing on its own drive, temporary files are created for

these changes, and when the modifications are complete, these new files are replaced with the old ones. If recognition is allowed for the module, answers can – and should also be entered. Figure 4.8 shows screenshots from the content creation part for 2 different modules.

Similar to the interface created for the grading part of main application, grading in YazÇöz Öğretmen is also possible, which is shown in Figure 4.9. Inputs from the users are plotted to the question pictures, and authorized users can label these questions as correct or wrong. In the end, all grading information can be exported to a spreadsheet.
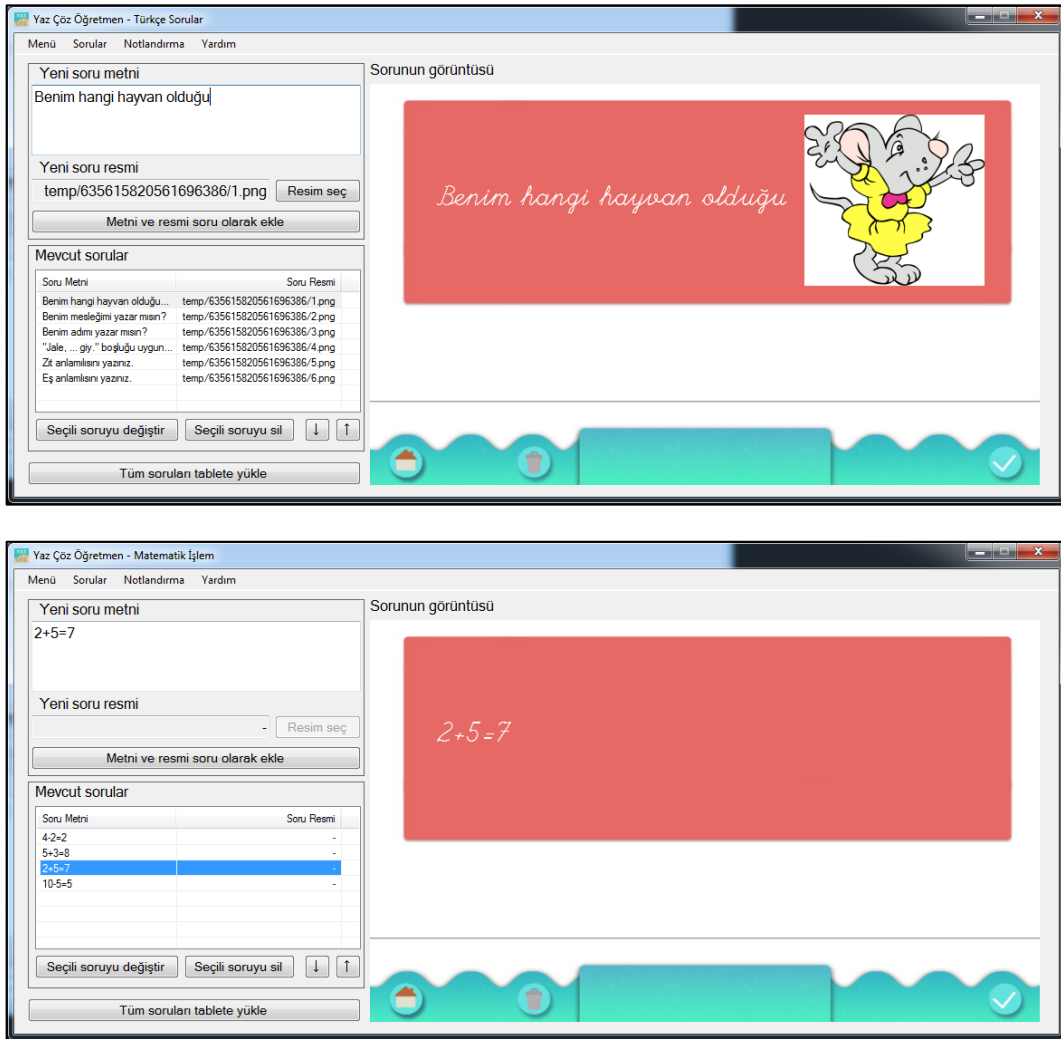
Figure 4.8 Content creation part of YazÇöz Öğretmen

While plotting is relatively simple, the resolution of the tablet computers was different. Therefore, to plot the data correctly, tablet resolution is also needed to calculate the placement. Also, plotted screenshot in computer differed from the tablet computer version to a degree. To remedy this, after exercise is answered, a screenshot is taken in application. A following iteration of this software used screenshots instead of plotting.
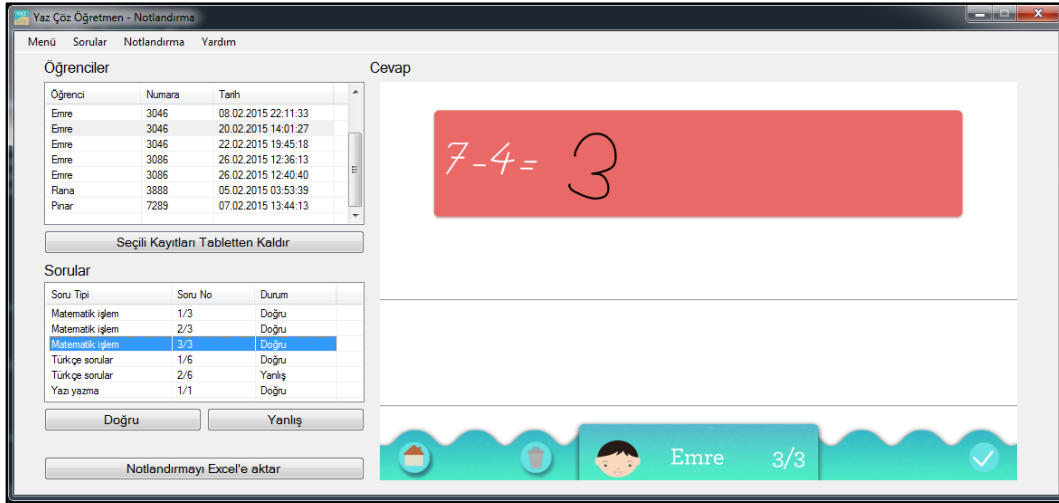
Figure 4.9 Grading part of YazÇöz Öğretmen

The software has been redesigned to have more similar look to the application. Usability remained same for the first iteration, which a sample screenshot is shown in Figure 4.10. The button cluster on the left side was identified as a problem, ergo it was tackled for the final iteration. The list on the left side of the screen is updated to use common computer usability patterns (e.g. double click to edit, press last item to add new…), and some of the buttons were removed in favor of a simpler design. Final look of the YazÇöz Öğretmen can be seen in a sample screenshot in Figure 4.11.

Figure 4.10 YazÇöz Öğretmen interface redesigned similar to the application

Figure 4.11 Final iteration for the YazÇöz Öğretmen software

CHAPTER 5

Technical Details

This section details some of the technical issues encountered whilst developing the application and implementation of the handwriting recognizer.

One particular challenge of implementation was the structural difference of a tablet computer from desktop computers, particularly in disk management. Tablet computers use Android only grants limited heap and stack sizes in order to keep the other applications in a semi-running state. Without native implementation, it is not possible for Android to dedicate all computational power to a single application. Therefore, additional steps regarding memory management were taken in course of application development.

Android also use Media Transfer Protocol (MTP) in its connection with computers, which allows no parallelism and works with only single operation at a time. Therefore, administrative software is also working relatively slow while connected to the computer for read/write operations.

5.1. Implementation of the handwriting recognizer

In this study, a separately developed handwriting recognition system was imported to the application. However, porting to the Android platform with its own limitations was a particularly challenging issue.

The HWR consists of two separate modules: one comprehensive system developed using HMMs and another system developed for recognizing digits (a much simpler task). The two systems were developed separately for speed and efficiency concerns, as well as starting with the arithmetic module immediately for the first assessment.

Figure 5.1 Custom debug view for displaying scores of classifications for digits

The application uses The Hidden Markov Model Toolkit for its recognizer. The Hidden Markov Model Toolkit (HTK) is a portable toolkit for building and manipulating hidden Markov models. HTK is primarily used for speech recognition research although it has been used for numerous other applications including research into speech synthesis, character recognition and DNA sequencing (HTK Speech Recognition Toolkit, 2016)

For its integration to Android, HTK was natively compiled into a library using Android NDK which allows using C/C++ native code in Android applications. HTK library was initially developed as a command line tool, where a new instance of the software ran with each command. HTK was included in the Android application as a library, therefore memory faults regarding initialization were observed, when HTK was tried to be used in the application more than once. Since source code was accessible, these initialization errors were fixed.

Performance of the recognizer was dependent of the number of words currently available for recognition, which are declared in dictionary files of the recognizer. It is possible for these dictionary files to be generated based on the questions loaded in the

modules. For digits, the recognition is done almost instantly. On the other hand, words could take a couple of seconds.

5.2. Structure of handwriting input data

For handwriting, default draw and canvas classes of Android were used. A special drawable view was created. This view class holds the information for when the stylus started touching the screen, where it was moved and when it was raised; with both time and x-y coordinate information. A sample from this data can be seen in Table 5.1.

[Down, 1207.7234, 1045.3539, 153756256, 153756256]
[Move, 1207.7234, 1045.3539, 153756262, 153756256]
[Move, 1210.4419, 1039.2081, 153756279, 153756256]
…
[Move, 1206.5414, 1045.472, 153756328, 153756256]
[Move, 1206.896, 1047.363, 153756328, 153756256]
[Up, 1209.6145, 1048.1903, 153756347, 153756256]

Table 5.1 Sample data for handwriting input

When an active stylus movement continues for some time, the line becomes jaggy and curves start becoming sharp ended. This is also true when there is a lot of drawing data to be plotted in each frame. This problem is encountered at most when a sentence is being written in YazÇöz. To reduce the number of data plotted in each frame, an algorithm has been devised. When a stylus movement is complete (Down, Move then Up), this movement is plotted into current drawing layer and the active drawing is reset. On the other hand, while clearing the screen is unaffected, this increases the cost of Undo operation, therefore it has not been implemented in the application.

CHAPTER 6

Assessments and Conclusion

6.1. Assessments

Assessments were conducted at a medium size public school in a metropolitan city. The two assessments had been conducted 1 year apart and in both assessments, the students were nearly at the end of their school year. Each classroom teacher participated in this study with heterogeneous group of students, selecting 4 students from different levels. No discrimination is done based on tablet experience, grades, personality or gender.

6.1.1. Preliminary Assessment

Preliminary assessment was conducted with 20 children and 5 classroom teachers. For this assessment, 4 tablet computers of 3 different technologies were used, which was detailed in a previous section. This assessment played a pivotal role in the selection of tablet computers.

18 of these children did not use tablet computers before. With this condition, even with the application being in the alpha state, students did not have any hard time navigating through the menus and using the application. It is deducted that easily understandable text and good visual clues negated the need of technological experience. Students in general loved using tablet computers and 14 students raised their opinion about preferring to use tablet computers instead of papers.

None of the teachers in this assessment owned or even used a tablet computer before. The teachers were surprised that their students were capable of using the tablet computer with ease. Observing their students' motivation, they emphasized that they would prefer the integration of tablet computers into their course plan if content is provided. Before the implementation, 3 of the 5 teachers did not have any idea about tablet computers could be used in classroom.

One of the teachers in this assessment raised her concerns about one of her students not being able to use tablet computer easily as her other students. This was expected, since the student in question was using the tablet computer with 3rd party stylus.

6.1.2. Second assessment

Second assessment was conducted with 24 children and 6 classroom teachers. For this assessment, 2 tablet computers of same brand and model were used, as the tablet computer preference was not explored in this phase of the study anymore.

20 out of 24 students stated they have used tablet computers before, and 18 of them stated they have one available in their houses. As stylus is not a familiar concept, 8 out of 24 students (7 of them owned a tablet computer) admitted they have a hard time using stylus with tablet computer. This time, 18 students said they preferred to use tablet computers instead of paper and pen. Again, the students generally loved using tablet computers.

Even with the application having more sophisticated look for its new iteration, students did not encounter with any hardships during the navigation of the application. This solidified the observations from the first assessment where clear design overruled the need for technological experience.

Half of the teachers in this assessment owned tablet computers, but ironically, none of them thought of using tablet computers in classroom before. More negative feedback was received in this assessment, as half of the teachers did not prefer using tablet computer in the classroom even after observing their students, by declaring the gain would be low.

A particularly interesting observation were, even with the grading tool prepared for this study, teachers generally preferred grading manually by looking at the answers themselves. They also complained about an educational content provision system for preparing examples, as they were even having hard time preparing content for their classrooms, adapting them to tablet computers were out of question. It was also stated that for the tablet computer, the content could be distributed in weekly packages rather than being question based.

6.1.3. Lessons learned from assessments

It has been observed that, in one year, previous experience with tablet computers increased dramatically for both students and teachers, validating the motivation of this study.

From our observations, the application was clear enough for all of the students to use it. After completing their first module, which also made them learn the buttons and how to use the pen; students easily completed the remaining modules without any need for help.

Most of the students could complete exercises on time and with high motivation, even though students showed a wide variation as to how accurate they completed the exercises, mostly paralleling their previous level of tablet use and academic standings.

Among the students, there were many children who still can't write clearly, therefore inputting unreadable text (e.g. Figure 6.1) even by the human eye. The children also had to be instructed (but not forced) to not use line breaks while entering their answers. When they realized that they can't erase their answers, they tried scratch over their faults and also tried to remedy their words and letters afterwards. All these actions actually make the input unrecognizable by our system. Even though the tablet computer is introduced as a notebook-like system, students should be made aware of the differences.

Figure 6.1 Bad handwriting of a student in the first assessment

Students were positive about using a tablet computer but without proper methods to analyze children, they were actually hazy with their verbal communication. The possible evaluation from the students would be listening their experience carefully. The success rate of the application could only be analyzed by looking through their educator's eyes.

One of the major concerns of the classroom teachers was content creation. Most of them requested for an application of this caliber to have previously prepared (and perhaps Ministry of Education approved) content in order to use it for teaching. Given that nearly all of the teachers participated in the study never used a tablet computer before, it is also possible for them not be able to use a computer efficiently enough to prepare content.

A general consensus was, even though a printed exercise could teach the same topic, a medium change by using a tablet computer were most welcome because tablets kept the students active and focused.

6.2. Future Work

In this thesis and in most of the research in the area, the content is based on currently available and accustomed exercise types; mimicking them in a sense. This approach should not be cast aside as it forms a familiar core of educational applications. However, for future applications, content should be structured around the capabilities of the tablet computer and should not be based only on what is common in the classroom.

Tablet computers can be used for concepts hard to visualize or not easily perceivable in classrooms. From primary school curriculum, course content such as solar systems, water cycle, plant genetics or body systems are exemplary suitable topics that can be illustrated and explained better with tablet computers, compared to the than stationary format of paper and books. Usage of gamification in education, which tablet computers are suitable for, is also a magnificent approach for increasing children's attention while learning.

The target group that was chosen in this study were 1st grade students with various academic levels. When academic levels are taken into consideration, applications can be used as idiosyncratic problem solvers or specially tailored augmentations, such as writing strokes in reverse order, as observed by some younger students.

For Android applications that would use many resources available in the tablet computer, a native approach from the beginning is necessary. If planned from the beginning, YazÇöz would be developed as a native application to have more support using the handwriting recognition algorithms. Also, possibilities of an application having ownership of all resources in the device by using custom OS or other plausible ways can be researched.

6.3. Contributions

In this thesis, a unique application designed to use handwriting recognition technologies was developed. Feedback from the students were very positive, despite cautious outlook of classroom teachers, who were mainly concerned with the extra time would be necessary, namely the design of content in this new format.

The success is not only achievement the creation, but the documentation of the design and implementation phases of this application. Several issues were tackled in a relatively new subset of a very studied area. Educational technology is rapidly evolving and in close future using computers will be taught to children as they learn writing. Lots of experimentation are carried out during this study, which allowed several iterations to be developed and also laid groundwork for future work.

Comprehensive evaluation was documented based on two different assessments with the target group of first grade students, unlike previous research in the area. From the observations, it can be deduced that the design for the application was very successful. Having clear navigation and being easy to use, it was used with ease by the majority of both students and teachers having little to no experience with tablet computers.

This study also proved wrong a misconception that a large-scale training is not essential for technological improvement in classrooms. New technology is easily understood when presented with a clear design, and could be incorporated easily into current curriculum given the resources are available.

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