



**FACULTY
OF INFORMATION
TECHNOLOGY
CTU IN PRAGUE**

ASSIGNMENT OF MASTER'S THESIS

Title: Application for enhancing cognitive and learning skills and encouraging speech development for children with communication impairment disability
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Study Programme: Informatics
Study Branch: Web and Software Engineering
Department: Department of Software Engineering
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Instructions

Analyze requirements and design an application for preschool children to encourage their speech development, decrease manifestation of communication impairment disability and improve cognitive skills in an enjoyable way. Implement a prototype and test the result with several target users.

1. Analyze by software engineering techniques- study of communication impairment disability,
 - collect user requirements,
 - find an appropriate digital device,
 - choose suitable technologies for implementation,
 - use cases.
2. Based on previous points design an application
 - wireframes,
 - design games/exercises,
 - design features based on target users' special needs and behaviour.
3. Implement a prototype of the designed application.
4. Test the prototype with target users (usability tests).

References

Will be provided by the supervisor.

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Prague February 22, 2019



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Master's thesis

**Application for enhancing cognitive and
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Department of Software Engineering

Supervisor: Ing. Jiří Chludil

February 14, 2020

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Declaration

I hereby declare that the presented thesis is my own work and that I have cited all sources of information in accordance with the Guideline for adhering to ethical principles when elaborating an academic final thesis.

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In Prague on February 14, 2020

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Abstrakt

Tato diplomová práce je zaměřena na návrh zábavné aplikace uzpůsobené předškolním dětem s narušenou komunikační schopností. Cílem aplikace je zlepšit kognitivní a učební dovednosti dětí a podpořit jejich rozvoj řeči. V průběhu této diplomové práce se moje zaměření zúžilo především na předškolní děti s vývojovou dysfázií. Práce zkoumá možná omezení z pohledu softwarového vývoje, analyzuje a navrhuje potřebné softwarové řešení: konečnou aplikaci - hru, včetně seznamu specifických nápadů (většinou UX/UI), které pomáhají přizpůsobit hru tak, aby lépe vyhovovala dětem s vývojovou dysfázií.

Výsledkem je funkční prototyp hry a uživatelské testování prototypu předškolními dětmi s vývojovou dysfázií i bez vývojové dysfázie a učitelkami z mateřské školy.

Klíčová slova vývojová dysfázie, narušená komunikační schopnost, návrh uživatelského rozhraní, vzdělávání dětí, vývoj her, REST, Unity, OS Android, Procreate, tablet

Abstract

This thesis is focused on how to design an entertaining application adjusted for preschool children with communication impairment disability, to enhance children's cognitive and learning skills and encourage speech development. During the work on this thesis, the focus narrowed, especially on preschool children with developmental dysphasia. The thesis analyses possible constraints from the view of software development, analyses appropriate software solutions and designs the final application - game, including the collection of specific features (mostly UX/UI) helping to adjust the game to suit better to children with developmental dysphasia.

The outcome is a functional game prototype. Usability testing of the game prototype was done by preschool children with and without developmental dysphasia and by teachers from kindergarten.

Keywords developmental dysphasia, communication impairment disability, user interface design, children education, game development, REST, Unity, OS Android, Procreate, tablet

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Introduction

When creating a user-centered software of high quality, there is a need to start with good analysis and design of the desired result. In the software development sphere, it means to actively communicate with clients, discuss with them and find the best possible way together. From the view of psychology and management, the group of clients and target users can be most easily categorized and generalized by their focus and activities. The steps of the whole process of analysis and design for mainstream may have a lot in common and it makes the procedure much easier.

But what if the target group, our clients, significantly deviates from the mainstream? How does it influence the process of analysis and design of the software?

There are many groups of the population with special needs. They think differently or have limited possibilities due to some kind of disabilities or disorders, such as visual impairment, hearing impairment, physical disabilities, mental disorders and so on. They need adjustments in the final software product in different ways. For some of those groups, there exists specialized compensatory software and tools to help those people to use digital devices and their contents as well. However, there is never enough of the compensatory software: there is always a room to come out with innovations and new ideas, as the possibilities of information technologies go forward.

During my master's study, I spent one year as an exchange student at National Cheng Kung University in Taiwan. Besides others, I was attending a class Seminar on Language Disorders in Children just out of curiosity. And that was the point, where my passion for the topic of this thesis began. In this thesis, I would like to focus on software development for one of the groups of people with special needs - for children with developmental dysphasia as my target users group. It may be a big challenge for a software developer without knowledge of psychology, speech therapy, pedagogy, other related studies, and

the limited possibilities of using the standard process of software analysis. Because of those reasons, I devoted the first chapter to the introduction to the problems of children with developmental dysphasia that I would like to focus on in this thesis.

Goal

The goal of my thesis is to figure out how to design educational and entertaining software for children with developmental dysphasia by using software engineering techniques. The application is intended to be used at any time without the need for supervision by a professional speech therapist. I would like to mention it is not intended to substitute professional care but to serve as a complementary tool to use in free time or as a reward.

The aim of the analysis chapter 1 is an introduction to communication impairment disability, collection of functional and non-functional requirements, and finding a suitable digital device and platform.

The aim of the design chapter 3 is to describe the application by a collection of wireframes, the content of the application, and by a set of special features to adjust the application for children with communication impairment disability.

The output of this thesis will be an implemented functioning prototype of the application 4, and evaluation of prototype usability testing 5 by children with developmental dysphasia, without developmental dysphasia and by teachers.

Analysis I

In this chapter, I would like to introduce readers to other fields than information technology (IT), as my thesis, transcends standard IT scope and connects it with additional multiple fields, especially speech therapy, psychology, and pedagogy. This chapter is important for understanding the rest of this thesis. As some terms in this chapter may be new for some readers, I prepared glossary B, where all specific terms used in this thesis are listed and explained.

I will first briefly introduce the communication impairment disability and how I selected the target group for this thesis.

1.1 Communication impairment disability

Every human being needs to have essential communication skills, it is the most significant tool for interaction with other people in society. [4] However, the path to developing communication skills and to communicate with others may be more difficult for some individuals due to communication impairment disability. The communication skills then may not develop as expected, which can have an impact on all aspects of future life and an individual's well-being. [5]

It may be one of the symptoms or consequences of another associated developmental disorder or disability, such as Attention-Deficit/Hyperactivity Disorder (ADD/ADHD), selective mutism, developmental dysphasia, childhood apraxia of speech, dysarthria, alalia, autism spectrum disorder, intellectual disability, hearing impairment, etc. (the short description of all of them is in the glossary B) [6], [7], [8], [9], [10], [11], [12]. I listed the disorders and disabilities that may manifest as delayed speech, moreover they may share the similar symptoms in the early stages of developmental disorder. That is the reason to use differential diagnostic: a systematic diagnostic method helping to identify the presence of one condition and excluding the presence of its multiple alternatives. It includes diverse testing methods which are not subject of this thesis and I will not mention them further. The communi-

communication impairment disability affects a person as a whole. Not only does it influence communication skills but can impact also cognitive area, emotional area, social area, and other areas. The therapy should be focused on overall development.

1.2 Target group selection

During my exchange study at National Cheng Kung University in Tainan, I had an opportunity to attend a class Seminar on Language Disorders in Children. There I was working on a semestral project about the analysis and design of a mobile application for mitigation of echolalia in children with autism spectrum disorder (echolalia is the meaningless repetition of another person's spoken word). From the beginning, I was focusing on how to give a useful tool to parents, teachers, and therapists that would help to develop diverse skills of childrens, especially their communication skills. However, my target group was not so clear from the beginning, and it changed twice during my work on this thesis.

My first intention was to fully focus in this thesis only on preschool children with autism spectrum disorder (ASD) as my target group, also because of my previous experience with a few children with ASD. Then I added preschool children with developmental dysphasia and intellectual disability to the target group, because I was convinced those three conditions are similar in children of an early age and so the intervention approach to these children would be the same. However, I got a very heterogeneous group, complicated to understand and to define, exceeding my possibility to deeply and sufficiently understand all the needs of each individual from the group, especially because autism spectrum disorder is very complicated in itself. So, in the end, after consultation with professionals, I decided to narrow my focus only to preschool children with developmental dysphasia, as the manifestation may be mistaken with children with ASD for its similarities. It is well documented and better-known in comparison with the other two conditions, and easier for me to react on with the software engineering methods.

In next section, I am describing the brain functioning, and why I decided to include only preschool children in my target group, and introduction to senses.

1.3 Brain functioning

In this section, I would like to clarify the reason why I decided to exclude adults and limit my target group only to preschool children.

At birth, children already have up to about 100 billion neurons; these are all of the neurons they will ever have. [13] During the first five years of a child's life, their minds are the most receptive to learning new things

and skills, their brain experiences a burst of synapses (connections among neurons) formation. [14] About 90% of the child's brain and nervous system is developed during this time period, the peak is around a third year of life. The synapses are formed faster than at any other time in their life, enhancing rapid development and learning, although the stages are affected by genetic factors. [15], [16]. It may be harder to form essential synapses later in life. [17]

The development of each human brain is a lifelong complex process; however, not only the body has a developmental and aging period but the brain also goes through an aging process. The brain's cognitive processes and cross-sectional brain functions tend to begin slowing down in healthy and educated adults in their late twenties due to synapses deterioration. It is called as age-related cognitive decline and cross-sectional age-related decline, which increases with the higher age. [18], [19], [20] On the other hand, it does not impact our intelligence, the postadolescent development may be broadened by new experiences, advanced education, social relationships, etc. [21] The memory and ability to learn new skills and general knowledge skills may increase until at least 60 years old. [22], [23]

These are the reasons why it is so important and most appropriate to start developing and strengthening the child's core life skills such as cognitive, communicative, physical and social skills from the earliest years, to secure child's future overall health, cognitive development, mental functioning, and well-being. [24], [25], [26] Early intervention is all the more important for children with delayed development for the same reasons. [27]

I was thinking of how to get readers familiar with all the crucial information, that is discussed and subsequently worked within all the areas of this thesis. I decided to describe disorders and symptoms using the terms and examples from the IT world, to make connections between a few different fields of study. The following chapter maps brain functioning to computer functioning.

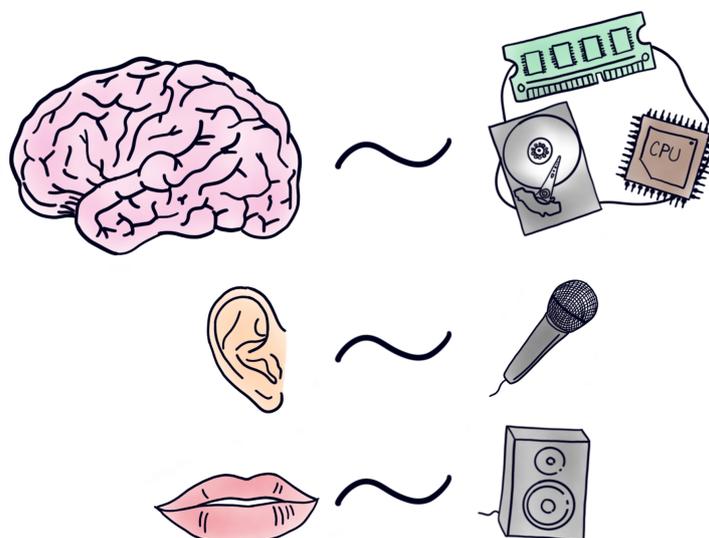
It is followed by a small introduction to the senses and a detailed chapter about developmental dysphasia 1.4 and its types. The chapter is very detailed, because it is very important to get to know the end-users for my application and what their weaknesses are in development, so I can adjust the application to their needs. It is a key chapter in the theoretical part of this thesis.

1.3.1 Brain vs computer

Some people are convinced that computers resemble humans and vice versa. We can use this for better imagination through a few examples. Some of the functions of a human may be mapped to functions of computer and its peripherals in a simplified way (with a bit of an exaggeration) to describe some thoughts in the following sections.

The central processing unit (CPU) is often called a computer brain as it has some functions similar to a human brain. CPU works together with memory as a team. We can classify short-term memory as Random-access memory (RAM), as it enables recalling immediate actions. [28] Long-term memory can be viewed as a hard drive (HDD). Speaker (or any other output device) may represent a mouth and a microphone (or any other input device) may represent an ear.

And how does the brain get and process the data? I explain it by an example on audio inputs. The sound is a wave; it can be gathered from the environment by a microphone: the diaphragm in the microphone moves as the sound waves hit it. Then, there are a few steps of sound transformation to a small electrical current. The cable connecting the microphone as an input device to the computer then transfers the information as a stream of data. [29], [30] The ear has similar functionality, the sounds are gathered by our outer ear, followed by a few steps of sound transformations in the ear ending with the creation of electrical impulses by the cochlea. There is an auditory nerve, a cable which links ear to the brain, that transfers those electrical impulses. Decoding the input information, evaluating the content, and processing it is now up to the CPU and the brain. The input information can be processed into some output action, it can be stored to short-term memory (RAM), or long-term memory (HDD) or it can be completely forgotten.



1.3.2 Senses

The brain receives information from all of our five senses. The sensory system sends signals to a part of the brain called the thalamus. Thalamus, located in

the cerebral cortex, is responsible for mediation sensation (except olfaction - a sense of smell) to the relevant cortical area, organizing and composing them into one coherent experience called sensory integration. [31], [32]

Out of all five senses, vision is the dominant sense. With eyes, we collect useful visual informations (about 80% of our perception); learning, cognition, and activities are mediated through vision. [33], [34] The second most important sense is the sense of hearing. [35] Those two senses are the most needed for interaction with any digital device. Exercising senses improves cognitive processes; however, the senses are just a gateway to our brain, which is responsible for the whole information process.

1.4 Developmental Dysphasia

Developmental dysphasia, also called developmental aphasia, is a speech disorder of neurodevelopmental origin that develops in children during prenatal, perinatal, and postnatal development up to 1 year old. [36], [37], [38] It is a condition where a child has an impaired the speech reception or impairment in developing and producing speech (speech expression) even if the surrounding conditions for speech expression and reception are optimal. [39]

The developmental dysphasia is needed to be diagnosed as a whole, in all areas of the development. It is important to exclude other possible similar disabilities and disorders with the usage of differential diagnostic.

That means hearing impairment, motor-speech impairment, mental disorders, and personality disorder are excluded. There is a lack of ability of the brain and central nervous system to correctly process visual and sound/speech signals. [40] It mostly goes hand in hand with speech delay and is one of the most common childhood learning disorders, affecting approximately 7 to 8 percent of preschool children. [41]

Besides communication skills, developmental dysphasia affects a person as a whole: his/her development is uneven. The perception in children with developmental dysphasia works a little bit differently, especially in the following: visual perception, auditory perception, motor skills, space and time orientation, and memory. I am writing about them more in the following chapter 1.4.5. Developmental dysphasia does not affect intellectual capabilities. It is treatable, but not curable. However, it continuously evolves and may mitigate throughout the life. [42]

As I introduced in the chapter about brain vs computer in 1.3.1, we can imagine developmental dysphasia as a problem of CPU decoding, processing, or encoding the binary data that it receives or sends to input/output devices. Both input and output devices work correctly as does the cable connecting the device to the computer. The result of the broken data sent to the output device may lead to an unexpected output, even if there is no hardware or software issue with the output device. The reason for incorrect processing by

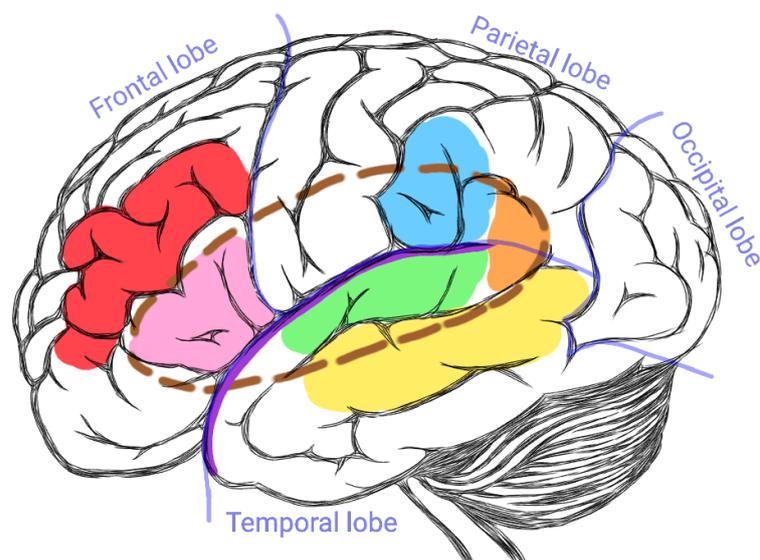


Figure 1.1: Basic functional neuroanatomy of brain areas associated to dysphasia

purple line - Sylvian fissure

pink area - Broca's area, inferior frontal lobe (Expressive dysphasia)

green area - Wernicke's area, superior temporal lobe (Receptive dysphasia)

blue area - supramarginal lobe (Conduction dysphasia)

orange area - angular lobe (Anomic dysphasia)

yellow area - middle temporal lobe (Transcortical sensory dysphasia)

red area - anterior superior frontal lobe (Transcortical motor dysphasia)

brown oval - Mixed dysphasia area

For drawing and completing this image, the following sources were used: [44], [45], [46], [47], [48], [49]

the CPU may have several causes, based on which part of the CPU does not work properly. Let's take a look at which parts are in the brain and what their incorrect functioning causes.

The brain area responsible for speech reception and expression is called the perisylvian language area, which is in the vicinity of the Sylvian fissure in the dominant hemisphere (usually left hemisphere), shown as a purple line in figure 1.1. [43].

The symptoms of developmental dysphasia vary based on the region of the perisylvian language area that was affected [39]. We categorize the following:

1.4.1 Receptive Dysphasia

Receptive dysphasia, also called fluent dysphasia and Wernicke's dysphasia, affects reception and speech comprehension due to a dysfunction of a part

of the brain called Wernicke's area. This area is located in the posterior superior temporal lobe in the dominant cerebral hemisphere (usually the left hemisphere), shown as a green area in figure 1.1.

The individuals are able to listen to utterances and sounds fully, but may have issues understanding speech. The situation of individuals with Wernicke's dysphasia can be interpreted as being in a foreign language environment without the ability to understand the language and culture. [39]

They may be capable of speaking fluently and may have excellent articulation; however, they make no sense and usually are unaware that no one is able to understand them. [50] Their utterance consists of nonsensical or irrelevant words and phrases, unintended syllables and/or word order mismatch, called paraphasia (described below). [51], [52]

In IT terminology from chapter 1.3.1, receptive dysphasia may be interpreted as an inability to decode information from an input device by the CPU correctly. The input device, such as the microphone, catches the input accurately and sends correct data to the CPU, but the CPU has issues decoding it. It may receive incomplete data, data with switched bites (paraphasia), decode the data partially, or it may not be able to decode the data at all. Then, it is obvious the CPU may consequently send distorted data to the output device because it has them incomplete from processing inputs.

Paraphasia

Paraphasia may be explained as a production of unintended words. We differentiate three types of paraphasias - phonemic, verbal and neologistic paraphasia.

Phonemic paraphasia, also known as literal paraphasia, may appear as the syllable substitution, addition, speech sounds rearrangement, syllables switching or compound words creation reversal. The intended word can be still identified and more than half of the intended word is usually produced correctly, such as pike/pipe, stable/table, lanana/banana, markbook/bookmark, tevilesion/television etc. [53], [54]

Verbal paraphasia is identified as a semantic replacement of the intended word with another (usually associated) real word, such as wife/husband, talking/hearing, etc. [55]

Neologistic paraphasias is substitution of some words with a non-existing, gibberish words that are combined randomly. More than half of the intended word is produced incorrectly, such as planker/comb, pinwad/light, etc. [55]

1.4.2 Expressive Dysphasia

Expressive dysphasia, also called nonfluent dysphasia and Broca's dysphasia, involves affection to a part of the brain known as Broca's area, which is situ-

ated in an inferior frontal lobe in the dominant cerebral hemisphere (usually the left hemisphere), shown as a pink area in figure 1.1.

Individuals with expressive dysphasia have difficulties expressing themselves through speaking, some may not even be able to speak or communicate verbally at all, including the ones with clear thoughts. [39] Individuals may have issues with articulation and word ordering while forming words and sentences. Sometimes, they may accidentally use opposite words. Their utterance is generally nonfluent, consisting of a single word or short, simple, and poor sentences with the usage of agrammatism, which is described below. They often understand speech well, especially the sentences with simple grammatical structure. They are able to follow simple instructions.

Some of the individuals fully realize their speaking disability, which can cause them a feeling of apprehension, stress, and hopelessness.

Using IT terminology from chapter 1.3.1, we can imagine expressive dysphasia as a problem of a CPU with processing and encoding the data it sends to the output device. The output device only presents received data, so the final output is incorrect and it may be misunderstood as a broken output device. It is a milder form compared to receptive dysphasia, as the processing and decoding of the input information and storing correct data to memory stays intact.

Agrammatism

Agrammatism is characterized as an inability to construct words in grammatical sequence to form phrases and sentences. [56], [57] Individuals use mainly fill words with lack of function, affixes, limited active vocabulary and limited content. [58], [59] Agrammatic speech is thought to be largely connected with Broca's dysphasia, but people with other types of dysphasia may be agrammatic too. [60], [61]

1.4.3 Mixed Dysphasia

Mixed dysphasia, also known as Global dysphasia, is a severe form of dysphasia and the most common type of dysphasia. [50] The individuals have symptoms of both expressive and receptive skills. [39] Multiple parts of the brain situated inside the brown oval shown in figure 1.1 are affected during mixed dysphasia.

1.4.4 Other types of dysphasia

We differentiate a few other types of dysphasia, such as Conduction dysphasia, Anomic dysphasia, and Transcortical dysphasia, which are considered as acquired types of dysphasia due to brain trauma or injury, genetic causes are rare. [62]

1.4.4.1 Conduction dysphasia

Conduction dysphasia, also called associative dysphasia, is a receptive type of dysphasia. Although this dysphasia is considered as an acquired disorder due to brain defect, co-called developmental conduction dysphasia can be a result of neonatal stroke (during the first month after birth). [63] It is characterised by poor speech repetition ability and poor object naming ability due to affected Wernicke's area (green area in figure 1.1) and/or supramarginal gyrus, the blue area in figure 1.1. Comprehension is intact and speech production is fluent; however, there is an occurrence of paraphasia and difficulties with repeating utterances.

1.4.4.2 Anomic dysphasia

Anomic dysphasia is a mild type of expressive dysphasia. It causes difficulties in retrieving specific words, especially nouns and verbs. Some levels of anomia may be one of the symptoms in all of the dysphasia types. [64], [65] Individuals use gestures, substitutions, or roundabout descriptions. [51] The cause is affection to various parts of the parietal lobe or the temporal lobe, shown as an orange area in figure 1.1. [66]

1.4.4.3 Transcortical dysphasia

There are three types of transcortical dysphasia - sensory, motor and mixed.

Sensory transcortical dysphasia is similar to receptive dysphasia, except for an ability to repeat words and questions instead of answering them, it is called echolalia (meaningless repetition of another person's spoken words). The affected part of the brain is in the temporal lobe, usually the middle temporal lobe shown as a yellow area in figure 1.1 [67].

Motor dysphasia shows off poor spontaneous speech even when the individual is able to repeat long utterances and has good auditory comprehension. [68] The affect is in an anterior superior frontal lobe of the dominant hemisphere, shown as red part in figure 1.1.

Mixed transcortical dysphasia is a combination of sensory and motor transcortical dysphasia.

1.4.5 Other symptoms of dysphasia

In the previous chapter, I described developmental dysphasia's symptoms of speech reception and speech expression. Beside speech delay and difficulties in producing and understanding speech, developmental dysphasia may affect even other areas with diverse intensity: it causes overall uneven development. It may have an effect on visual perception, auditory perception, motor skills, time and space orientation, memory, etc. [69], [70] Those areas are usually not as seriously affected as speech reception and expression area is. Still, I

would like to describe them, as it is indispensable to support their growth in children with developmental dysphasia to support overall development, to lead up to successful therapy. The following resources were used: [70], [71], [38], [69], [72], [73].

1.4.5.1 Visual perception

The possible difficulties are summarised in the following areas:

- Visual-motoric coordination
Possible difficulties in coordination of visual perception and graphomotor movement.
- Shape and colors
Children with developmental dysphasia may have difficulties with distinguishing colors and shapes. Practising distinguishing shapes and colors and recalling them may take some time.
- Position in space, figure-ground perception
Basic transformation, rotation, mirroring, or a multiplication of the same object or using a different color of the object may cause confusion, children have a poor ability of differentiation. It correlates with the difficulties in distinguishing foreground from the background on images or in space, especially on complex images with several objects.
It may be hard to understand abstract visual forms and visual closure (to imagine a missing piece in an image).

1.4.5.2 Auditory perception

Children may have issues to discriminate phonemes, syllables, similar words, to process the spoken information, save it, and load it from memory. There may be some latency in processing information. It may be difficult to split a word to syllables or phonemes and also to merge syllables and phonemes to full words. Rhythmic structures and melodies are usually repeated insufficiently. Music is, however, well accepted by most of the children with developmental dysphasia.

1.4.5.3 Motor and graphomotor skills

The speech motor level correlates with overall motor level. We differentiate motor skills to speech motor, motor, and graphomotor skills. The discrepancies and delays may manifest as uncoordinated movements difficult to plan and control, called dyspraxia. The possible difficulties are summarised in the three areas.

- Gross motor

Difficulties involving movements of large muscles of the arms, legs and torso in both dynamic and static coordination, such as standing on one foot, jumping with both feet, coordinating movements of hands and legs, climbing stairs without support, switching legs, etc.

- Fine motor

Difficulties making small movements using the small muscles in hands and wrists, such as holding pen in the right way, coordination of visuo-motoric skills, coordination of fingers, precision in drawing and hand-crafting, getting dressed (using a zipper, button, shoelaces), precision in isolated movements (such as hammer blow), etc.

The drawings by children with developmental dysphasia share the common features - shapes are deformed, the drawing is located on a single place on the paper and most of the paper surface stays unused, pictures lack details (no eyes and nose on a figure, etc.), lines are not straight and don't connect to each other, drawing is rotated, some parts may overlap others, etc. It is hard for them to redraw a provided example pattern.

- Speech motor

Difficulties in making and coordinating articulatory movement, controlling lip movement, movement of tongue and face, using mimic, etc.

1.4.5.4 Time and space orientation

Children with developmental dysphasia may not be able to fully use and make relations of their knowledge about time and space. The orientation in a spacious area is unorganized, children may get disoriented, may confuse directions and left-right orientation, overlook obstacles. They may not remember repeated routes (such as from home to kindergarten). There are issues with their positioning things in 3D space or on a 2D surface and discriminating them from other things placed there (so-called figure-ground perception).

There is an inconsistency in developing time relations (like playing with a kite should be associated with an autumn season). Children associate a time period with some circumstances happening at that time instead (when the leaves are falling and it is windy, then it is the time for playing with the kite). The understanding of timing may be limited only to one day before and one day after the current day. There is difficulty with time seriality, story sequence, an order of things, time links between family members.

1.4.5.5 Attention and memory

Attention-Deficit/Hyperactivity Disorder (ADHD) or Attention Deficit Disorder (ADD) may be comorbid with developmental dysphasia. Poor psychic performance and attention may lead to impulsiveness and easier fatigability. Children may have impaired short-term memory that may cause forgetting order of instructions or instructions themselves, difficulties reproducing graphics, repeating words and sentences, using right word order, etc.

1.4.6 Summary

In this chapter, I described what is developmental dysphasia and what are its types and symptoms. Developmental dysphasia typically involves difficulties in communication skills, speech reception, speech expression, and even difficulties in other areas. To understand more about speech reception and expression (not only speech but also other senses), I created next chapter 1.5 where I am describing how people process input (reception) and output (expression) of information with the connection of developmental dysphasia.

1.5 Input output information processing

Let's take a look to the IT world again, so I can explain to you my thoughts. Few decades ago, there were incompatible networks without a possibility of connection and communication among computers. The seven abstraction layer conceptual model OSI, which is probably well known to each IT guy, was developed to state communication functions. The layers specify steps and processes that computers do to receive data or send data to other computers. Each layer is responsible for special function crucial for a good operation of all other layers and smooth transfer of information without defects and loss. [74]

For a better understanding of individuals exhibit speech difficulties, it is needed to start exploring the root of the brain information flows and processes while receiving and producing speech. It is possible to get inspiration from the OSI model to design a communication model with layers describing the communication of person within society: how it is received, processed, and sent some information by individual. The goal is to understand each of the steps from the input stimuli perception (reception - receiving information) through all layers of brain information processing interactions till the final output behavior or action (expression - transmit information) by an individual. Speech is a complex whole-brain activity and a brain is complicated and not easy to understand processing system [75]. The processing can vary from person to person and is not exactly and uniformly described.

I used my knowledge about modeling from software engineering to create a theoretical framework diagram of input and output processing of information

in ordinary, mental, and physical healthy developed individual with already developed speech (figure 1.2). The complex framework diagram shown in figure 1.2 is composed of diagrams from books Language And Communication Disorders in Children [27], Cognition, Brain, and Consciousness [76] and is extended by my own understanding of perceptual processing and brain processing based on my acquired knowledge from diverse literature resources, [27], [77], [76], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92]. The model is applicable to both children and adults. The start is on the top layer and it continues layer by layer downwards. I would like to explain and describe each layer in the same order as it processes the information.

1. ANALYSIS I

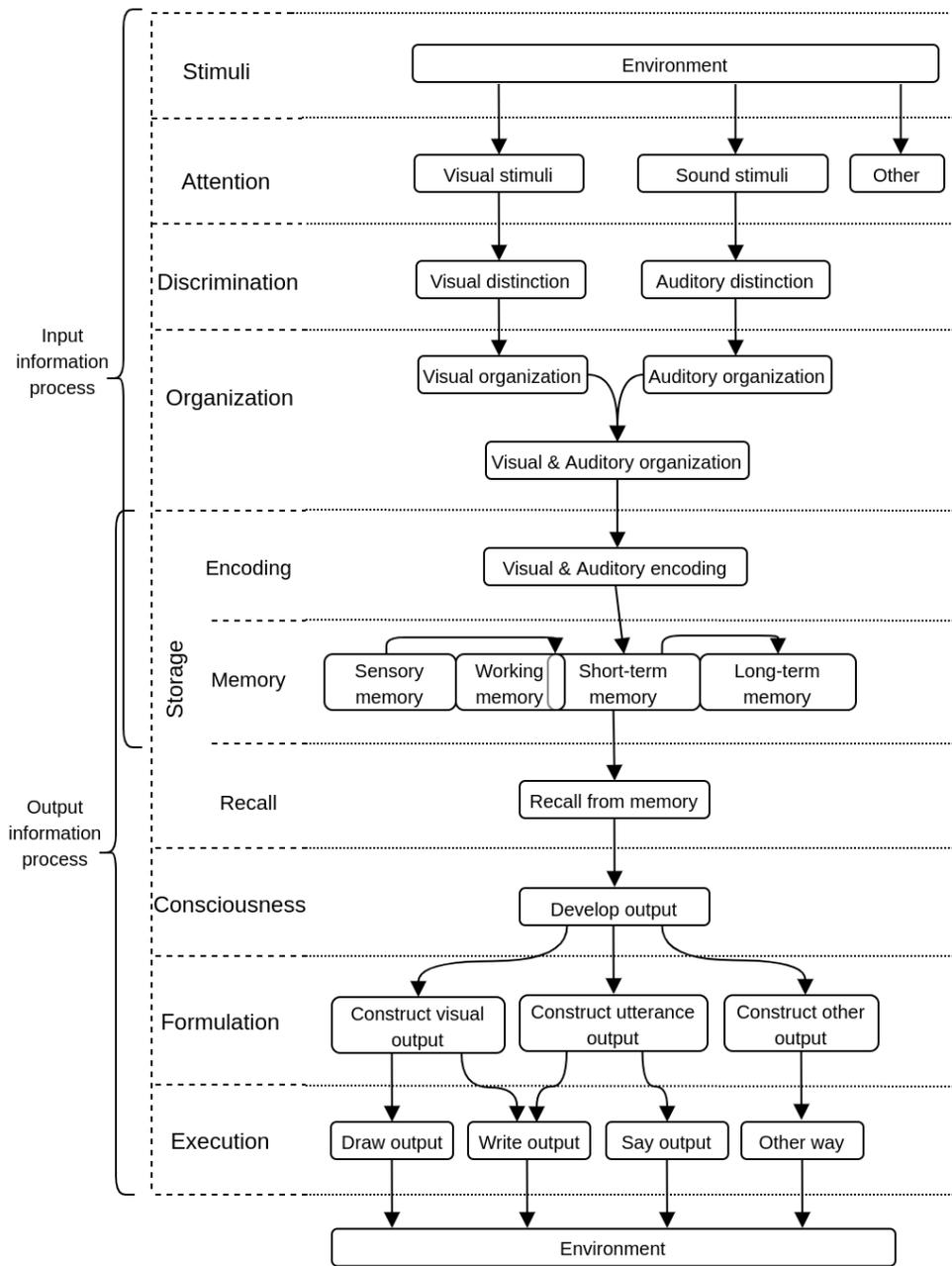


Figure 1.2: Information Processing Model

1.5.1 Stimuli

In the world around us, we are surrounded by an indefinite number of stimuli that we can perceive every second to acquire information. [93] Stimulus from an environment can be detected through the perception by one or more of our senses – sight, sound, smell, taste and touch.

1.5.2 Attention

Attention is the action of focusing our energy on a stimulus, an incoming sensory stimulus stimulates our receptors and transmits them to our brain through our nervous system. [94]

We scan the environment around us all the time with our senses; our senses perceive everything, but the amount of information is more than our brain can process. That is the reason why we have an attention that is finite and selective: the selective process works as a filter, which includes the ignorance and averaging of other, not actually relevant, information. It protects us from overloading and helps to focus only on important stimuli. [95] When some stimuli capture our interest and it becomes the center of our attention, we call it as attended stimulus - the active cognitive processing. [84]

There are groups of certain stimuli, that capture our attention easier, we react to them more quickly and accurately. They can be life-threatening stimuli, difference (shape, color, size, pattern, position, orientation, sound), motion, people, animals, emotions, hearing own name, and others. [95], [96] Also, some special characteristics of stimuli can help to attract more attention from people. These could be stimulus intensity, stimulus changes, magnitude, and repetition. [97]

The attention is crucial for whole information processing, not only as the beginning of stimuli perception but also for processing the information through other processing layers.

In the Figure 1.2 I am focusing especially on visual and sound perceptions because these senses are the most critical to control application and to support development in preschool children.

1.5.3 Discrimination

Discrimination is the ability to distinguish one stimulus from a field of similar and not similar stimuli based on their individual characteristics. We learn to respond to the original stimuli and ignore all other not so important and relevant stimuli, such as finding a circle among ovals, differentiate foreground from background, differentiate borders, separate kinds of sounds and voices, and other being able to differentiate situations. [27], [98] There can be more than one criterium for the difference, such as a combination of size, color, luminance, eccentricity, shape, depth, noise, rotation, etc.

1.5.4 Organization

Organization helps to classify the stimuli to the category of similarities that we already are aware of from our past experience, memories and expectations. [84] It can be viewed as a grouping of stimuli by patterns - visual, auditory or by other patterns. [99] Stimuli can be even grouped by a combination: by two or more of the patterns together. In the case of a combination of visual and auditory grouping we talk about visual-auditory organization. For example, if we see and hear a washing machine, similar objects as a dryer machine or a refrigerator would be classified to the same group in visual and also auditory classification (it looks similar and sounds similar), but we would rarely classify it to the same group as a spoon, chair or some of other visually and auditory unrelated object. Another example may be to fill the appropriate word to "Black and ___", "Salt and ___". Most of the people would associate the words in the pattern group with words "white" and "pepper". [27] Also, the stimuli can be classified to parallel categories by different attributes that the stimulus has, such as object functionality, color, size, place, sound, etc. It is an important layer for later retrieval. [27]

1.5.5 Encoding

This layer is close-knit with an organization layer, it is the mediator which is responsible for efficient search of the right place in our passive brain objects where the input stimuli can be allocated based on the classified category of similarities. The organization layer just classify the stimuli, but this layer saves it.

The passive brain objects database is composed of data we already have in our memory; it helps the brain to easier encode, compare and remember new input information as a result of a process of synthesis; it gives us a cue that the input information has been perceived before. The organization might be faster with better recall - finding more common attributes with data in our memory or with a higher occurrence of encountering associations. [86] It can be trained and developed through rehearsal and repetition.

1.5.6 Memory

Sensory memory is the initial process of storing information that is perceived through our senses. The information then can be transferred to short term memory. The information lasts only a small period of time and is continuously replaced by more recent. For sight perception, it is iconic sensory memory and lasts about one second, for hearing perception, it is echoic sensory memory and lasts about four seconds. The haptic memory is the memory that holds our memories about touch.

Working memory is overlapping with the short term memory. Short term memory is a place for manipulating temporary stored information with lim-

ited capacity, the information is usually kept for only 20 to 45 seconds. [100] By repetition, we can hold the information in short term memory longer; after some period of repetition and rehearsal, the information will be stored in long term memory. [101] This area is crucial for task processing, combining analysis, evaluation, decision making, inference, classification, and synthesis. [102]

Long term memory enables us to remember things for a long time, even for a whole lifetime, without any capacity limitation. [100] Long term memory can be explicit, also marked as declarative, or implicit, marked as non-declarative. Explicit memories can be described and expressed explicitly, and they must be consciously renewed not to forget the information. Implicit memory is about remembering without awareness, it is based on our own experiences, such as riding a bike, swimming, etc. Implicit memories are usually not forgotten, they are lifelong memories and abilities. [90]

1.5.7 Recall

The ability to recall (retrieve) is an essential function of our minds to remember, it plays a vital role in the way we learn, interact, and adapt to the environment. [100] It enables us to re-access and withdraw information and memories previously encoded and stored in our long term memory to short term memory, to our mental working space for immediate use or application. [103] The function of the recall layer is very similar to the function of the retrieval layer, which is important for receiving inputs and compare with information stored in the brain. In this case, the information is reproduced from memories, and it is necessary for developing logical response output, including decision making. [104] A way to achieve better memory abilities and recall process is by developing efficient cues to remember back the encoded information, such as by using a mnemonic system. [88]

1.5.8 Consciousness

Consciousness or awareness is an ability to internally process and organize recalled information (processed attended input stimuli, thoughts, feelings, imagination, dreams, abstract concepts, ideas, etc.) to a notion about output or an answer. [105], [76] This notion is not yet connected with words or images or other aspects based on language, vision, etc.

Sometimes everyone probably experiences a situation in which they know an answer or a response with the internal feeling of knowing, but with the inability to develop logical output and expression at that moment. It means you processed some information from the top layer down to this layer but without involving the following bottom layers from figure 1.2.

1.5.9 Formulation

This layer is essential for converting the notion to a comprehensive interpretation including planning output response (speaking, singing, drawing, acting, moving, behavior, emotion, ...), response selection in mind (creating a sentence, utterance, image, etc.) and planning the motor movements to express the response. The content and quality of individual's interpretation is limited by individual's knowledge, experience, abilities to express itself and other factors, such as speech abilities, correct usage of constructions of a sentence, knowing how to present an image by drawing, being able to mimic, by level of motor skills, stress factor, medical history, life events, etc. [106] There can even be no response at all as the state of accepting information as absolute truth - just the way things are. [107]

1.5.10 Execution

The last layer serves to execute and deliver task result as a response to the environment, to transfer the constructed output through expression. It is a synergy of muscle coordination and continuous self-attention to own expression to achieve expected output presentation. [108] The execution can be processed by speaking, making sounds, drawing an image, a body movement, or pointing or using other forms of execution based on an individual's abilities (preschool children would not have writing, but drawind an output, etc.).

1.5.11 Discussion about Input-Output Processing model

If we observe answers of individuals with communication impairment disability, it can seem they only are not capable of using appropriate words and constructing the correct output to answer a question (bottom layers). And it is true, however, it is just one of the possible causes. There is a need to know how deep is an individual able to understand and process the input stimuli, what are the levels of his/her cognition and comprehension: there can be a significant difference.

The view of the distribution of layers in the information processing model in figure 1.2 indicates that speaking is a complex process requiring a cooperation of all of the mentioned layers. The model should raise awareness that people who are unable to speak sense and produce utterance smoothly, may have difficulty with processing information in one or in a combination of more layers and that every individual may have a different core of their issues.

Each of the communication impairment have some own patterns defining the point of deficiency in the information processing. For dysphasia/aphasia there is Wernicke-Lichtheim model, also called Lichtheim's House in figure 1.3 describing the disruptions in processing areas for each type of dysphasia. [109], [110]

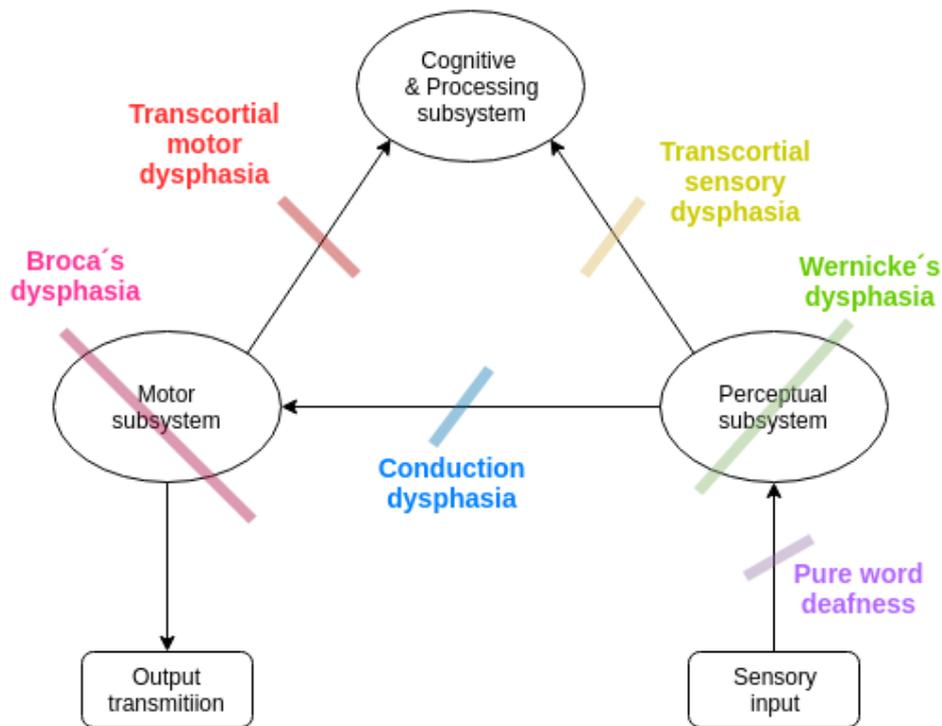


Figure 1.3: Wernicke-Lichtheim model of Aphasia

Based on my knowledge, Information Processing Model in figure 1.2 and Wernicke-Lichtheim model 1.3, I created a new model in figure 1.4. It shows how the same model from figure 1.2 looks when something doesn't work as intended. There are visible all types of dysphasia and other disorders and symptoms in the assumptive view of possibly affected information processing layers. The bars indicate which layers may be insufficient: each one may be affected by a different level or be intact. It would be possible to show there also other communication impairment disabilities, such as selective mutism, childhood apraxia of speech, dysarthria, alalia, hearing impairment, etc., but I chose only those possible comorbid with developmental dysphasia and the most interesting to compare, to keep the model simple.

Except dysphasia, in figure 1.4 are also bars for echolalia, intellectual disability and ADHD. Let's explore, why I made the bars in this way. ADHD is an abbreviation for Attention Deficit Hyperactivity Disorder. The name may tell us it describes an issue with attention and executive functions of a brain, which are crucial for smooth function of each processing layer. Individuals with ADHD often have comorbid disorders including autism spectrum disorder, intellectual disability, and developmental dysphasia. [111]

1. ANALYSIS I

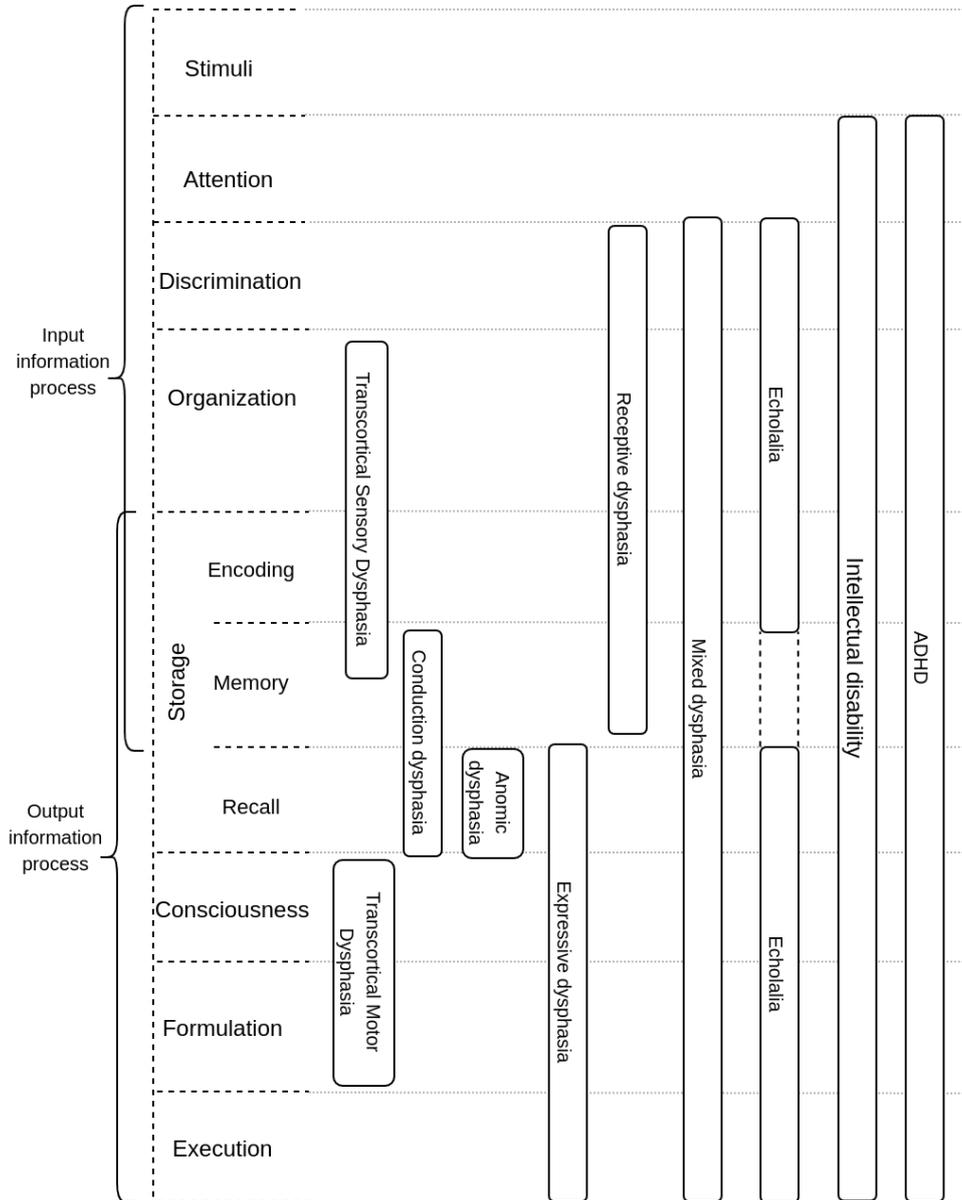


Figure 1.4: Affected layers of information processing due to disorders and symptoms

Intellect has a huge impact on how the processes on all the layers are working. Children with an intellectual disability may be significantly slower in processing all layers in comparison with intact peers, especially in the receptive area.

Echolalic utterances in children are usual and necessary for early language development. By the age of 3, echolalia should be minimal to nonexistent. [112] My assumption based on literature and observation is that echolalia in later age may be caused by insufficient functioning of any of the mentioned layers (except the memory layer).

The children at the age of 2 should already be in the process of continuously building and shaping functionality of all the layers as a whole. Accordingly, it is already a good age to support this process in both cases, to support natural development of children and mitigate the possible future issues with the language disorder, as an early intervention.

1.6 Summary

In this chapter, the first part of analysis, I introduced you to the problematic of communication impairment disability, described my path of how I chose preschool children with developmental dysphasia as my target users, introduced you to the developmental dysphasia (description 1.4, its types and symptoms) and described the information processing to show and to understand better where developmental dysphasia may affect communication. In the second part of analysis 2, I am applying this knowledge to the adjustments needed to make an application for my target group of users. In chapter Design 3, I am describing what is needed to include to the application to support the development of children with developmental dysphasia. Those are the connections of the theoretical part with the practical part.

Analysis II

2.1 Methodology

When designing good software, there is a need to set up good-quality functional and non-functional requirements. The standard process includes several to many interviews with clients, discussion on both sides (client and supplier) about the desired result, some cooperation and adjustments based on client's wishes, evaluation, and synthesis of the gathered data to find out the problem and to set the final requirements on the end. This description applies to the process with ordinary clients.

In my case, it is an uneasy task. I can ask my target users about their wishes and needs about some software for them, but I can not expect useful answers. As can be seen from the preliminary chapter, my target group is diverse with various level of understanding and level of speaking or expressing ability. It was needed to establish an adjusted methodology to get proper information for further functional and non-functional requirements setup, followed by designing the adjusted application acceptable by my target group. I set up the following qualitative methods that can be categorized as theoretical and practical.

- Reading
- Observation
- Interview
- Comparison

2.1.1 Theoretical part

As the first stage, I got an appropriate knowledge background and awareness about areas related to my topic.

Reading

I have gained theoretical information by reading sources related to my topic written by specialists and researchers - research articles, books, blog posts, web articles, etc. Most of the sources used in this thesis are free electronic sources available online. Some of the books and research articles were provided to me by National Cheng Kung University Library in Tainan.

During the last two years of working on my master thesis, I have read hundreds of sources for a purpose to immerse myself into the problematic, to widen my knowledge. I was looking for written sources by following:

1. searching any sources by keywords related to my topic
2. finding books and articles used as references in literature, that I found interesting and valuable
3. recommended books and articles by specialists

After all, not all of the literature is fully relevant to my topic. Therefore, only part of the sources is used and cited in this thesis. However, all the literature reading helped me to get some knowledge foundation and general overview that helped me to sort out the important and most relevant details.

It is important for readers of any professional focus to get acquainted with the basic information to get the facts and to empathize with target users. Based on my reading, I wrote the preliminary chapter about developmental dysphasia and related information and constraints 1. I also wrote the section 1.5, which is dedicated to my understanding of the brain processes of each human during receiving inputs and generating outputs. The information was gathered and pieced together using well-founded sources; all of the sources were listed according to the standards. I would like to pinpoint the most helpful sources, such as [70], [27], [76].

Comparison

Comparison is the evaluation of two or more things to find similarities, dissimilarities, and which thing is better compared with the other. In the beginning, it is needed to define comparison criteria, those will be evaluated and scored to help to order the compared things from the best to the worst.

I reviewed available digital devices, ranked them by their usability, and chose the final digital device for implementation of the prototype application. The detailed methodology is written in the chapter about devices. It is followed by a chapter with a comparison and overview of platforms available for the final digital technology.

2.1.2 Practical part

Theory without practical experience is nothing. I chose two ways to get practice and useful information: observation and interviews in two institutions in Prague. First is kindergarten Litvinovska 300 for children with communication, physical, psychical, mental and combined disabilities. [113] Second is a day-care center Diakonie Praha ČCE Ratolest for clients with mental and combined disabilities of ages 7 to 64. [114]

As it can be seen, clients from Diakonie Ratolest don't match the scope of the preschool age, which I set as my aim. In the beginning of my work, I was focusing on everyone with mental age of preschool children, no matter the real physical age. Later, I decided to focus especially on children of the preschool age as my target group. In the preliminary chapter 1 about disorders, I wrote a section about brain functioning for reasoning this decision.

Anyway, my notes and interviews in Diakonie Ratolest helped me to acquire more useful information for this work, so I decided to mention it in methodology.

I was visiting kindergarten Litvinovska one day a week for about half a year and a day care center Diakonie Ratolest several times a year.

The data gathering was not the only motivation to visit the institutes often. Another reason was to get children familiar with myself, not to perceive me as a stranger anymore. It was important for the sake of further prototype testing with minimizing nervousity or other children's negative feeling that limits their natural manifestation and could affect the real testing result.

For the purpose of this thesis, legal representative of 9 children from kindergarten Litvinovska signed the informed consent to write findings of them and test the final prototype with them. Consents can be seen in appendix . Children gave their verbal assent. The range of the age of children from Kindergarten Litvinovska is 4-6 years.

Observation

Observation is a process of monitoring something or someone to acquire information. We can divide observation into direct and indirect methods.

- Direct

During the direct observation method, the observer is physically present with the observed, and it is a straight-forward observation. We can see an example of a direct observation setting in figure 2.1.

- Indirect

Indirect observation is mediated through a recording device. The observer is not present in the same place as the observed. Observation can be made in the natural environment of the observed using a piece

2. ANALYSIS II

of portable recording equipment or in a specialized lab originated especially for this purpose with mounted recording equipment. An example of an indirect observation setting is visible in figure 2.2.

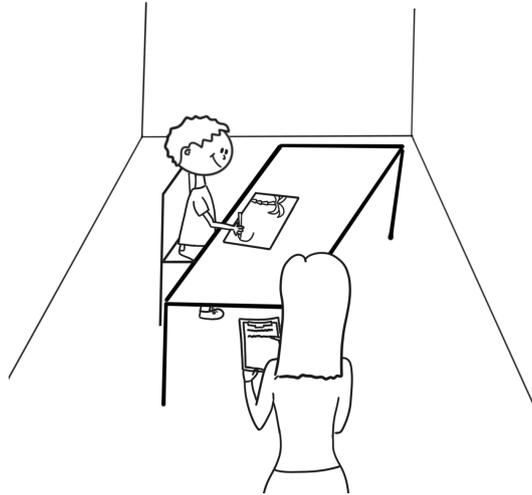


Figure 2.1: Direct observation

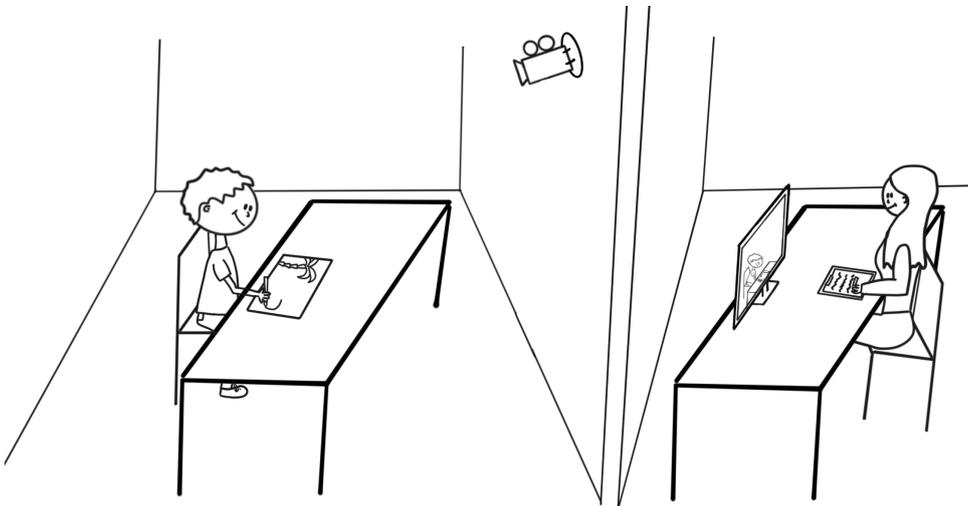


Figure 2.2: Indirect observation

At our faculty, we have a specialized Usability testing lab. It is equipped with basic furniture and mounted recording devices to the wall; recordings can be streamed online in real-time to screens in another room. The setting of the lab is not ideal only for usability testing, but also for indirect observations.

The disadvantage is that users in the lab are not in their natural environment, and that can influence their usual behavior, their nervousness, and their attention. Children, especially children with some sort of disabilities, may be more sensitive to a new unknown environment, which could distort the result. Another disadvantage arises for long-term observations, as it is difficult to manage regular attendance of more users.

I decided on direct observation of several children (and adults) in their natural environment. I spent a lot of time with children in kindergarten Litvinovska and clients in Diakonie Ratolest with diverse diagnoses. I was observing them in daily basis activities, in speech therapy sessions, in canistherapy, art therapy and art class sessions, special events (Christmass academy, a trip to the theater, etc.). I was also playing with them, working on several tasks with them and teaching them. During all of these, I was collecting useful information about their manifestation and habits, daily plans, interaction with other people, reactions during activities, people and things, mood and attitude to activities.

Interviews

An interview is a face-to-face structured dialog where one side asks questions and the other side provides answers. We can divide interviews into the following:

- Unstructured

This kind of interview is more like an open-ended conversation without an exact plan or pre-arranged questions. [115]

- Structured

It is a highly structured conversation with prearranged questions a in specific order. [116] It is usually recorded on a video camera or a dictaphone, or just recorder by using pen and paper.

When the interview is done with children, especially children with some disabilities, we should follow their thoughts, trying to get into the same mindspace with them. It is difficult to achieve it with structured a plan. In this case, it is better to improvise and get information by playing together. It is also needed to give it more time compared to the structured method of interview.

During my stay in kindergarten Litvinovska and Diakonie Ratolest, I was doing unstructured interviews not only with children and clients but also with

professionals there, including assistants, special pedagogues, speech therapists, caretakers, and psychologists. They were helpful in guiding and advising me in my process of getting insight into the issue and shared with me their personal observations, interactions, and opinions based on their many years of experience with pre-school children with diverse diagnoses. I was also asking specific questions about each child there, such as experiences with digital devices, especially tablets, their behavior, what distracts them, what therapies they undertake, what level of disabilities they have, etc.

2.2 Constraints from the view of Software Development

The attentive readers may guess the process of analysis and design of software for children with developmental dysphasia would be quite different than the process of analysis and design for intact children. From the information about developmental dysphasia in chapter 1.4, my interviews with professionals and my observations, I summarized several possible challenges and limitations that I need to deal with during all the next stages of my work.

My target users may have issues with the following:

- **C1** understand spoken instructions (in the meaning of decoding the information)
- **C2** remember several instructions
- **C3** have a bad pronunciation of words
- **C4** use different (wrong) words for naming things
- **C5** use non-existing words for naming things
- **C6** express answers through speaking (in the worst case don't speak at all)
- **C7** repeat sounds and words
- **C8** repeat melody and rhythm
- **C9** express answers through mimic and motion
- **C10** body coordination
- **C11** graphomotor skills
- **C12** short-term attention, hyperactivity
- **C13** slower processing and reactions

- **C14** integration with people
- **C15** memory issues
- **C16** understanding time and space
- **C17** left-right orientation
- **C18** making time relations and seriality
- **C19** drawing
- **C20** recognize same object with different properties (color, rotation, mirroring, etc.)
- **C21** differentiate between several sounds at once
- **C22** differentiate too many objects on a picture/screen
- **C23** visuospatial processing
- **C24** association between sounds and visual stimuli
- **C25** comprehension of abstract objects
- **C26** distinguishing between similar colors
- **C27** figure-ground (distinguish main object from background)
- **C28** difference in singular/plural
- **C29** fantasy, visual closure
- **C30** prediction
- **C31** recognizing emotions and empathy
- **C32** practical area, basic challenges of daily living
- **C33** comorbid physical issues

Those constraints are marked with codes, because they are discussed and analysed in detail in chapter 3.2 and 3.4

2.3 Plan

In the discussion in chapter Input-output information processing 1.5, I wrote an assumption that communication impairment disability may be a dysfunction of one or more layers of the information processing. All the layers are significant for the right processing of the information and correct output given by the individual. Still, only the last layer (Execution layer) is for expressing the output to the environment by producing utterance: that is the only result that we can perceive and that we can evaluate as the only problem. I believe it is needed to treat communication impairment disability with a focus on gradual training from the base layer. That enables us to treat and bend the disability from the possible core of the problem even if it is difficult or even impossible in some cases to find the exact core of the problem.

As it is mentioned in the chapter about senses, the visual sense is the dominant one. If the individual is not able to process the visual information, how can he/she be able to process the auditory information then? And how probable is, that he/she will be using correct response through speech?

I would like to mention a book [117] about speech development that I very much appreciate. The book tells us about the importance of keeping children in a naturally speaking environment without pursuing the child to speak. It helps to develop a passive vocabulary, language patterns, grammar, and the proper foundation for later speech production and speech development. It also works as a stimulating factor to start speaking spontaneously.

Moreover, it is recommended to not only focus on speech production and pronunciation during therapies, but to strengthen the overall skills - visual perception, auditory perception, thinking, attention, memory, motoric, graphomotor, orientation, spatial perception. [70]

Based on the findings, there may be three stages of speech development support:

1. Visual perception

In first stage, it is needed to train and improve the individual's non-verbal processing through visual information processing and visual-auditory integration. The aim is to support receptive language development, comprehensive spoken language through the visual system, to extend passive vocabulary of the individual, to be familiar with words and sounds, to comprehend short spoken instructions, remember basic grammatical structures etc.

This stage is focused especially on training visual-auditory input information processing, the seven layers in figure 1.2 from chapter Input output information processing 1.5.

2. Visual and speech perception The second stage would also train non-verbal processing through visual processing, visual-auditory integration,

but especially train comprehension and evaluation of spoken instruction and questions without the need for support by visual cues. The aim is to gradually understand longer spoken instruction or stories, build passive vocabulary and grammar, etc.

This stage is focused on training especially auditory input information processing, the seven layers in figure 1.2 from chapter Input output information processing 1.5.

3. Visual, speech perception and speech production

The third stage would train both previous stages with added training of individual's sounds and speech production to support verbal/expressive language development. The aim is to start using passive vocabulary for active communication gradually, from imitation of the training sound to speaking syllables, short one-syllable words to more syllable words up to using sentences composed of multiple words.

This stage is focused on previously trained input information processing and adding a training of output information processing, so the focus is on all layers in figure 1.2 from chapter Input-output information processing 1.5.

Each stage is a complex part of a diverse kind of support deserving its own space, analysis, design, and its own software solution. Especially the third stage, which requires us to include a software solution of voice analysis and evaluation. The content of exercises in each stage should be oriented on a balanced training of all kinds of skills supporting overall development. The following parts of my thesis deal with the first stage. I would like to design and implement a prototype of a 2D game for preschool children, focused especially on visual perception, and building passive vocabulary and speech patterns. The second and third stages are planned for future development.

2.4 Usability heuristic for User Interface Design

Usability is a part of the user experience. It indicates the ease of use by users, learnability and achieving the user's goals with effectiveness. [118] Jakob Nielsen set up 10 heuristic criteria for Web Interface Usability. Those heuristic criteria are well known in the information technology field. Probably every professional specialized in software development has at some point heard about those rules and followed them when creating and testing software. Those rules can be seen as general approximate principles to evaluate the level of usability and user-friendliness of interface, no matter the subject area of the software. Nielsen's heuristic criteria are mostly used for testing the websites, but it may be used as a great tool for evaluation and as a universal guideline for the process of design of any user-centered software, not only websites.

In 1994, Jakob Nielsen set following 10 general rules for interaction design [119]:

1. ***Visibility of system status***

The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

2. ***Match between system and the real world***

The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

3. ***User control and freedom***

Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

4. ***Consistency and standards***

Users should not have to wonder whether different words, situations, or actions mean the same thing.

5. ***Error prevention***

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

6. ***Recognition rather than recall***

Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember

information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

7. Flexibility and efficiency of use

Accelerators — unseen by the novice user — may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

8. Aesthetic and minimalist design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

9. Help users recognize, diagnose, and recover from errors

Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

10. Help and documentation

Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Those rules are commonly used for general user interfaces and are important for my case as well. The part of the software that is intended for adult users to manage child users and make settings should follow Nielsen's 10 rules in the usual way.

The part that is determined to be used by my target users, children with developmental dysphasia, is the most important. Most of Nielsen's rules are crucial and should be strictly followed with higher priority in design and implementation stage.

In the following points, I am considering, exploring and describing the importance of Nielsen's rules for the smooth usage of the software by my target group. I adjusted some of the rules a little bit to fit them better to my target group. It will serve as a proper foundation for later design part and as a building bridge of understanding among people from the information technology field.

1. **Visibility of the system status**

Children users should know where they are at each moment of the game. They should be informed how much was already done in the current level, what is still needed to do to accomplish the current exercise/level/game and that they are moving forward (such as a progress bar, getting points during the game - an increasing sequence, etc.). There should be an easy option to go to the next level or repeat the same or a previous level. Those are intended as a clear definition of activities and orientation in the game.

2. **Match between the system and the real world**

This point is very important. When I want to enhance and strengthen children's visual and hearing cognition during their daily life, the content, especially the graphic part and naming, must follow the real world. Although the graphical content will be drawn/painted, it must have enough similarities with the real world, and it must be clear what it's meant to represent to everyone.

The same rule should be followed for the icon images and other parts of the user interface so any user can understand them even without importance and reading ability.

In spoken messages and spoken instruction, only one language should be used: the children's native language. The used language should reflect language from child's environment, be basic and clear.

3. **User control and freedom**

Children users need to have a feeling of freedom when controlling the game, having the opportunity to choose anything on the screen without restrictions. If we restrict anything, the desire to break the restriction will become stronger. As one idiom says, forbidden fruit is the sweetest. Also, children users may get to unwanted screens by accidentally touching random buttons on the screen. That means we should minimize the possibility of getting to those unwanted states instead of giving restrictions or giving options of going back from the unwanted screens. It can be done by hiding irrelevant buttons, making them unappetizing, or just lock them until some condition is accomplished. Following this settings, we can define (almost) linear walk-through of the game and still satisfy children users with the feeling of freedom of choice.

4. **Consistency and standards**

Simply said, everything should be unambiguous. For icons and graphical content we should use simple, but as real as possible representation of what it means. We can leave the standard icon sets and graphical rules

of UX/UI and rather use a graphical content, that is more familiar to children users, so they are more likely to understand the meaning.

5. **Error prevention**

Ideally, children users should not encounter any errors. Application should be designed well enough not to need to display error messages.

One reason to avoid them is the disruption during the game; it can affect children user's attention. Another reason is that preschool children users usually don't have reading skills yet, they are not able to understand the meaning of the error message. They only see something is wrong (error messages frequently go hand in hand with a red symbol of X mark or exclamation mark) and any of those error messages they may easily interpret as their own failure in game.

6. **Recognition rather than recall**

All the important and relevant information should be visible on the actual screen or be said at the right time. Text information should not be used in the children section but can be used in the section for adults. There the text information should be full a explanation; it shouldn't disappear after some time period. It should be on the screen all the time, without the need to remember it.

To not overload children users memory system, levels, and exercises should be memory independent except the cases, where the memory training is the aim of the exact level/exercise.

7. **Flexibility and efficiency of use**

I think I can skip this point. If I will make the application minimalistic but effective, it should be usable on a similar level by both novices and experts.

8. **Aesthetic and minimalist design**

Less is sometimes more. It is true even in our case and, it is a very important rule. Children with developmental dysphasia may have limitations in figure-ground perception (differentiating the main object from the background). The simpler is the background and visible elements on the screen, the better it is for orientation and understanding by children users.

9. **Help users recognize, diagnose, and recover from errors**

As I said in error prevention point, error messages should not appear in the children section at all. It is up to us to design and implement application sufficiently enough not to have errors and not to need to

show errors. We don't need to deal with other issues of how to help children users to recover from errors then.

In the adult section, it is a welcomed rule, as it serves as a feedback to recognize what was done incorrectly with the possibility of correction (incorrectly filled form, for example).

10. Help and documentation

Children section of the application should be intuitive and without the need to have a text manual. If some explanation is needed, the only possible form is the visual form with speech explanation accompaniment to enhance the children's understanding. That combination is the most relevant, demonstrative, and user-friendly.

An adult section can contain text instruction, but only in moderate quantity. The instruction should be brief.

2.5 Device overview

The market is abundant in diverse technology solutions available for various kinds of usage, such as work, research, education, fun, social connections, etc. Of course, some of the technical facilities are still inaccessible for ordinary population and institutions due to their high price, unusual technology, early development of the particular technology, or narrow and specific kind of usage. Anyway, most of the homes, educational institutions and health care institutions in western countries have some of the common technical facilities available, such as mobile phones, tablets, desktop PC and others. The technology has a huge potential to improve and transform education: it can bring new knowledge in any form to everyone. It is usual to use educational software, which can not only be joy and fun involving users attention and interest but can even bring significant educational value. However, it depends mostly on the user, which activity he/she would prefer to do with available technologies. Finding the optimal device for users with specific needs is important for better effect of intervention and skills development. Let's explore some of the most suitable and interesting devices for the purpose of this thesis, not only the popular ones but also the less-known devices.

2.5.1 Methodology for device choice

The most suitable device was evaluated as a result of qualitative methods of collecting data. I was gathering data especially by reading and interviews. I focused on collecting information about the usage of these devices in the meaning of interventions and playing of the game by our target users. The information about devices was gathered in general: how it can be used and what are advantages and disadvantages. Then I focused on the same intention

from the view of children with developmental dysphasia in preschool age, if the usage of the device by child with developmental dysphasia differs.

Based on my acquired knowledge I set up the following evaluation criteria for the comparison of the devices.

Evaluation criteria

Selecting the device that would fit to our target users the best is an uneasy task. There are a lot of variables needed to be borne in mind; some of them are more specific than for people without any difficulties. I selected a few important criteria and added a description of point ratings.

- Size

The size of the device itself, the diameter of the screen or projection, requirements to space size and space type.

From the interviews and observational findings, medium-sized screens seem to have the best size for children. Children with low graphomotor skills have problems with being accurate on screens that are too small. On the other side, bigger doesn't always mean better. It can be a tough task to manage movements and eye control over a screen with a big diameter. I decided to set three categories based on the screen diameter.

Evaluation Small (up to 6 inch): 1 point, Medium (6 inch to 12 inch): 3 points, Large (12+ inch): 2 points, no display: 1 point

- Portability

Weight of device (some devices may weigh up to hundreds of kilograms), the possibility to transfer device easily, installation of the device and it's weight and size of needed accessories in the meaning of transfer.

Evaluation Easily portable and installable: 3 points, Portable with help of other people or harder to set up after moving: 2 points, Heavily portable (almost unportable): 1 point

- Motoric skills

The level of the user's needed motoric skills to use the device on the appropriate level. The application may be controlled by touches of fingers, pen, a mouse, keyboard, tracker, body movements, voice, etc.

The easiest control is by touch. It is followed by mouse, keyboard, tracker, and other devices that require using an entire hand to control it. Pen is one of the hardest devices to control because it requires a good grip of pen, which some preschool children still may not be familiar with.

Evaluation Touchable: 3 points, using full hand or body movements: 2 point, devices requiring good grip: 1 points, full body movement: 1 point, passive watching without need of user's interaction: 1 point

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- Resistance

Shake resistance, fall resistance, hit resistance, fluid spill resistance and other possible situations that can happen to the device during sessions, especially with children with unpredictable behavior.

These criteria are hard to evaluate: each device has different resistance weakness. The resistance can be increased by using the available protective accessories.

Evaluation by my subjective feeling, evaluated from 1 to 3 points

- Interactivity

Stages of interaction between users and devices, such as active vs. passive, using visual, hearing and speaking interaction, touch interaction with the support of diverse gestures, etc.

The passive receiving means the user only watches the content and doesn't need to touch the device. Full interaction means user can change the content by using input devices.

Evaluation Watching: 1 point, Full interaction: 3 points

- Price

Price per unit, including all the needed accessories. Also the estimated price for paying human resources, if the device needs special service.

Evaluation One-time payment up to 10 000 CZK: 3 points, one-time payment up to 100 000 CZK: 2 point, repetitive-payment or price higher than 100 000 CZK: 1 point

- Positive impact

Possible positive impact on the user's development in diverse areas, such as vision, auditory, motor, memory, social, behavior, etc.

The impact of each device may be positive and also negative based on the usage by users. A computer can be a great tool with a positive impact when used for education. On the other side, it can be a negative element, when someone is playing games all day at the expense of health and social life.

Evaluation Subjective evaluation, 1 to 3 points.

- Risk factors

Possible individual's health and development risks by using the device by our target users, such as vision, auditory, motor, memory, cognition, space orientation, etc. Another risk to consider is if the device may contribute to causing epileptic seizure.

Long exposure to any device may cause harm to overall health. It is also a very subjective to evaluate, because it is dependant on time of usage.

Evaluation Subjective evaluation, 1 to 3 points.

- **Intelligibility to operator**

Level of needed skills required from the adult operating person. Does the operator need to be professional IT specialist or is an average user without significant knowledge of technical details sufficient?

Evaluation Needed professional operator: 1 point, operable by average user: 3 points

- **Availability of the device**

Possibility to buy or build the device and its accessories, requirements needed to set these by oneself.

Some devices are available everywhere, easily accessible. But some devices are intended only for special institutions or schools or are so unique that there are only a few pieces of them in the world and is hard to find compatible and available components.

Evaluation Available to buy in the store in Czech republic everything needed for using the device: 3 points, Available only abroad or hard to get accessories: 2 points, Unavailable to buy (only on special requests): 1 point

- **Developer friendliness**

Availability of video tutorials, documentation, and other supporting material for a smoother development of the final product by the developer. Also availability of good-quality software for developers for an affordable price and the possibility of running the software on all platforms.

Evaluation: Well documented, with plenty of tutorials, low price: 3 points. Poor documentation, high price of software: 1 point.

On the end of this chapter, there is settled the synoptic table with evaluation of devices and summary with the final winning device for my thesis.

2.5.2 PC, laptop

Desktop Personal Computers (PC) are generally known devices for individuals. The same with laptops as their lightweight portable versions with the usually smaller screen and lower resistance to falling down. It may be controlled by diverse input device; however, the keyboard and mouse are the most used ones.

I am skipping the detailed general description of both as almost everyone is familiar with those devices.

2.5.3 Smartphones, Tablets

Nowadays smartphones are not just tools for calling and sending text messages anymore. Those are smart devices offering a number of diverse applications substituting now old school paper notes and calendars and offering fun, social interactions all over the world, and so on. Tablet can be viewed as a bigger version of the smartphone. Some tablets, however, don't support SIM cards are not supporting SIM cards (that means no mobile internet). Most of the devices uses one of the two most popular operating system - Android or iOS.

The biggest advantage is the portability, affordability and developer friendliness.

2.5.4 Wall/table touchscreen

Touchscreen is a tablet without the possibility of easy portability, as it is attached to the wall or the table. It is more resistant than a tablet due to the fixation to a large surface. With it comes a disadvantage of the first installation and not being able to move it or tilt it: it is possible to work on it in one place only. Children with developmental dysphasia may have issues to draw on vertical surfaces, so even the manipulation with a vertical touchscreen would be problematic.

2.5.5 Virtual Reality, Augmented Reality and Mixed Reality Headset

This device was one of my top favorites in the beginning and because it is less known in comparison with previous devices, I decided to make a more detailed exploration.

Virtual Reality (VR) is a mediated artificial environment (also called an immersive environment) which creates the psychological sensation of being present in physical alternative surroundings, the simulation fills the user's whole visual field. [120] The scene is transmitted to the user by using a set of tools and techniques, especially the headset with a screen. [121] It enables users to separate from rushed surroundings, and fully concentrate on the virtual scene, fully use the ability of their own perception. In contrast with other common technologies such as computers, mobile phones or tablets, using a VR headset is a full-body experience. [122]

Augmented Reality (AR) and Mixed Reality (MR) also belong to the VR section. AR uses the real environment blended with additional virtual content. [121] MR is defined as the reality and virtual environment mixture between VR and AR. [123]

VR headset can be made easily by placing a mobile phone into the additional construction; its price starts at about 200 Czech crowns. Another option is to buy the complete VR headset, which costs about a few thousand Czech crowns. The low price and the possibility to use any smartphone



Figure 2.3: Example of augmented reality (Podpořeno z projektu MKČR NAKI DG18P02OVV15 Věnná města Českých královen)

causes this type of VR to be very affordable for most of the people. The actual VR view can be beamed to another display device that can be used as a control by adherents. No professional manipulation skills are needed, an average technology user is able to maintain necessities to make VR headset work satisfactorily.

VR is a relatively young technology with rising popularity in about the last three years. It is too short period of time to fully explore all the possible uses, possible purposes, negative repercussions on users, and long-term health and psychological effects. There is insufficient evidence focused on the negative long-term impact of using VR by children, especially the children with some disorders. There are yet unanswered questions about how the usage of VR/AR/MR headsets by children can impact their ophthalmic health, immersion, and balance and cause cognitive and sensory overload, isolation and addiction. [124]

One of the first studies about the impact of virtual reality headsets on children was conducted by researchers from Leeds University. They looked at 20 normally developed children from 8 to 12 years old using a VR game for about 20 minutes, then they examined them. Two of the children had disrupted the ability to detect differences in distances, and one child showed drastic degradation of his balance ability right after finishing the VR game. One of the Leeds University's professor, professor of Cognitive Psychology, Mark Mon-Williams, said: "In a VR device, a virtual three-dimensional world is displayed on a 2D screen, eyes are focusing in a way that can cause fatigue and strain on the human visual system. In adults, that can lead to headaches and sore eyes. But with children, the long-term consequences are simply

unknown.” The scientists from Leeds University believe and have warned that the continuous VR usage can trigger eyesight and balance problems in young people. [125] Also, the wearing of the headset can lead to musculoskeletal problems through bad posture. [124] The VR headset itself is easily portable and lightweight for transportation, but not for wearing by a child on the head for a longer period of time. Professor Mark Mon-Williams sees the VR as a valuable aid to educate children, but he believes children should use VR in small doses with frequent breaks. [126]

Another question is the impact of using VR on the visual system of children. Child vision develops from birth up to around 8 years old. [127] Children, especially children with mental illness and lower expressioning skills due to communicatin impairment disability or due to other reason, seldom complain of having vision issues or poor vision quality, these things can easily go unnoticed. One of the first noticeable signs by an adult can be child’s complaints about eye pain, which is a culmination of the antecedent unnoticed eye strain. [128] Reduced vision can have an impact on a child’s following learning and development. [127]

The VR headset creator settled the minimum suggested age starting at 10-13 years old. There is a general rule that no child under 7 years old should use a VR headset. [129] Most of these companies are taking a ”better safe than sorry” approach. [128] and [130]

2.5.6 Hemispheric projection

Similar to the virtual reality’s immersive environment for a single person, there are also types of immersive environments multiple users in mind. [131], [132] Those are advanced projections, sometimes called immersive theater. It can be understood as an extended wide projection that surrounds the users and draws them into the virtual environment without any need to use a VR headset or other hardware touching the user’s head. Some of the projections offers similar feelings and perceptions to the VR headset, however, it is like a kind of cinema with the advantage of surrounding users and drawing them more into the projection. There are not many options for user interaction with the projection.

Most of us have been to the planetarium. It is a hemispherically shaped building with a dome-shaped projection screen on the ceiling in the interior. [131] Usually, the planetarium building is huge and spacious. Spectators are sitting under the projection screen and watch projections passively. They are usually about topics related to astronomy. Planetariums usually use a set of several precisely calibrated high-resolution projectors and computers to display the entire full-dome image, called as digital multi-projection. [133] Another options to orject the content is using one fish-eye projector. Unlike them, smaller hemispheric domes use spherical mirror projection with just one

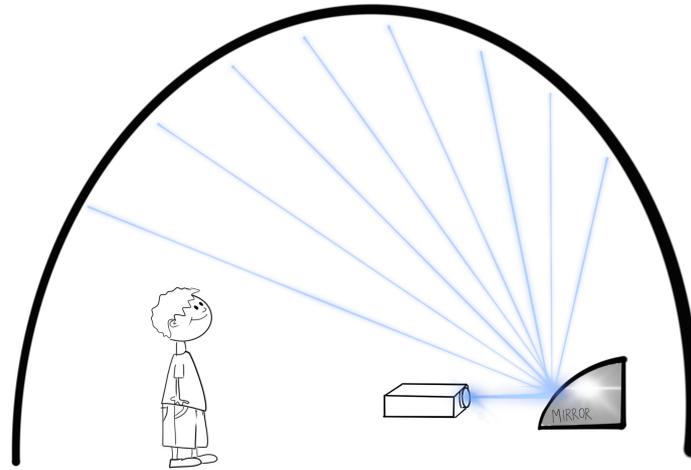


Figure 2.4: Single projector hemispheric projection

projector and one computer, it is visible in figure 2.4. Both solutions require a video recorded or transformed into special formats. [134]

Hemispheric domes popularity has been on the rise for past few years, as they become more accessible. A few companies in the market are selling diverse sizes and styles of domes, intended for home use, entertainment, educational use or commercial use. The price starts at about 1000 US dollars for a small home basic dome up to tens of thousands US dollars for a professional solution. The free version of the dome is also available as do-it-yourself projection for building small paper home planetarium. [135] The price for the final solution is much higher, due to the need to invest money in the projector and a spherical mirror. An example of a hemispherical dome available for buy or rent can be seen in figure 2.5

I was not successful in finding any academic evidence about what impact hemispherical projections may have on children with developmental dysphasia. Nevertheless, I found that many planetariums all around the world anticipate visitors with special needs, especially children with autism spectrum disorder. They provide plans of the planetarium with highlighted high sensory areas, special quiet opening hours, reduced lighting, a limited number of visitors, freedom of movement during projections, special price, cool down area, and so on. [136], [2] In figure 2.6 a sensory map of Melbourne planetarium can be seen.

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Figure 2.5: Example of dome for hemispherical projections by Dometech [1]

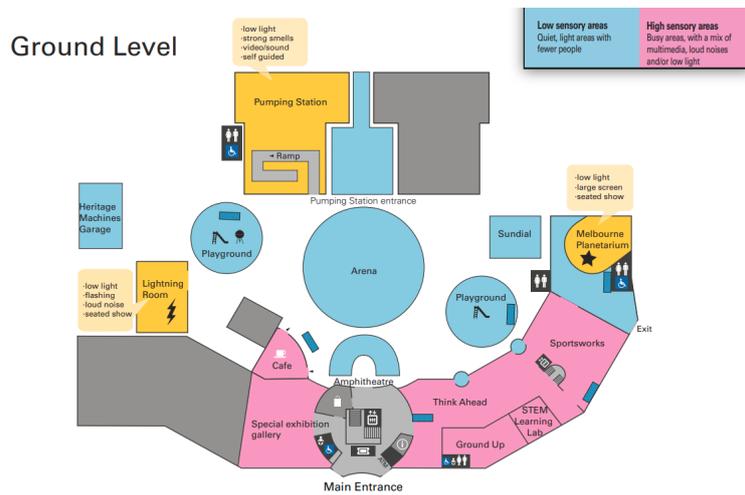


Figure 2.6: Melbourne planetarium's sensory map [2]

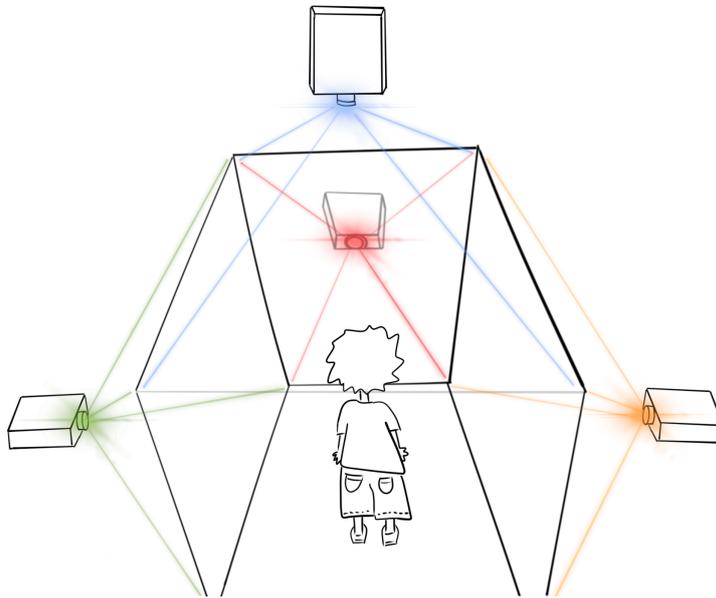


Figure 2.7: Projections in CAVE

2.5.7 Cave

The word CAVE is a recursive acronym for Cave Automatic Virtual Environment. The intention is halfway between a VR headset and a basic projection. The room constructed from large projection screens with the projectors outside each wall projecting the content on them (usually including the ceiling and floor). [137] The user is standing inside the room, typically wears 3D glasses, VR headset, or head-up display. Some caves support interactions with the content through input devices such as joysticks, data gloves, wands, and so on. It can be used by a single person, but it can support multi-users as well. The main user may wear a location sensor, the projection then may move according to the user's movement and rotation. [138]

In comparison with VR which is a single person experience, CAVE has the advantage of multi-user presence. Some of my target users may have a feeling of anxiety and uncertainty that leads to a fixation to the well-known people from their life, who gives them the feeling of safety. Inside the CAVE, there may be a supportive person, such as a parents, teacher, therapist, etc. whomse presence may be positively perceived by the main user all the time. The user may feel calmer and assured he/she is not alone in an unfamiliar environment.



Figure 2.8: Example of a Cave room at Faculty of Electrical Engineering at Czech Technical University in Prague [3]

2.5.8 Interactive surface

The interactive surface may be vertical, such as the SAGE (LCD displays controlled by the SAGE system, with the resolution 9600x4320 px [139]), or horizontal, such as an interactive floor. They are rarer, one of the reason is that those devices need a lot of empty space, the difficulty of their installation in the begining, professional operators, possible higher investment, and high operating costs.

2.5.9 Gaming console

A gaming console is a computer device offering interactive joy to one or multiple users. According to the choice of the game, it can be a full-bodied experience. It can be controlled by the body's movements without any additional input device or using a handheld device connected to the console (it may but also may not contain the connecting cable). The device itself is not in a direct touch with the user, so the risk of damage is lower.

For me, subjectively, the gaming console is especially for entertainment. The educational content is made mostly for another kind of devices with different kinds of game control. Using the handheld or be dependant on the accurate body movememnts may be difficult for children with developmental dysphasia, who have issues with their motoric skills.



Figure 2.9: SAGE at Faculty of Information Technology at Czech Technical University in Prague

2.5.10 Robots

The last type of devices that I was interested in are robots. The human appearance of some of the robots makes it a great candidate for an interactive device for children. Some robots, such as a robot Nao created by SoftBank Robotics, can display emotions through blinking colorful led diodes around the eyes. It can speak and it can record and evaluate sounds. It is a great device offering to use the full interaction of the user and a device.

The disadvantage is price and resistance. Any downfall may cause defects, so it need to be supervised by a responsible person all the time when used by small children.

2.5.11 Devices evaluation

I filled the table of devices and evaluation criteria with the corresponding values. There is the sum of points in the bottom line. As can be seen, the tablet device has the highest number of points. It is light and portable, but big enough for children users with dyspraxia. The price of a tablet is low compared to other devices. The average computer user is usually able to operate with tablet device without a need for any professional help. And children are usually used to using the tablet from home or from kindergarten.

	PC	Laptop	Smartphone	Tablet	Touchscreen	VR	AR/MR	Hemispherical projections	Cave	Interactive surface	Gaming console	Robots
Size	2	2	1	3	3	2	2	2	2	2	2	1
Portability	2	3	3	3	1	3	3	1	1	1	3	3
Motoric skills	2	2	3	3	1	1	1	1	1	2	2	2
Resistance	2	1	2	2	3	2	2	3	3	3	3	1
Interactivity	3	3	3	3	3	3	3	1	1	3	3	3
Price	2	2	3	3	2	2	2	1	1	2	3	1
Positive impact	2	2	2	3	2	2	2	3	3	3	1	3
Risk factors	2	2	2	2	2	1	1	3	3	3	3	3
Intelligibility to op.	3	3	3	3	3	3	3	1	1	1	3	1
Availability of d.	3	3	3	3	3	3	3	2	2	1	3	1
Dev. friendliness	3	3	3	3	3	2	2	1	1	1	2	1
Sum	26	26	28	31	26	24	24	19	19	22	28	20

2.6 Platform overview

The software environment for tablets (simultaneously for mobile phones, smart watches, etc.) combines advantages of a personal computer with advantages of mobility use. Based on statistics [140] we can see, not suprisingly, that the two worldwide mostly used operating systems prevail, Android and iOS. Other operating systems are negligible, with less than 1 % occurrence among all the mobile/tablet devices. I will introduce both operating systems only briefly, as they are well known by most people.

iOS is developed by Apple Inc. and is exclusive for Apple devices including iPhone, iPad, iPod Touch, etc.

Android is an open-source mobile operating system based on Linux kernel. Let's compare these two operating systems by a few criterias.

Popularity

Android is known as the world's most popular mobile operating device with its 74 % use [141]. For tablet devices, it is in the second place with 36 % compared with iOS with 63 %. However, in the Czech republic, Android on tablets still keeps the first place of popularity with its 50 %.

Price

In general, devices with Android are way cheaper than products from Apple. It makes Android devices more affordable by a wider population. When it comes to devices for schools and state institutes, the price is usually the first criteria.

Publishing

These criteria reflect, how much time it takes to successfully publish the final application in the app store, which can be Google Play for Android applications and the App Store for iOS applications. After the application is submitted for review, it may take from 45 minutes up to a few hours to be reviewed on Google Play [142]. On the App Store, it may be about 24-48 hours. If the review was successful, the application is published to the app store and is available for anyone to download, install and use it. [143]

App quality

The App store is more strict for iOS applications. It is more difficult for developers to make a satisfactory application that will be accepted by Apple. On the other hand, it means better quality of available applications with a low amount of bugs for iOS users.

App smoothness

Android is known for many system versions and updates. Unfortunately, the high number of actually supported android versions makes the applications behave differently in each system. Apple has a unified iOS software, it warrants a smooth run of the applications across all iPhone devices.

Less focused software

In this criteria, I want to prioritise the devices, which have fewer games and apps focused on children and children with some disabilities. iOS is known for a wide selection of diverse games, even for children with special needs. Most of those games are not free, the price usually starts from tens of Czech crowns and can be up to hundreds or thousands of Czech crowns. In the Google Play selection, there are fewer games to choose from.

Summary

I marked the winner for each comparison in table 2.1. As can be seen, Android is the winning platform for this thesis.

	Android	iOS
Popularity	✓	
Price	✓	
Publishing	✓	
App quality		✓
App smoothness		✓
Less focused software	✓	
Total	4	2

Table 2.1: Platform comparison, what is better

2.7 Requirements

2.7.1 Functional requirements

- **F1 - Maintain user**

Adult user can add, edit and delete new accounts with names and photos of child users.

- **F2 - Listing existing users**

Adult and child users can browse through already created accounts. Adults can manage existing child users.

- **F3 - User login**

A child user can log in to the game part by selecting his/her account when the account is already created. Login would be a no-password-required login.

- **F4 - Change user settings**

Adult users can adjust settings for each child user based on child's personal needs and preferences.

- **F5 - Show user statistics**

Adult users can browse statistics of the score and time of each child user.

- **F6 - Show list of levels**

Child user can open a list of all the levels, no matter if the levels are locked or unlocked

- **F7 - Unlock level**

Adult users will be able to unlock any locked level in advance by using a special gesture. Child users can unlock a new level by getting enough score from previous levels.

- **F8 - Play an unlocked level**

Child users can open and play any of their unlocked levels. There are no restrictions on how many times a child user can repeat levels.

- **F9 - Interact with character**

Child users can interact with the main character by touching him. The main character will be visible on the screen all the time when the game is open and will give voice instructions or voice information to child users.

2.7.2 Functional requirements in the game

- **FG1 - Back to menu**

Child users can go back to the list of levels anytime during their play of the level. The state of the game will be stored, and they can return later.

- **FG2 - Play the game**

Child users can submit answers in the assignment of each exercise. For each correct answers, they will get score points and positive praise from the main character. Based on the correctness of answers, they can fix their answer or continue to the next exercise.

- **FG3 - Operating the level**

After finishing all of the exercises in the level, users can repeat the same level from the beginning or unlock and play the next level (if their score is high enough for passing).

- **FG4 - Get the game information**

Information about the user's score and progress in the current level will be visible throughout all the exercises.

2.7.3 Non-functional requirements

- **N1 - Support for OS Android 5.0+**

The application will be native, available for all the Android devices running Android 5.0 (Lollipop) and higher.

- **N2 - Landscape mode**

All screens in the application will be landscape orientation by default.

- **N3 - 2D**

The scenes in the game should be 2D.

- **N4 - Data stored remotely**

All data will be stored remotely: application will download the data needed for playing the levels to the local storage in advance.

- **N5 - Internet connection is not required all the time**

The application will require internet access for downloading the data of the next few levels in advance. The data needed for the first basic application will be downloaded when installing it.

- **N6 - Language**

Texts and voice instructions in the application will be in the Czech language. The application should be adjusted to adding new languages easily during the future development.

- **N7 - Adjusted user interface**

The user interface and graphics will be adjusted to suit the special needs of the target users. More about this topic is in chapter Application features 3.2

- **N8 - No advertisements**

The application will not contain any third-party advertisements or other distracting third-party content.

- **N9 - Free of charge**

The application will be provided for free. Anyone will be able to download it from Google Play services and use without limitations.

- **N10 - Restricted application permissions**

The application will ask users to agree only to those permissions, that are needed for the proper functionality of the application.

2.7.4 Specific game requirements

- S1 - Each level will train one new skill or a combination of two to several previously trained skills.
- S2 - One level can contain several to many exercises to deepen the exact skill/skills applied to various image sets.
- S3 - The difficulty of the levels will rise together with the level number
- S4 - The difficulty of exercises in one level will rise very slowly
- S5 - Each exercise will start with voice instruction
- S6 - Every user's tap on any image on the screen should return voice feedback to the user saying the name of the object on the image

Design

Software design is a process to demonstrate the concept of an application, its properties and behavior. It reflects collected functional and non-functional requirements 2.7 from the Analysis chapter for further implementation.

At the beginning of this chapter, we are going to take a look on use case diagrams to get aware of the main interaction of users in the desired application. It is followed by section listing possible features, whose integration helps to adjust the application to be more acceptable by children with developmental dysphasia. The Wireframes section shows the screen layouts throughout the whole application. This chapter ends with a description of the application from the software engineering view; there is a room for architecture solution, domain model, and class diagram.

3.1 Use cases

A use case is a list of actions or events that potential actors (users) can do in the system. It visually describes the system functionality based on functional requirements.

The main role in the game is the role of a child, who should be able to interact with most of the game individually. The administration part is intended to be maintained by adults, as it can be seen in the diagram in figure 3.1. However, I do not plan to keep adult users profiles, because they can maintain the administration without login.

The first use case diagram 3.1 shows possible actions in the administration part and the game dashboard. The second use case diagram 3.2 shows possible actions inside the game.

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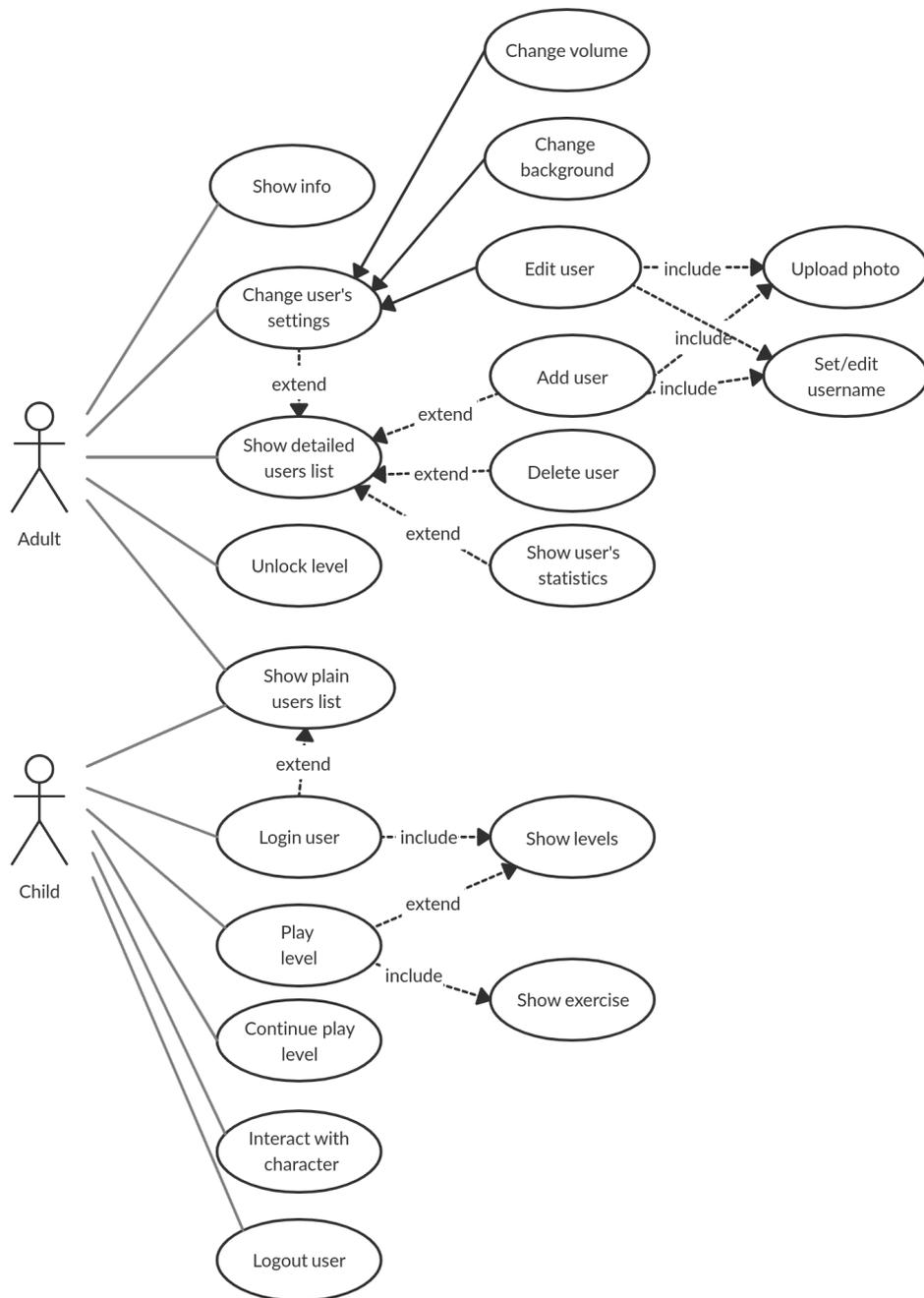


Figure 3.1: Use case - part 1

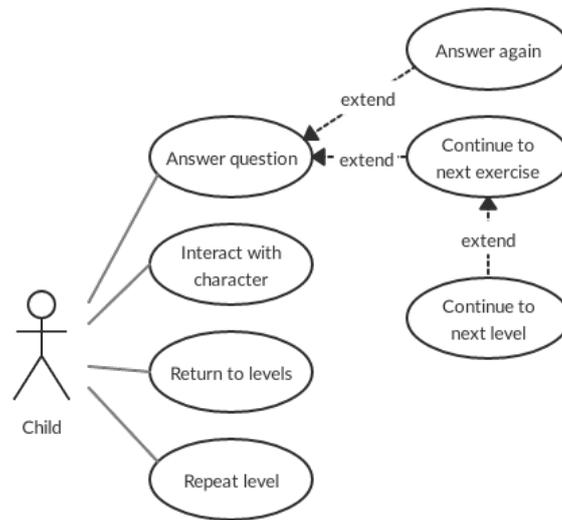


Figure 3.2: Use case - part 2

3.2 Application features

This chapter was conducted to find out the features of diverse categories that would help to make the result game application more usable by my target users, based on constraints from chapter 2.2, principles applied in speech therapies and general UI standards or recommendations. Based on literature review, observations and interviews I collected a few ideas to elaborate.

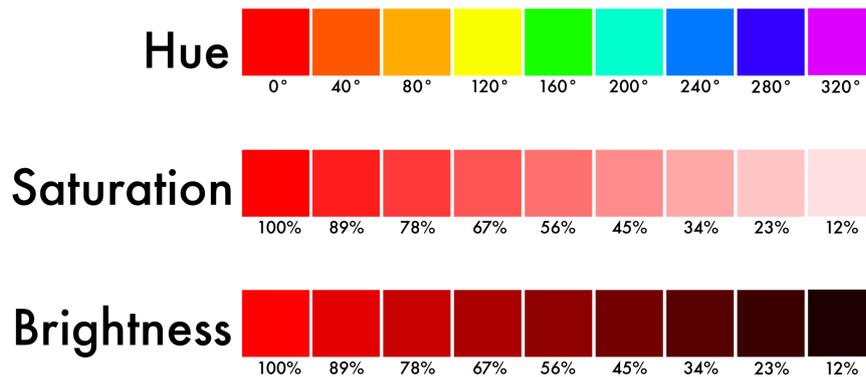
3.2.1 Color setting

In user interface (UI) field the application relies heavily on used colors. [144] Color perception is one of the initial processes in the visual system: color is the first thing we notice. [145] Colors have an impact on how long we are able to look at the image feeling comfortable and can affect our attention time positively or negatively, can have the power to improve our memory. Some colors may be calming, pleasant; others may be irritative and deepen our feelings about what we see.

I haven't found enough adequate information about color perception in children with developmental dysphasia, but children in general may be more sensitive to colors than adults. [146] It is another reason to give room to the appropriate color setting.

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Colors can be identified in color space numerically in several ways. I would like to highlight the HSB representation of RGB color space, which I used for investigation and adjustments of final colors for the graphical content of the application. The abbreviation HSB stands for a combination of hue, saturation and brightness.



Hue effect

Color psychology examines the way how the brain perceives what it visualizes, the influence of the hue to mood, emotional state and people's behavior, as we perceive each color differently. It is highly debated in the marketing industry as it may help to attract customers, strengthen the feeling about brands and influence decision making. However, the color psychology figures and is applied in general in entire visual aspects we perceive, even for children with developmental dysphasia.

I would like to list a few characteristics of each color, what feelings they may arouse in majority of people with intact color perception. The color perception of each individual may be influenced by culture, experiences, memories and others. [147]

- **yellow** - positivity, optimism, happiness, warning
- **orange** - adventure, creativity, success, balance, alert
- **red** - captures attention the most, excitement, passion, desire, danger, action, energy, aggressive
- **pink** - femininity, love, playfulness, immaturity
- **purple** - royalty, wisdom, spirituality, nobility
- **blue** - peace, harmony, relax, trust, stability, coldness, meditation

- **green** - nature, wealth, growth, health, money, envy
- **brown** - earth, nature, security, comfort
- **white** - innocence, cleanliness, humility, goodness, sterility, cold
- **gray** - calmness, neutrality, balance, depression
- **black** - power, elegance, mystery, sadness

Each of the colors has positive and also negative attributes. The way we feel about it depends on what and how the color is used. The large surfaces of pure colors (Hue = 100 %, Saturation = 100 % and Brightness = 100 %) may be perceived as excessive stimuli and evoke the negative attributes of that color.

The study [148] says preschool children prefer warm and bright colors. Most people, even children, have an affixed association of red color with danger and aggression, punishment. The yellow color is often used for warning. Those colors should be used moderately and should not be used in a pure way as background color or as filling of large areas on the screen. Cold colors are appropriate to use for backgrounds and large areas on the screen as they have a calming effect. It may especially help hyperactive children to be more concentrated. [149] In both cases, it is better to focus on adjustments of saturation and brightness for each hue to achieve more pleasant colors for viewers.

Saturation and brightness effect

Pure colors (Hue = 100 %, Saturation = 100 % and Brightness = 100 %) are very intensive and eye-catching. It is confusing to pay attention to them for a longer time: they overstimulate the retinas and cause strain in the eyes. [150] To keep the user's attention for a longer time, I need to adjust the basic color palette of the user interface to milder, acceptable colors.

For a better demonstration of color settings and to experience the difference, I sketched a simple drawing with a thick black brush: I will adjust the drawing step by step to a better and more acceptable form. All of the following pictures were made in digital form in application Procreate 4, on Apple iPad Pro 11 (2018) with the usage of Apple Pencil (2nd generation). To see graphical content in the desired way, I recommend reading the rest of this section electronically on any screen with balanced brightness and contrast settings, in a room with moderate lighting and width of the document on the full screen. Images printed on papers may not properly represent the real color settings.

Firstly, I filled the picture only with pure colors.



Watch the image continuously for a few minutes and then ask yourself a question: "Am I feeling comfortable and relaxed watching the image?". You may probably think that the image is too loud and irritating. It gets our immediate attention as the colours are shiny and full, but the attention to watch the picture would not last long.

I adjusted used colors by reducing saturation and brightness values, the level of reduction was the same for all displayed colors in the picture.



Colors seem milder, not so distracting. However, the picture looks washed-out, charmless, the overall picture makes a cold feeling. The shades of green colors are similar to each other: warm colors became dull and too light, the blue color on the sky is still too shiny. It is needed to adjust each color differently based on the color's hue and the area on the image that should be

filled to get a better-looking image. I started to collect and apply colors from diverse sources. I set up some colors by myself and my selective feeling about the overall picture, other colors I found searching for muted colors palettes and safe colors palettes and also by using drop tool to get colors from pictures that I found out calming. I was trying to make the image feels warmer without the usage of too bright warm colors, because in general warm color objects are easier to remember compared to the cold color objects. [103]



I haven't set just one universal color palette, the optimal color palettes may differ based on the preferences of each person. I instead made a helping tool in figure 3.3 showing area of safe colors, no matter the selected hue.

I have set up a few rules to follow about colors:

- all colors used for graphical content should fit inside the safe area (that means not using pure colors and not using pure black and white) in figure 3.3
- larger surfaces should be filled with less saturated and less bright colors
- smaller parts may be filled with more saturated and bright color, but still need to fit safe area
- use enough contrast between objects on foreground and background, to not visually blend two objects together
- use the colors based on their real representation of objects (a banana is yellow, a leaf is green, etc.) or psychology influence (backgrounds, abstract objects, items that can have variable colors, etc.)

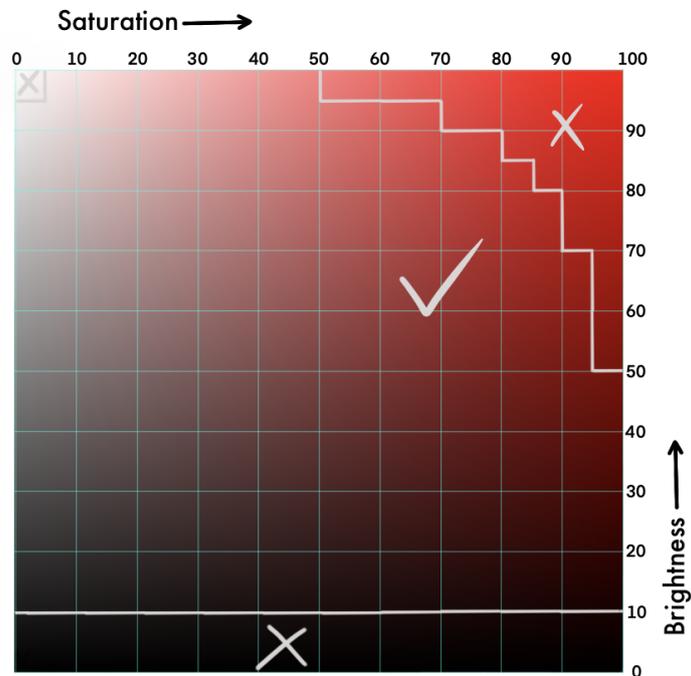


Figure 3.3: Safe colors area

- try to choose nice combinations of colors that keep the image visually pleasant as the whole image
- avoid too dull and almost colorless color combinations: color scenes are easier to remember than black-and-white ones. [103]
- try to prefer warm colors as the objects with warm colors are easier to remember than objects with cold colors. [103]

3.2.2 Using contour lines

Children with developmental dysphasia may have issues in figure-ground perception (differentiating the main object from the background). There should be enough color contrast level between two overlapping or touching colored objects to help them visually discern objects on the image. The shape of objects should be highlighted by using dark color contour lines or outlines. Those lines should be thick enough to give the cue and support the visual perception, but not too thick to look distracting.

I tried to apply this rule to the image from above for comparison, the lines are softer and have milder color (dark brown), but also they are thick enough to highlight shapes and details of each object.



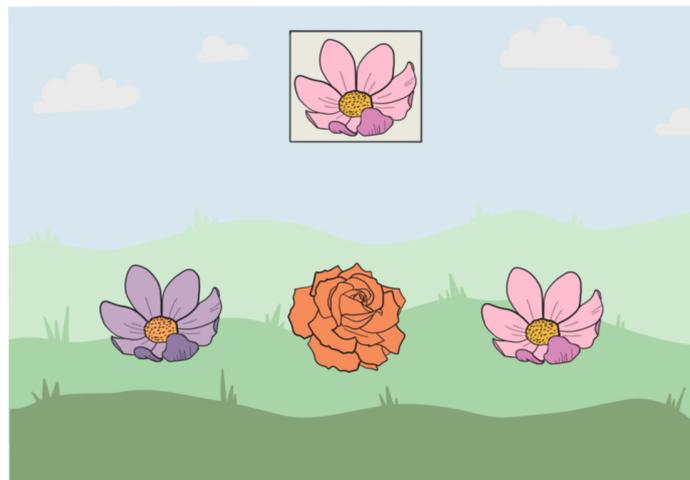
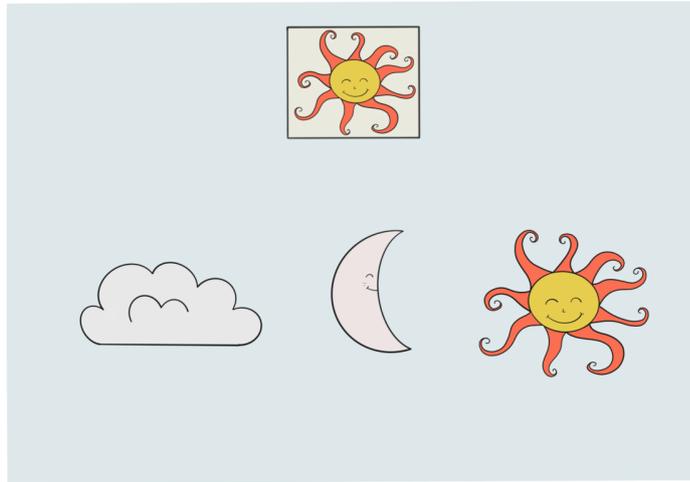
3.2.3 Screen content simplicity

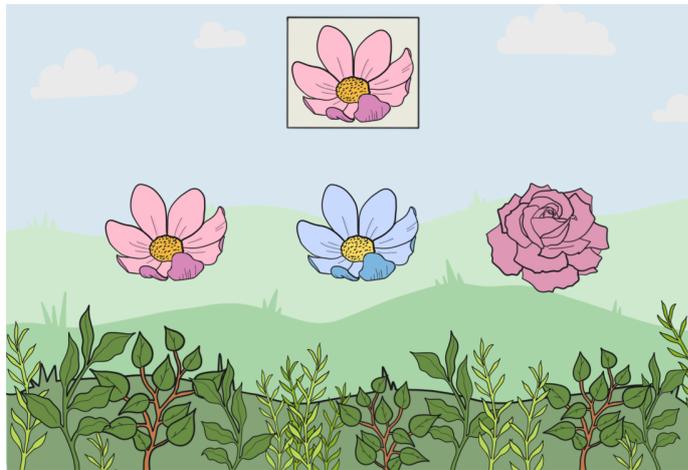
The figure-ground perception mentioned in previous subsection may be supported in an additional way. The screen should stay as clean and simple as possible, containing only the most important game elements and simple object images. At first, at the beginning of using the application, background should be a simple homogeneous area, so the objects placed on the foreground are easier to accept, recognise and remember. Later, when a child user gets familiar enough with the objects in the foreground, the objects may become a part of the background, because known objects are easier to discriminate. In this way, child users can gradually reinforce the skills of visual discrimination among more objects in more complex images. [70] I set up a few levels of background and content composition from the most basic combination up to most difficult and complex combination:

1. one-colored background, isolated objects in the foreground
2. simple background with shapes without any usage of contour lines or outlines, isolated objects in the foreground (often referred to as a flat background)
3. simple background containing shapes with the usage of contour lines or outlines, isolated objects in foreground

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4. complex background composed out of objects previously used in the foreground, foreground is a part of a background
5. complex background composed out of any objects (also new ones), foreground is a part of background

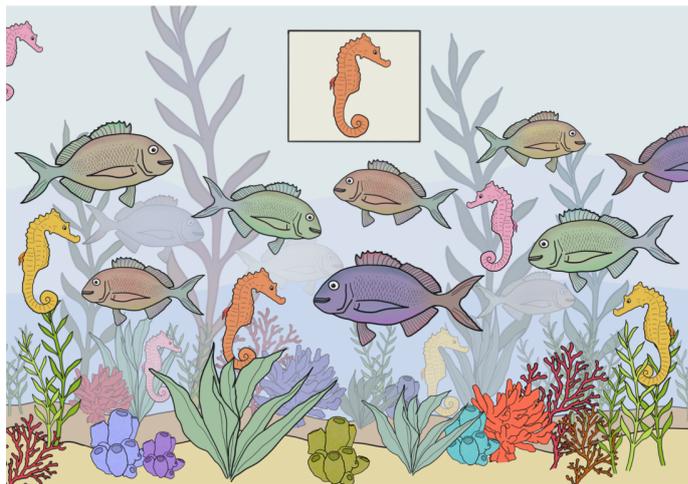




3



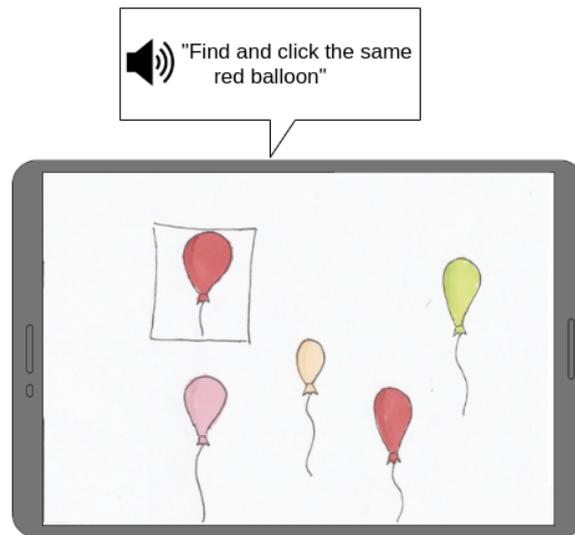
4



5

3.2.4 Audiovisual learning

A spoken message played from the device may not be understood entirely by children with developmental dysphasia. To enhance understanding of spoken content and instructions, we can involve one other sense - sight. The spoken language may be accompanied by visual cues showing objects or actions that are talked about on the screen. The opposite case is also important: to play names of objects that the user interacts with on the screen. It helps to make brain connections of listened names with the seen objects, to develop language.



3.2.5 Guide character

This feature relates with the previous one. In 1967, Mehrabian proposed the model 7 - 38 - 55 demonstrating the ratio of communication components and their effect on the information delivery among people. [151], [152] Only 7% of what we communicate is verbal (a literal content of message), 55% is visual communication (body language such as mimic, gestures, additional movements, and so on) and 38% is non-verbal vocal communication, called paralanguage (tone, intonation and volume). As children with dysphasia may have issues understanding, especially the literal content, their understanding is more dependant on the other two components in comparison with intact peers. If there is only basic voice record playing from the device (literal content), it is obvious the information is impoverished by the absence of the other two important components.

To add the visual part of communication to the literal content, we can place a virtual character on the screen. Children users should see who is speaking. Character's purpose is to fulfill the role of a protagonist, a narrator and a guide throughout the application. It should continuously reflect emotions and facial

expression associated with spoken content through animations of mimic and body movements. Another important reason to have a character on the screen is that therapy sessions are usually one on one, a counselor (usually adult as therapist, teacher, parent, etc.) and a client (child). The counsellor gives instructions, coordinates the activities, reinforces the child when answer is good, encourages the individual when the answer is bad, and tries to navigate him/her to the correct answer. I want to simulate the role of the counselor via the character. The character should be visible all the time, on all screens intended for children users.

Guide character has a significant impact on overall application likeability by children and on providing a productive and positive learning environment as well. Children would accept the application easier if they can feel some relation with the character, to consider it as a peer and a friend.

To achieve a positive attitude towards the character, we need to arouse the feeling of trustworthiness, safeness and interest in the child user. The character can be set by a combination of four main things - appearance, voice, personality and behavior. The first three are explained here and behavior is described throughout this section and in the following sections as it relates to other app features.

Appearance

I collected a few tips to design a character. The character should:

1. look cute

Cuteness is the key to appear trustworthy for children, as it arouses caregiving instinct, protective behavior, and dismantles fear and anxiety. [153], [154] In 1971, Konrad Lorenz came with the set of facial and body features called "baby schema" to make a creature appear cute. [155] The baby schema includes these infantile physical features [156]:

- round face, large head
- large eyes
- small nose and mouth
- high and protruding forehead
- chubby cheeks
- short and thick legs and arms
- plump body shape

To demonstrate the effect of Lorenz features, I created an example image in figure 3.4 with a step-by-step face transformation from a boring basic face to a cute face. I extended the Lorenz schema with my own additional steps which I found to make even cuter face.

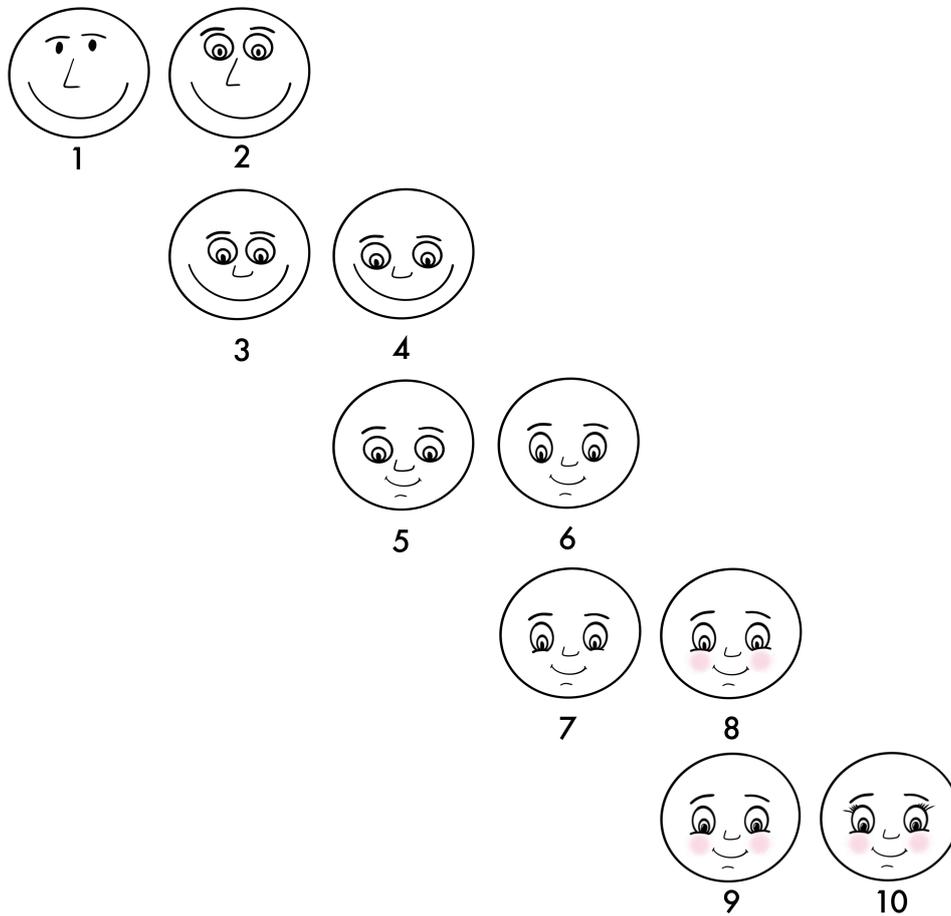


Figure 3.4: Cuteness sequence

- 1 - round basic face
- 1 to 2 - bigger eyes
- 2 to 3 - smaller nose, eyes moved down, closer to the middle of the face, forehead looks higher
- 3 to 4 - longer distance between eyes
- 4 to 5 - finer mouth, chubby chin
- 5 to 6 - shape of eyes from circle to oval
- 6 to 7 - concave eyes, chubby cheeks
- 7 to 8 - pink cheeks, eyebrow rotation and position
- 8 to 9 - reflection in the eyes
- 9 to 10 - eyelashes

2. don't look too cute

The extreme cuteness may be distracting, overwhelming and lead to something called "cute aggression". [157] It is hard to find the borders between cute and extremely cute, the advice is to use cuteness criteria for design characters moderately.

3. share a similar visual style with humans

The character should have human-like facial and body features to be able to properly visualize facial expressions and body movements as a part of the communication. It means the character should be a complex drawing with eyes, nose, mouth, eyebrows, head, arms, legs, torso and so on.

4. be exaggerated

As one of the Lorenz features is to exaggerate the ratio of head and rest of the body to pinpoint head as an important part, the exaggeration can be used to pinpoint any other important trait or emotions of a character. For example, if the character should look strong, exaggerate muscles on the body. If the character should look happy, exaggerate the smile and facial expression.

5. be original, distinctive, quirky

People are, in general, more likely to memorize and recognize something/someone with distinctive features. [158] One of the ways is to use exaggeration from the previous point or just add any special features making the character visually different and special.

6. be colored by well considered colors

Character personality and persona

Persona is a social role. Personality is a set of qualities, behavior, habits, aims, interests, emotional patterns, and other factors that make oneself unique. A character without personality and persona is hard to relate to; it can act boring, dull, humdrum. The stronger the personality set to the character is, the stronger the experience and inclination towards the character by children users may be.

In a game for children, especially for children with some disability, the protagonist - the main character, should act as it is on the children's side. It means to be motivational, positive, charismatic, warm, sensitive, supportive, unassuming, and so on. A character should have a name, some story about its life or aim in the game. It can be strengthened by game background story that I will write about later.

Character behavior

Character in a narrator role should be a non-playable character as it is on the screen for the purpose of support, not as a main user-controllable element. However, the possibility of some interaction is strongly recommended. Interactions can strengthen the connection of children towards the character and towards the game and its content as well. For example, a character can say something or move when it is tapped by the user. It might be helpful for dysphatic children to have a possibility to repeat instructions when a child user taps on the character during the game at any time and as many times as needed.

Character voice

Voice is often neglected in the user experience (UX) field as it is an invisible interface. But the non-verbal communication component (paralanguage) has a non-negligible impact on receiving the overall message by a listener. Tone, intonation, volume, and quality of voice all reflect the speaker's attitude.

I collected a few properties that may affect a paralinguistic of character's speech in a desired way, however the perception of diverse voice settings may differ from person to person:

1. using a pleasant young voice

A pleasant voice is subjective to each listener's preferences and hard to define. When choosing the person for dubbing the character, we should consider his/her voice quality and the effect on the listeners. People consider voices from younger people more trustworthy than voices from older people. [159] The voice should sound warm, soft, soothing, with no tension, and should sound confident.

2. keep the sound continuous, harmonic

The intermittent sounds should be avoided as it can disrupt the concentration of child users or may feel unpleasant. The transition from one utterance to another should be smooth and harmonic.

3. clear speech

The speech of the character should be recorded and played without any background noise. The emphasis should be placed on good pronunciation, adequate speech tempo, generic prosody, and intelligibility.

4. speech volume and pitch

The best volume and pitch are the same ones we use in a normal speech. Avoid screaming when it is not needed. Scream wins our attention, but not in a positive way because it can cause roughness. Also avoid an extremely high or low pitch.

5. intonation

The speech can increase its dimensionality with the proper use of intonation. Speaker's effort into speech and a desirable level of volume and pitch serves as an emotions carrier, as an invisible information carrier and also juices up the listening pleasure.

Character creation

I set up my own character based on my collected tips about it. The process of getting a final graphical representation of character consisted of several rounds of brainstorming, sketching, and drawing.

I would like to introduce Bruno, a boy character for my game, to you. In figure 3.5 we can see the first paper drawing representing the character used for wireframing, the digitalization of the same for the first prototype, and the final form of character drawing for the final prototype.

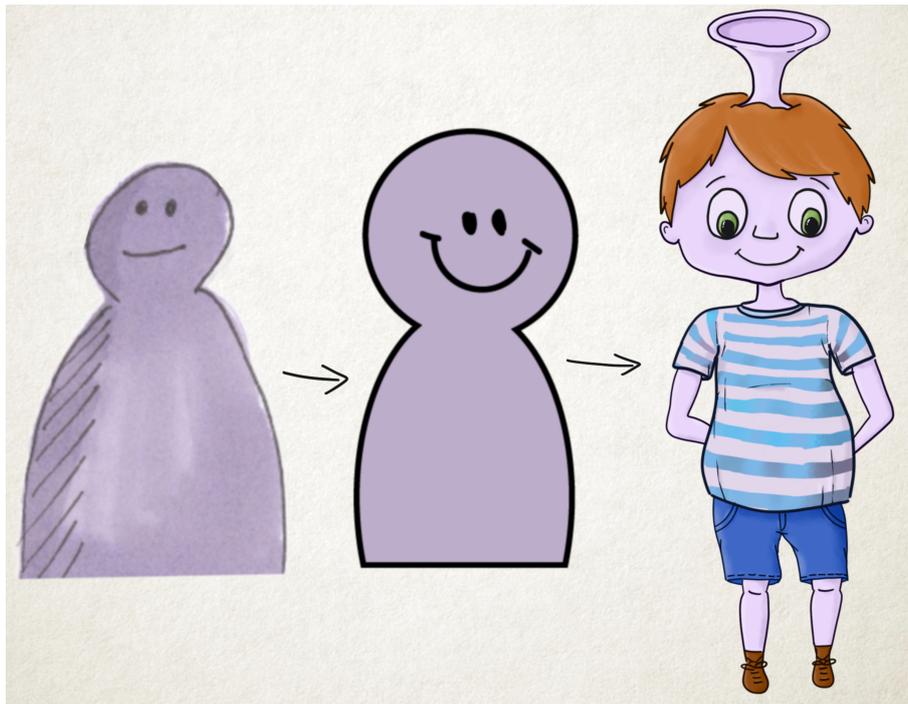


Figure 3.5: Bruno, game character

I decided to use cold colors for coloring the character as it is a boy. All used colors fit the safe area from figure 3.3. A very light purple color was used instead of the white, color and very dark colors were used instead of a black color.



Bruno looks like a preschool child, has a human-like visual style and looks friendly, trustworthy, and cute. The distinctive thing about Bruno is especially his purple skin color and a funnel on his head. The funnel works to visually exaggerate happiness. The happiness is not only visible through appropriate facial expression, but also by popping stars from the funnel. It is another non-verbal cue for children with developmental dysphasia to recognize Bruno's positive attitude.



3.2.6 Using children's language

In the guide character feature 3.2.5 I described the desired paralinguistic features of speech. Here I would like to give a room to the literal content of speech. This feature also reacts on Nielson's rule number 2 (match between system and real world), from chapter 2.4, from the perspective of the voice user interface.

Children acquire speech patterns from what they hear. [160] Literal content of any talking in the application should reflect natural language from children's environment.

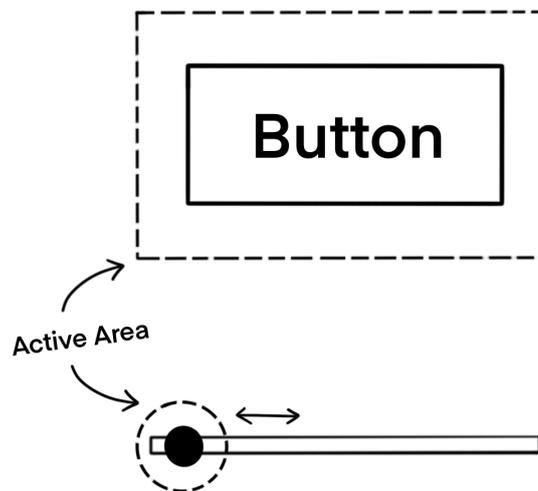
We should avoid using spoken abbreviations (such as "LOL" for laughing, "BFF" for best friends etc.), some specific less-known loanwords, specific jargon or specific dialect (such as word "šnuptychl" rarely used in Czech language for tissue instead of "kapesník", "fusekle" for socks instead of "ponožky", word "šalina" used in Brno city for tram instead of "tramvaj" etc.), other unimportant rarely-used words or vulgarisms. One reason is to make the language more understandable; the other reason is that children's vocabulary should be gradually extending by fixation of most basic and common important words from daily life. Some specific words may be inappropriate or irrelevant, causing words glut. The application should be focused on teaching the most frequent words from children's environment, to make the connection of the word with visual representation, and to remember vocabulary for later practical use.

3.2.7 Gesture control

Dyspraxia is a commonly occurring symptom in dysphatic children. They may struggle with motor and graphomotor skill, and they may find it difficult to be accurate when controlling the application, such as touching an exact place on the screen, touching and holding, sliding with a finger on the screen, using more fingers at once and so on.

The application can be used to train and fix those specific motor skills of the hands and can be adjusted to be easily controllable by children users with those problems. The complexity of each gesture is composed of the type of the gesture itself and the size of an active area or element which is needed to complete the gesture.

The easiest hand control gesture is a basic single tap. It is easier to tap something when the tappable area (active area) is big enough. When the tap area is big enough, even children users with very poor motoric skills should be able to successfully master it.



When one gesture skill is acquired, the more difficult skill may take a turn, or the active area can get smaller to increase the difficulty and to train the accuracy of the movements. I ordered gestures used for games by motoric difficulty. Those can be seen in figure 3.6. In application, those gestures should be trained one by one, gradually with a combination of previously fixed gestures and active area reduction.

1. tap
2. touch and hold
3. slide

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4. double tap
5. drag and drop
6. pinch open/close
7. tap two fingers
8. tap three fingers
9. touch and follow path

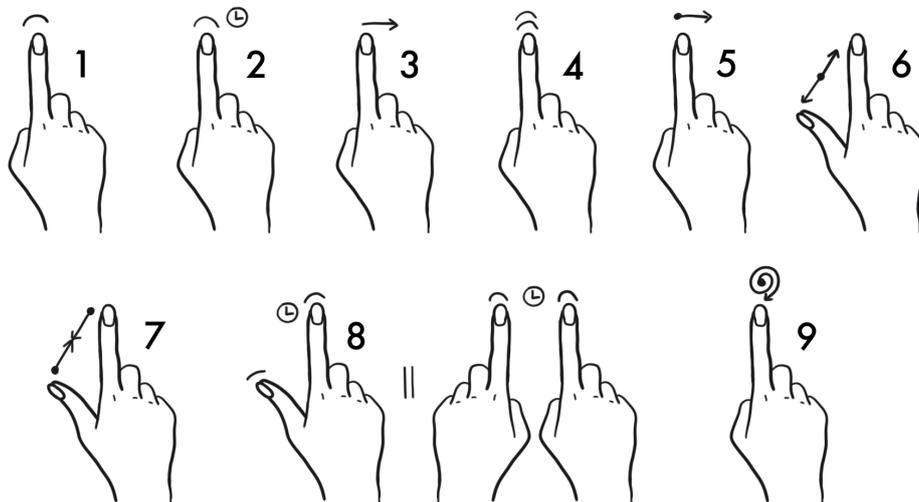


Figure 3.6: Gestures

- 1 - tap
- 2 - touch and hold
- 3 - slide
- 4 - double tap
- 5 - drag and drop
- 6 - pinch open
- 7 - pinch close
- 8 - tap two fingers
- 9 - touch and follow path

3.2.8 No time limitation

By setting a time limit on performing any task, we expose children to time pressure which causes bad stress. The bad stress, also called as a toxic stress or

distress, is something we should try to minimize and avoid. It affects decision making, perceptual, cognitive, and motor performance, influences our brain development, and it may also lead to negative psychological and behavioral lifelasting disruptions and health effects. [161]

There should not be any countdown and even time counter on the screen, as it would be distractive and stressful. Any other form that can be understood as a time limitation should also be avoided, such as a sound of ticking clock, a graphical representation of passing time, etc.

The time should be measured, but only in the background, so children users will not know about it. One reason is to keep user statistics, and the other one is to show the help dialog to users in exercise after some time passes without any user response.

3.2.9 Avoid sad and inappropriate content

Bad stress can be induced not only by limitations and pushing someone to better performance but also by exposure to inappropriate content. It includes topics and graphical representation about death, serious illness or injuries, sexual content, violence, and so on. If those topics should be included in the game content for educational purposes, it should be served very mildly, with great caution. For example, if children should get familiar with common injuries, we can show a picture of a boy with a small cut on his finger with a drop of blood, but we should avoid a scary scenario such as amputated limb with blood splashing everywhere.

Another inappropriate content that is problematic comes from advertisements. It can show inappropriate content because it is usually a content from third parties, and it also distracts attention. It is better not to include any advertisements, even if it is the only profit for some game makers.

3.2.10 Repetition

Children with developmental dysphasia may have issues with memory, especially short-term memory. The principle of repetition is the foundation of success. It is a powerful method of learning; it builds ways in our brains, strengthen synapses and helps to fixate the acquired knowledge and skills. [13]

To remember new information, we usually need to repeat the same information several times at different intervals. The information will be stored in our working memory first, then it moves to short-term memory, and then it can be saved to our long-term memory. The repetition can be driven by using exact graduated intervals. Based on Ebbinghaus forgetting curve (curve describing the decrease in the ability of the brain to retain memory over time) [162], In 1967, Paul Pimsleur came up with a set of basic intervals for new information reminding, and he called them as graduated-interval recall: 5 sec-

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onds, 25 seconds, 2 minutes, 10 minutes, 1 hour, 5 hour, 1 day, 5 day, 25 day, 4 months, 2 years. Pimsleur’s method of repetition in the set of graduated intervals helps to keep learned information in memory; it facilitates and significantly speeds up the language learning process.

In practice, exercises in the game should contain and train words using graduated intervals to repeat the word in various exercises in diverse situations.

3.2.11 Slowing feature

Children with an attention deficit disorder may tend to rush in trying to accomplish a task just to get it done. [163] When the focus is concentrated mainly on answering tasks quickly and thinking about the task is usually superficial.

I was thinking about how to slow down these child users, and what slowing feature I should add to the application for children. It has to be something known from daily life, easy to understand by anyone. My first idea was using a semaphore with a progress bar in the top corner of the screen. Application would not accept any answer when the red color is visible. Users need to wait until the green color appears. The time of the semaphore showing red color would vary based on the user’s speed and answers accuracy from previous exercises.



But there is an issue: not all the children are familiar with a semaphore. Also, I would like to avoid using bright red color in the user interface, when it is not necessary. During my class MI-NUR (user interface design class) on our faculty, my team and I came up with another and better solution. The main character will take a nap after the question is assessed. Child users have as much time as they need to think and process the answer. They can tickle the main character on his belly any time: the main character will wake up and child users can answer the question. It is easily understandable and clear

for children when is the no-answer time and when is answer time. Beside the slowing feature, it is also an entertaining interaction with main character.



3.2.12 Control buttons

Buttons used in game application should follow design rules based on their functionality. If the button is intended for adults, such as the button to the user's administration or buttons to go back, the appearance should not attract child user's attention. It can be achieved by the following:

1. Place the button out of the main area of the game, usually to the top corner
2. Make the button small
3. Use dull, unsaturated color for filling the button icon
4. Use button childlock (the action of the button will trigger after holding for 5s, click the button several times, button is needed to swipe instead of click, etc.)

On the contrary, when the button is intended to be clicked by a child user, we can do the opposite - make the button bigger, use a saturated color, place the button in the middle of the screen.

3.2.13 Motivation

Motivation is one of the principle applied in speech therapy and also in games as the driving force to surpass oneself. It can be divided into two types of reinforcement: reinforcement and feedback.

Reinforcement

Reinforcement means to enhance the desired behavior and increase the likelihood that a response will occur. There are two types of reinforcement - positive and negative (punishment). The negative reinforcement should be avoided in the game application. [164]

Positive reinforcement is adding a pleasant stimulus to strenghten the desired behavior. [165] When teacher gives chocolate to a child as a reward for drawing a picture, the pleasant stimulus is the chocolate and the desired behavior is drawing a picture. In game development, the desired behavior is answering questions and finishing tasks. The pleasant stimulus is limited in game development, as it can not be anything material. All the possible pleasant stimuli (the reward) have to be virtual. Most of the games use virtual money as a reward: users are collecting coins for accomplishing tasks. I instead came up with an idea about collecting stars because I think the accumulation of wealth is not a good example for children.

The number of stars serves as an indicator for children users that they are moving forward. Child users should not see the number of stars of other child users, because it is not an indicator for their comparison (some children may be significantly slower or less successful in accomplishing tasks and have fewer stars than others)

Feedback

The application should signalize correct and also wrong performance throughout the game. Child users need the reflection, they can learn from their own mistakes and improve in the next attempts.

However, how the feedback is served is very important. Especially in the beginning, child users with developmental dysphasia may need more attempts to find the correct answer, and no one would be happy to continuously watch a big shiny red X mark on the screen with audio saying "Oh, no, you did a mistake!". It would probably lead to a quick rejection of the game by child users and might negatively affect self-esteem. The information about a wrong answer should be clear, but minimalistic. The big red X mark can change to a small, less saturated pink-red X mark with the audio reinforcement "Try again, you can do it!".

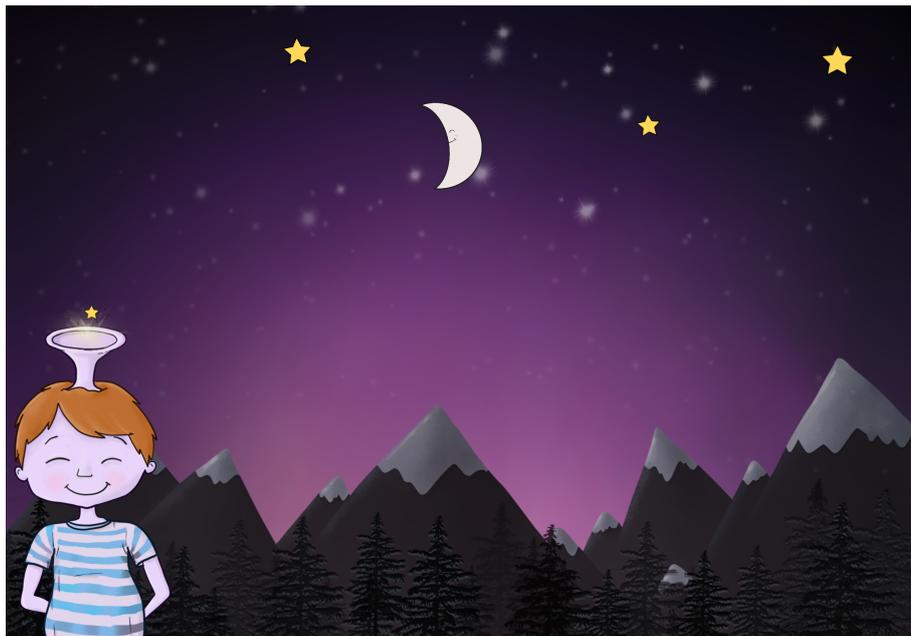
The reaction on the correct answer may be a bit exaggerated, as it is a confirmation of success.

3.2.14 Background story

The game is always better when there is a plot and the tasks have some aim. It's much better when a user can influence the story by themselves, it strengthens motivation.

In previous application feature, I mentioned rewards in the form of collecting stars. Bruno is flushing stars out of his funnel when he feels happy - such as when a child users select the correct answer or finish the whole level. The stars are then added to the total count. But why?

My idea of the background story contains a scene of the night sky without stars and Bruno complaining about it. However, there is a solution! He can change some amount of the small stars flushing out of his funnel to real stars and can place them in the sky. Child users then collect the small Bruno's stars throughout the game and exchange them to fill the sky with real stars (or other astronomical objects and bodies). In following image, my preliminary graphical draft of this idea is shown.



3.2.15 Summary

In order to react on constraints from chapter 2.2 I came up with diverse features for user interface to make the game application for children with developmental dysphasia more profitable and supportive. In table 3.1 can be seen which application features reacts which constraints.

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	Color setting	Contour lines	Screen content simplicity	Audiovisual learning	Guide character	Gestures control	No time limitation	Using children's language	Repetition	Slowing feature	Control buttons	Motivation	Background story	Covered by app features
C1				✓	✓				✓					✓
C2				✓	✓				✓					✓
C3				✓	✓				✓					✓
C4				✓	✓				✓					✓
C5				✓	✓				✓					✓
C6														✗
C7														✗
C8														✗
C9														✗
C10							✓							✓
C11							✓				✓			✓
C12										✓		✓		✓
C13								✓		✓				✓
C14						✓			✓					✓
C15									✓					✓
C16														✗
C17														✗
C18														✗
C19														✗
C20														✗
C21														✗
C22	✓	✓	✓											✓
C23			✓											✓
C24					✓									✓
C25														✗
C26	✓	✓												✓
C27	✓	✓				✓								✓
C28														✗
C29												✓		✓
C30													✓	✗
C31						✓								✓
C32											✓			✗
C33														✓

Table 3.1: Constraint coverage by application features

3.3 Wireframes

Before implementation, it is a good idea to think about screens, their layout, and content. Wireframing is one of the very important phases in software design. It is a quick and simple illustration of the user interface design, including the size and positions of the elements, app features, and navigation. [166], [167] The word "wire" in wireframes stands for using black lines on a white background as wires for drawing the user interface as simply as possible. It is also called a low-fidelity (lo-fi) prototype. There are plenty of online or offline and free or paid available tools on the internet for an easy wireframe creation. But still, a quicker way is just using pen and paper, which was my first choice when I planned to draft my ideas in the beginning. I could not resist using colors and shapes when drawing my ideas, so instead of creating basic black and white typical wireframes, I made them more specific, something between wireframes and mockups (mid-fidelity prototype). They contain colors, graphical content, and they are more similar to the desired result.



I used A6 plain papers, black liner, and Promarker alcohol-based markers for creating wireframes .

3.3.1 Screens description

In figure 3.8, we can see the wireframes flowchart of the overall application with the simplified representation of exercises (exercises are discussed in detail in the following section). In figure 3.7, there is the same diagram, simplified, with labels of the screens. Based on the purpose of the actions, screens can

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be divided into two sections - screens for adults and screens for children. The starting screen is an entering gate to both sections and is as simple as possible because it is the only place with the opportunity to switch between those two sections and only place intended for child and adult users at once.

By clicking the icon with users in the right top corner, the administration section will open. Adult users can create new child users, edit them, delete them. They can adjust different setting for each child, compare results and progress of all children and see detailed statistics of each child.

Child users can easily get to their game space by clicking the row with their photo avatar on the start screen, without the need of any reading skills (only if they are already added to the children list by an adult user). Section for children contains Bruno character displayed on all screens. Bruno is giving instructions and guides children, so children should be able to go through levels and exercises independently of adults.

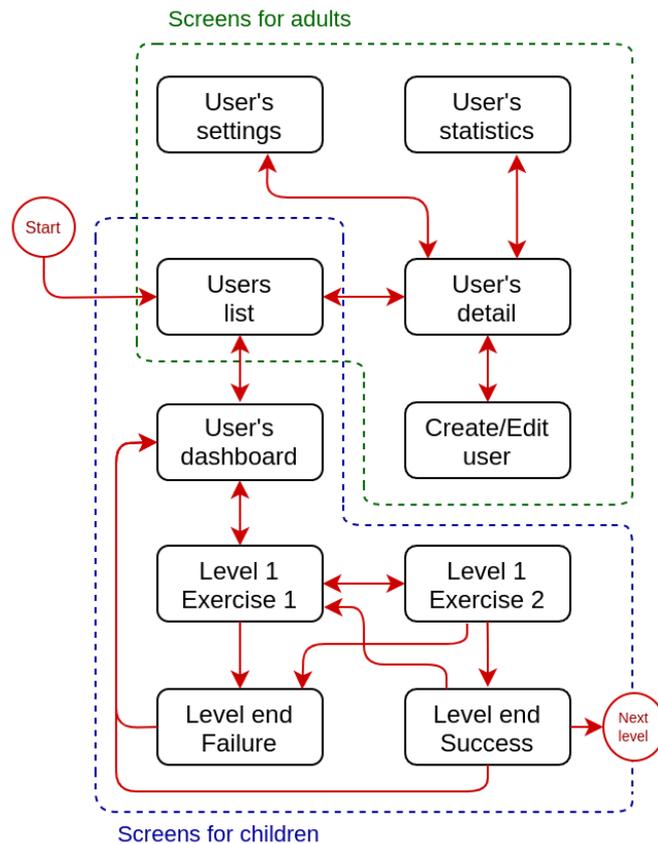


Figure 3.7: Screen flowchart

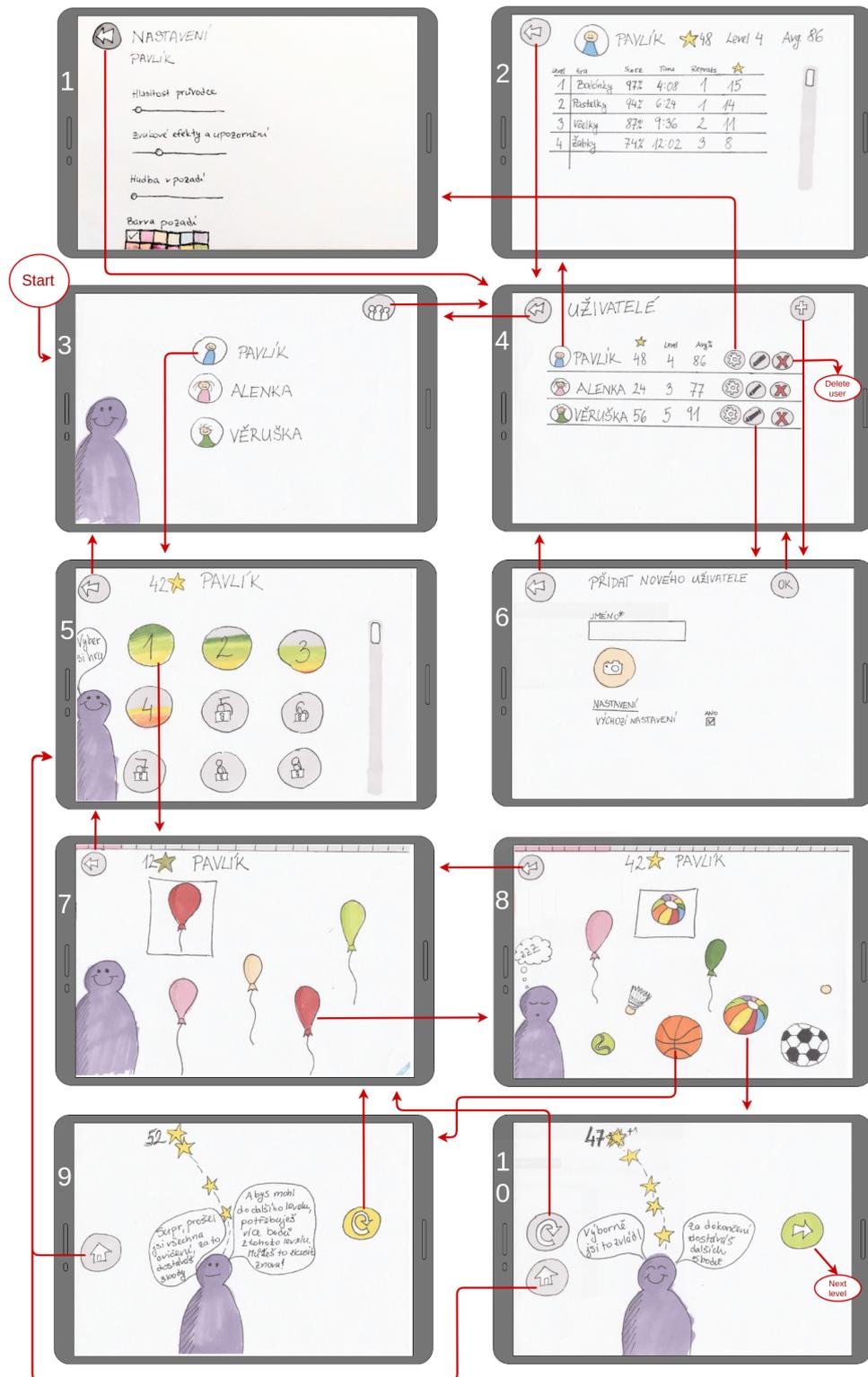


Figure 3.8: Screen wireframes flowchart

3.4 Level/exercises outline

I set a few application features oriented on user interface and user experience in chapter 3.2. The necessary counterpart to that is the real content: the games that should be strengthening child user's settled skills and also supporting and developing the unsettled and new skills.

In the beginning, I would like to explain what is a level and what is an exercise in the context of this thesis.

Each child user has his own personal section with a game board composed of unlocked and locked levels (frame number 5 in figure 3.8). One level is determined to train one new specific task or a skill through a set of exercises (or to train a set of previously trained tasks or skills in higher levels).

It is needed to successfully pass the current unlocked level by getting at least a minimum required score to unlock the next level. It is counted as right-to-wrong attempts ratio. The flow of the game can be seen in figure 3.9 and it visualizes the game concept together with figure 3.8. Unlocking the levels linearly one by one allows us to control the training of the new skills gradually: from the basic ones to the more complex and difficult ones with the affirmation that the all previous skills were trained well.

3.4.1 Trainings

I prepared tens of different pieces of training to the game application for children with developmental dysphasia. Those trainings are focused on various cognitive skills, motor skills, memory, etc. Each of them serves as a demonstrative exercise for one level, so the level consists of many exercises made by modifications of the demonstrative exercise (for example changing the set of objects on the screen for different sets of objects as it can be seen on frames 5 and 6 in figure 3.8).

The order of how the pieces of training would be used in the game needs to be well considered to start the first level with the easiest one, train the current skills well and continuously raise the difficulty in the following levels.

Several factors which influence the difficulty are:

- Manipulation difficulty

One of the application features 3.2.7 talks about the size of the clickable area of a button and diverse gestures that can be used to control the application. The gesture and accuracy needed for task completion determines the manipulation difficulty.

- Logic difficulty

This factor considers the complexity of the task by the need for active thinking about the task. Some pieces of training are focusing on one

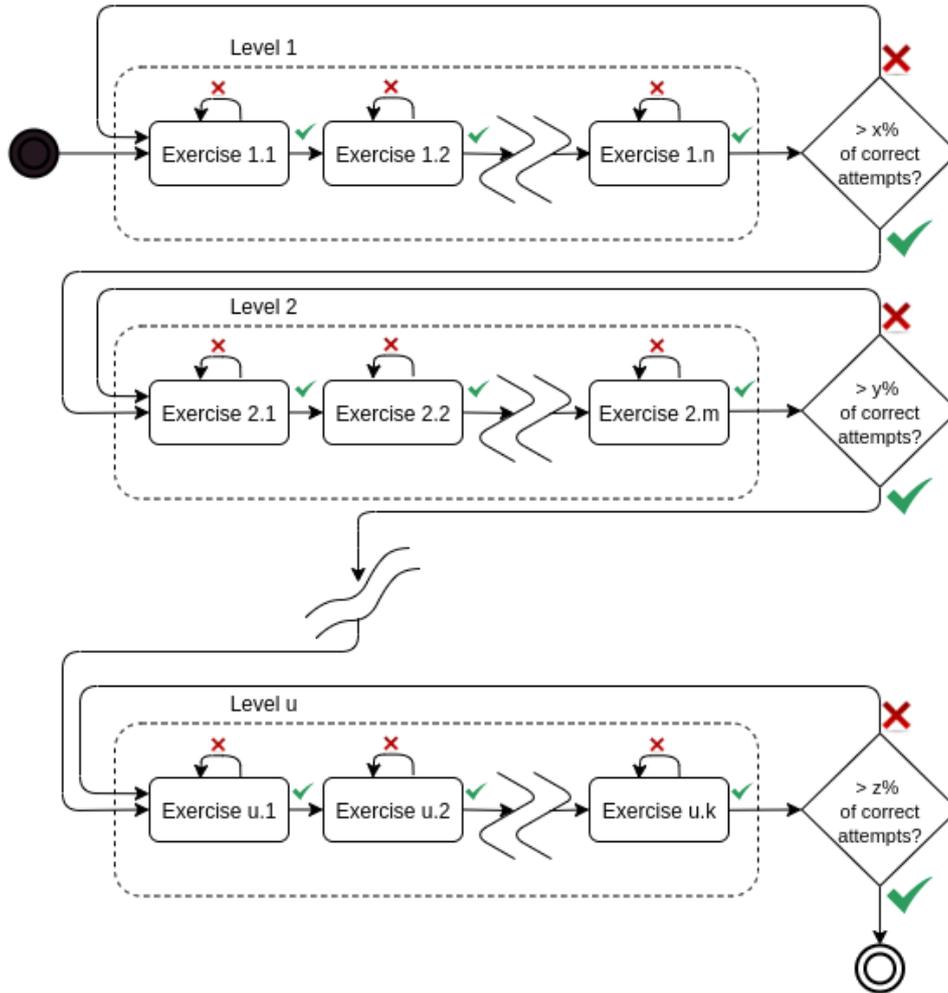


Figure 3.9: Game flow diagram

single task and are logically easy to accomplish. Other pieces of training require a logical composition of several aspects to find the correct answer.

- Specific focus

In some pieces of training, I tried to focus on areas that are often problematic for dysphatic children, such as training singular/plural, spatial processing, rotation and transformation, visual closure (what is missing to complete the image), etc.

- Trained layers

In a chapter 1.5 about how are people processing input and output information, I described the process of receiving, processing, and expressing information by humans in several layers in figure 1.2. All of the layers are crucial even for visual processing and decision making that should be trained in this first stage of speech support, in an application for enhancing visual processing based on plan 2.3. For processing tasks in the pieces of training, some of the layers are less or more involved based on the complexity and intention of the task. This factor is the most important, as the pieces of training should be completed in the order of how many and which layers (from the top) are crucial for solving the task.

I described and rated each training based on difficulty factors. Manipulation difficulty and logic difficulty are rated with stars. One star is the basis, and the difficulty grows with each additional star.

I selected a few pieces of training to show and describe their difficulties, in figures 3.10, 3.11, 3.12 and 3.13. Other pieces of training, over 60, are available on the attached media.

3.4.1.1 Trainings patterns

In software development, one of the known foundational principles is the term DRY, meaning "Don't repeat yourself". Simply said, whenever you write something twice, it can be done more efficiently. [168] Since now I have tens of various pieces of training and I expect to continue creating more and more of them without limitation, it is needed to save some effort and don't write duplicate code.

From the view of software development of the pieces of training, we can see they have something in common - generic layouts. There are few basic layouts patterns repeated in various pieces of training, the example of two patterns is visible in figure 3.14. The layout pattern can be implemented as templates that will serve as a base for the resulting training creation.

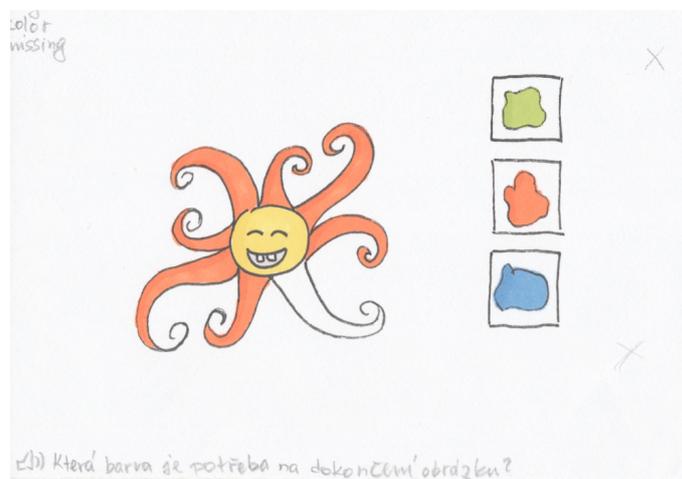


Figure 3.10: Exercise example 1

Task Find the right color to finish the image

Name Single color missing

Logic difficulty *

Manipulation difficulty *

Layer focus Attention, Discrimination



Figure 3.11: Exercise example 2

Task Move the puzzle pieces to right places

Name Drag drop multiple shadow

Logic difficulty ***

Manipulation difficulty **

Layer focus Attention, Discrimination, Organization

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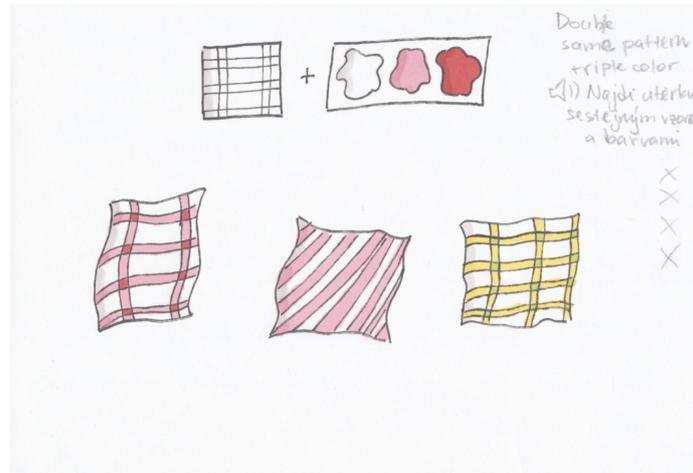


Figure 3.12: Exercise example 3

Task Find the right dishtowel
Name Double same pattern triple color
Logic difficulty ****
Manipulation difficulty *
Layer focus Attention, Discrimination

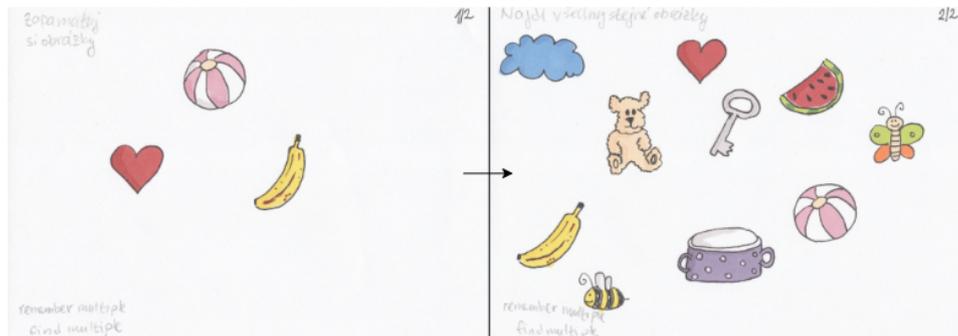


Figure 3.13: Exercise example 4

Task Remember objects and then find them
Name Remember multiple find multiple
Logic difficulty ****
Manipulation difficulty *
Layer focus Attention, Discrimination, Working storage layers

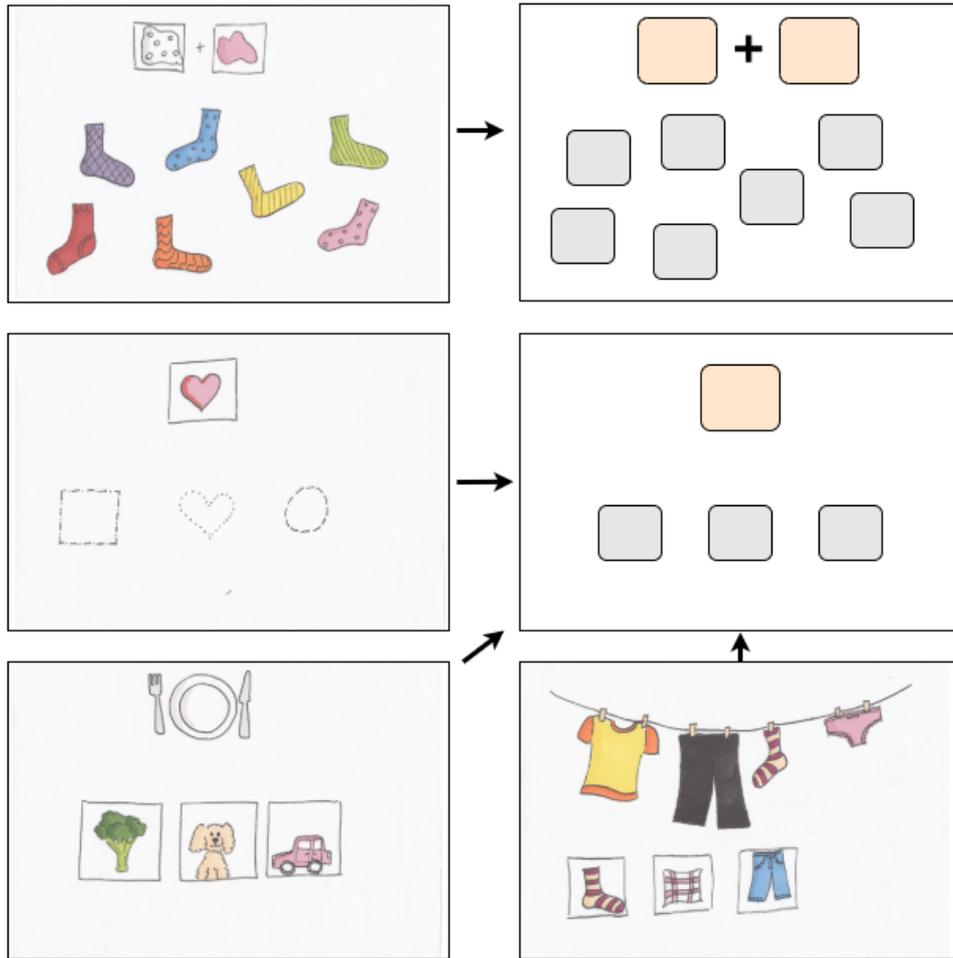


Figure 3.14: Example of common patterns

3.4.2 Summary

In trainings, among other things, I tried to cover some constraints that I described in chapter 2.2. The constraint coverage doesn't mean bringing a solution or dismantling that issue in dysphatic children, but it means I added content to train their possible weaknesses and support their development in those areas in the game application.

The following constraints are born in mind of the designed pieces of training: C15, C16, C17, C18, C20, C22, C23, C24, C25, C26, C27, C28, C29, C30, C32.

3.5 Architecture

The way we define an architecture is critical to the smooth functioning of the application. First, I will describe what the most decisive and influencing circumstances of the application are.

1. As we have seen in the previous chapter 3.4, the game content is going to be very expansive. For now, I have planned for more than 60 levels: each of those levels consists of several to many exercises to practice diverse skills. I assume the number of exercises is not finite yet as I am still coming out with new ideas. One thing to bear in mind is that I need a solution that would allow me to extend and maintain the app content and to add new/edit levels and exercises at any time.
2. Another thing to consider is the data volume. Application size is one of the decisive factors when you want target users to download and keep your app. The size of data will grow in proportion with the number of levels/exercises, as most of the graphical content for exercises is stored as raster images. Some reductions can be made during the app development lifecycle by using a few tips such as image conversion, redundant code removal, etc. [169], but it would not be enough for large assets. Google Play limits the installation APK (Android Package Kit) file size up to 100 MB, with an option to use additional APK expansion files, which can store up to 2 GB of additional data each. [170] Android App Bundles can be used for downloading application data on demand. [171]
3. The third issue is the way of obtaining data statistics. I would like to collect progress and data about all answers from all users using the application. It serves not only to see the user's success but also as a feedback for further improvements and development.

It is obvious the simplest solution, one APK file including all the data, is not sufficient. I need to move towards a more sophisticated solution to the usage of client/server architecture, which offers more variability.

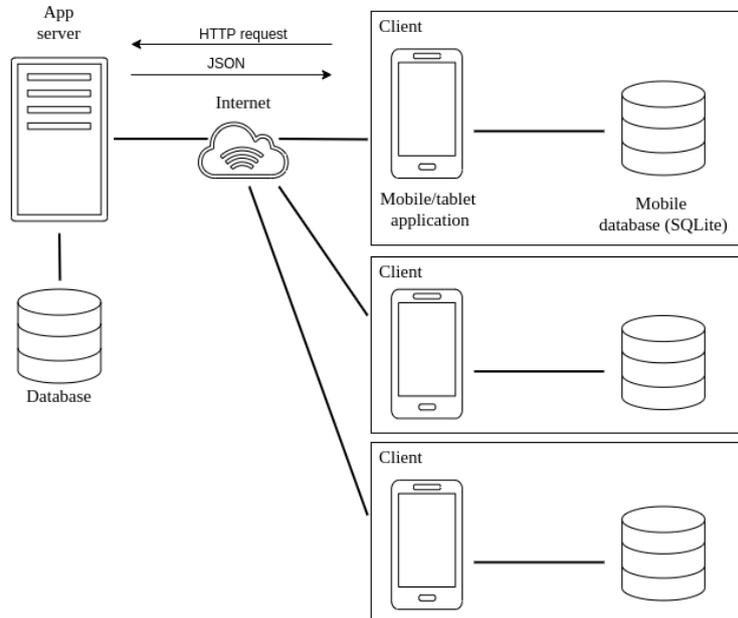


Figure 3.15: Architecture solution

3.5.1 Client/server architecture

Client/server architecture is a computer network in which a client requests and receives services and resources from the server side. There can be more clients connected to a central server over the internet connection. [172]

In figure 3.15, a three-tier client/server architecture for our game is designed. The client represents an application in an Android device installed by APK file from Google Play, defining the application logic. The application uses local storage (SQLite database) and is the place where all the game data are stored after an installation of APK file. The initial APK file from Google Play may have a small size and contain only basic assets needed for the first interaction with the game because we can use the advantage of external storage and getting further data on demand. The application will request data from the server for further playing automatically on the fly, in small chunks, when internet connection is available. If the internet connection is not available, users still can play in offline mode all the games in the application whose data have been previously downloaded. All levels and exercises are keeping their version number.

Widely used REST API is suitable to mediate communication between server and application. API (Application User Interface) is a set of rules allowing systems to talk to each other, REST (Representational State Transfer) determines what the API looks like. [173] It is a software architectural style

making easier communications between computer systems on the web [174]

To maintain levels and exercises data, REST API would provide three endpoints accessible by GET HTTP method. One endpoint provides JSON file containing the actual version of application and list with all levels and exercises overview including their name, path and the number of actual versions. The second endpoint serves for getting JSON with data of the exact exercise or level, including the definition of level/exercise and paths to download needed binary data - graphical and sound content. The third endpoint serves to get those binary data. When the version number of any level/exercise from the server response doesn't match the version of level/exercise in the application, the application would send a request to the second and third endpoints to get updated data of that level/exercise.

The application will send data about user's answers to the server in JSON format using POST HTTP method, when an internet connection is available. We need to keep those data for complex statistics of progress and success for levels/exercises adjustments, additional development, and evaluation.

Because the application is not directly dependant on the server and can be used offline, the server's downtime may not be as critical for application users.

3.6 Domain model

I created the following domain model 3.16 and class diagram 3.17 representing my intention based on functional and non-functional requirements from chapter 2.7, the application features from chapter 3.2 and explanation of levels/exercises in the game from chapter 3.4

I would like to clarify a few things:

- The user entity's function is keeping information about each child user. Adults don't need to register or login because the adult section is uniform and shared, it can be accessed and adjusted by an adult using a shared device.
- Each answer for each exercise from each child user is stored with additional parameters, those are needed to assemble detailed statistics of each child user.
- System entity takes care of downloading new levels and their exercises when the internet connection is available. It also uploads the score of each user to the server.

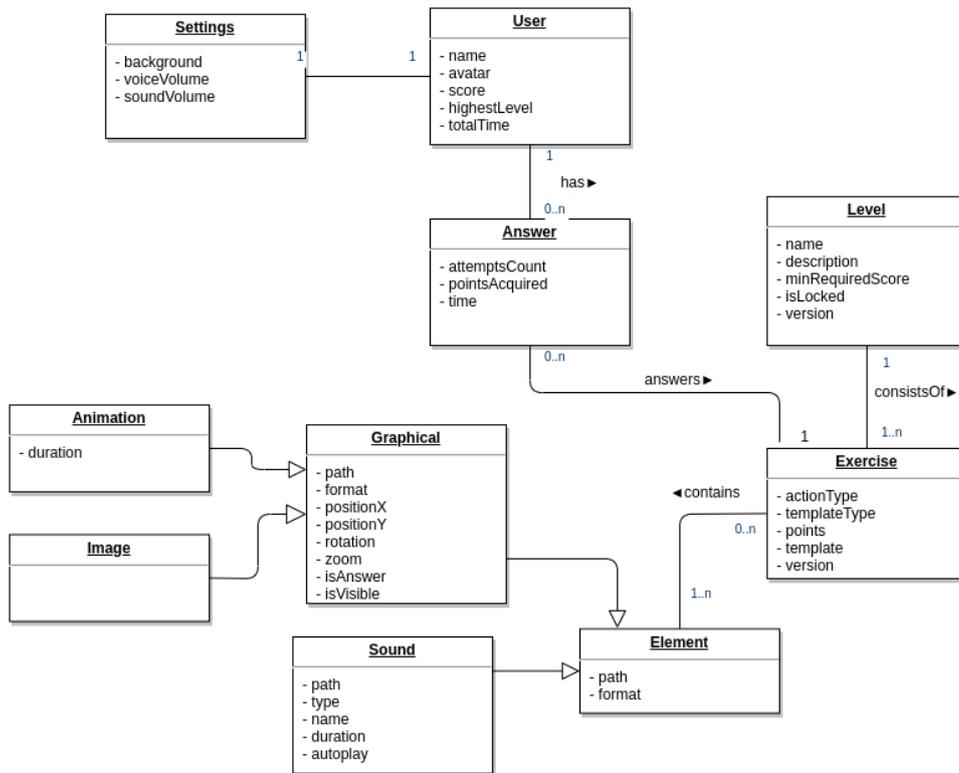


Figure 3.16: Domain model

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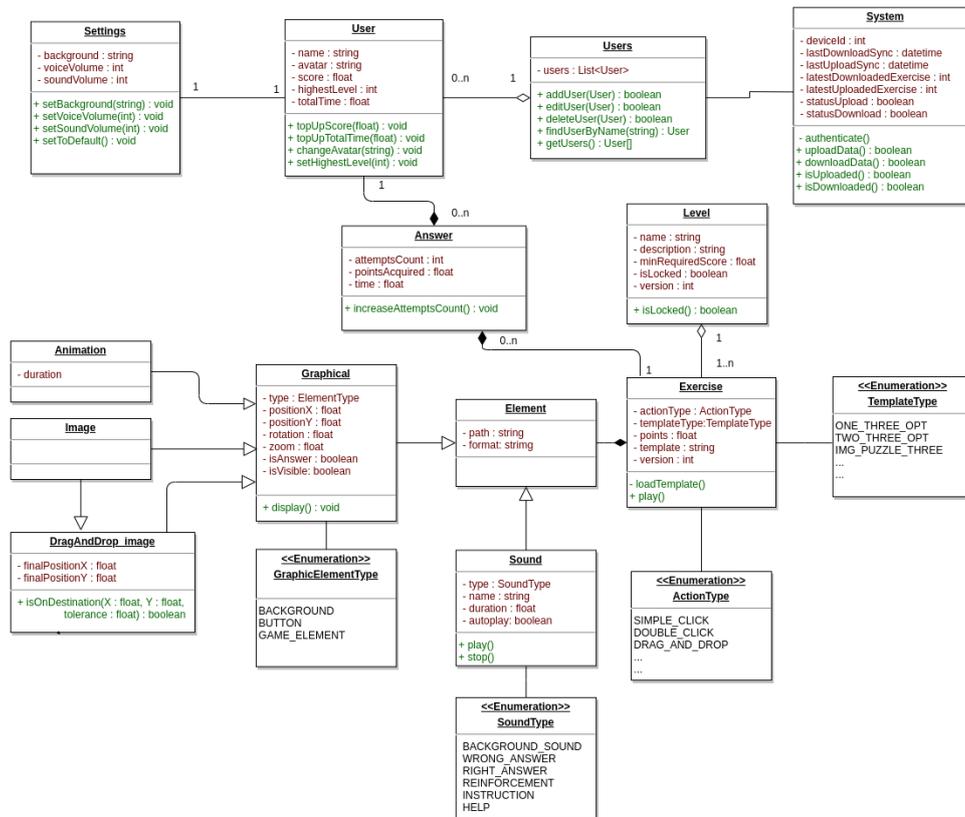


Figure 3.17: Class diagram

Implementation

A prototype is a high-fidelity representation of the desired result with the ability of user interaction. [175] It allows users to experience content, fundamental design, layout and functions as if it would be a real product, however, it doesn't contain any backend. [176] The main benefits are low costs and easier adjustments of UI before starting the implementation of the real product.

In this chapter, I will describe used development tools, how the prototype was created and how to install the prototype application to an android device.

Because the goal of this thesis is to create a functional prototype with the vision of further development of the real product, the prototype doesn't reflect some functional requirements, designed class diagram, and architecture from previous sections, as it doesn't have a backend.

Two functional prototypes were made and tested with real users during my work on this thesis. The first prototype was made with my two schoolmates in class MI-NUR (user interface design class). The second prototype is extended and adjusted version of the first prototype based on the results of the first usability testing. I will be talking only about the second prototype here.

4.1 Development tools

4.1.1 Unity

Unity is one of the most popular development platforms for creating 2D and 3D games. It is a cross-platform game engine, which allows its users to deploy across all major platforms such as desktop pcs, gaming consoles, VR/AR/MR and mobile platforms. [177]

Unity game engine is intuitive, it provides game creators with essential tools and features to build games efficiently and provide a real-time and debugging game preview. It is possible to import 2D and 3D assets from other software, assemble those assets into scenes and environments, add audio, animations, lightning, physics, special effects and more. [178] It is necessary to

code scripts for the interactive content and game logic, which is needed in most of the games. The primary programming language used for the engine is C#. Unity comes with Visual Studio as a default code editor for editing C# scripts.

The fact that Unity is free for personal use, cross-platform, easy to learn with a wide variety of learning materials, real-time preview, etc. makes it also a powerful tool not only for creating full games, but also game prototypes, which fits my needs perfectly. For the purpose of this thesis, I used free Unity Personal Edition version 2018.4.14f1.

4.1.2 Procreate

The prototype is intended to be tested by real users, children with and without developmental dysphasia. Besides testing the functionality of the application, also the acceptability by users should be evaluated. Application features from Design chapter 3.2 were made to make the application more acceptable, so it is important to include those features even in the prototype. Some of them are about graphic design; I was using graphics software Procreate to fulfill those and to create all the graphic content.

Procreate is a raster digital illustration app for iPad. [179] With an intuitive interface and a lot of features, it is a great tool for both professionals and beginners as well. It offers well-stocked library of brushes, canvas resolution up to 4K, a layer system, and many additional tools and settings. Using Apple Pencil, the app becomes much more amazing, as it responds to touch and pressure for detailed work. [180]

I was using Procreate 4 and 5, on Apple iPad Pro 11 (2018) with the usage of Apple Pencil of 2nd generation.

4.2 App prototype realization

The process of creating a game prototype in Unity can be described through three main steps:

4.2.1 Assets preparation

An asset is a representation of any item you can use in your game. An asset may come from a file created outside of Unity, such as a 3D model, an audio file, an image, a texture, a script or any of the other file types that Unity supports. [181] In following points I described what I added as assets and how were they created. Each point represents one subfolder in the assets folder.

Images

I made my own set of images used for UI elements, game elements and also for animations. First images were created in vector graphics editor Adobe Illustrator, later I switched to graphic editor Procreate, which is more user-friendly for me as a beginner and a self-learner in the graphical design. I am using format PNG for all of the used images. The graphical content of all the images follows the previously defined rules about color settings 3.2.1 and contour lines 3.2.2 from chapter Application features from Design chapter 3.2.

Sounds

For the character's speech I used a free online tool [182] to download text-to-speech conversion from Google Translate in mp3 format [183]. Google Translate has great pronunciation across multiple languages. In the Czech language, Google Translate has a woman's voice, which is soothing and suits Bruno's character well, because it sounds childish. The voice sounds a little bit mechanical but is sufficient for the prototype.

Because of an unclear license of using sounds from Google Translate and a mechanical voice without paralinguistic features, recording with voice professional is intended for the real application in the future.

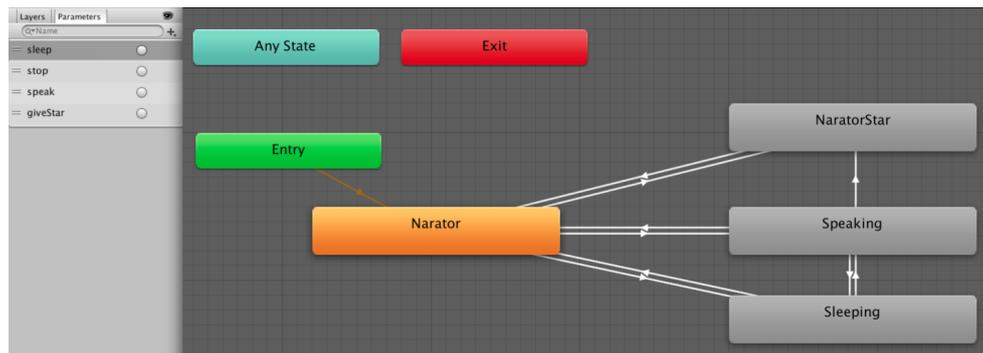
Animations

Unity has an intuitive animation tool for handling animations. It enables me to animate a sequence of objects with the desired sampling rate. I used the animation tool especially to enliven the Bruno character.

The behavior of Bruno's character in the game can be divided into four states: Bruno doing nothing, Bruno speaking, Bruno sleeping and Bruno giving a star. Each of the state has its own animation as a repeating loop of one or several images.

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A transition tool in Unity offers a graphical user interface for animation settings and specifying their transitions as deterministic finite state automata. The behavior is managed by scripts; I am talking about them more in scripting section 4.2.3.



Scripts

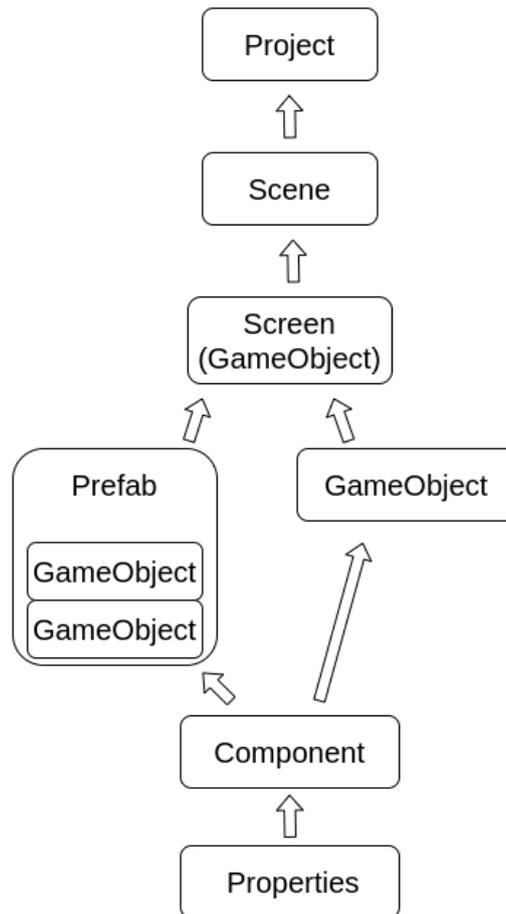
Scripts belong to the asset folder as well. They offer a very versatile way of going beyond the basics in the game development and implementing gameplay features. Unity supports the programming language C#.

Other assets

Scenes, prefabs, plugins, and any other source files belong to the asset folder as well. I am talking about scenes and prefabs in the following section because they both use previous assets to create the game.

4.2.2 Creating Gameplay

There is a specific hierarchy for everything in Unity as we can see it visualized in the following model. I am not going to describe Project, Scene, and Screen, as their purpose is obvious from their names.



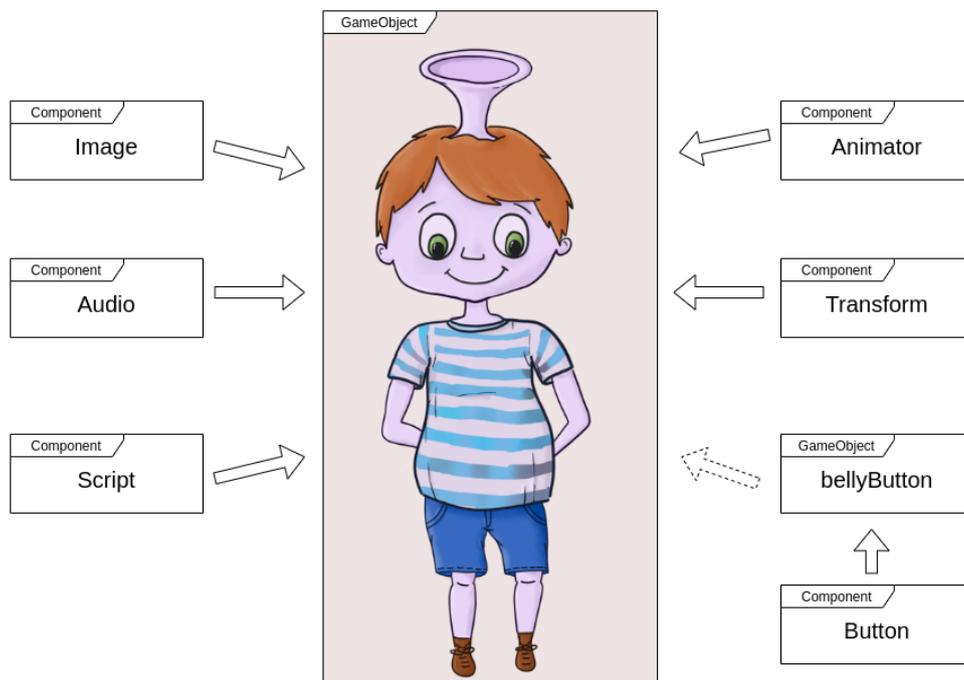
I will briefly describe **GameObjects** and **Prefabs**, then we will take a look at the scene composition in the prototype game.

GameObject

GameObject is a fundamental general Unity object; it doesn't do anything by itself. It works as a container for any number of **Components**, which together defines the real functionality. [184] A component can be, for example a button, a material, an animator, physics, or many more others. It can contain C# scripts or values for variables from the assigned script.

In the following model, there is a model of the most important **GameObject** in prototype - Bruno's character **GameObject** and its components. Because Bruno's character can be woken up only by touching his belly, not by touching any other part of his body, Bruno **GameObject** itself doesn't contain a button component. This is solved by adding another **GameObject** with button component of the size of Bruno's belly.

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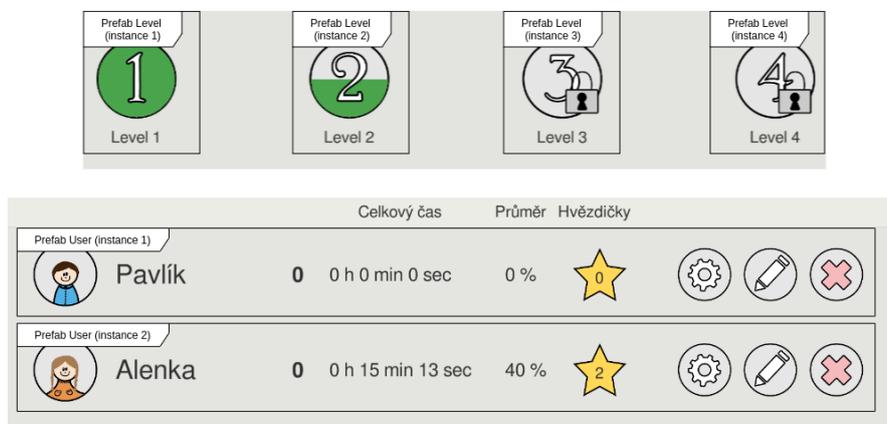


Other GameObjects in the final prototype were made analogously.

Prefab

Prefab asset allows storing a GameObject with all of its components and property values as a reusable template to create new Prefab instances throughout the game. The Prefab instances can be edited independently, but the changes in the main Prefab will be reflected across all of its instances.

Prefabs are used for repeated game elements, such as list of levels or a list of users in the prototype.



4.2.2.1 Scene composition

The final prototype consists of one main scene, including many screens composed out of GameObjects and Prefabs. There is a ScreenManager script that manages changing the content of the scene by first deactivating all the content except Bruno's character and then activating only the desired screen's elements.

4.2.3 Scripting

When the assets are imported and GameObjects and Prefabs are added to the scene, it is time to set up the game logic and behavior by scripting. The power of Unity is in its wide possibilities; scripting is one of them. Scripts in C#, most widely using object-oriented design, work together to develop real-time interactive content. It includes handling user input and reacting to it, modifying Component properties, triggering game events, manipulating objects in the scene, and others. [185], [186]

The full Unity project of the final game prototype with scripts is available on the attached medium. In this section, I am describing the steps to finish the enlivening of Bruno's character.

In assets, we have defined individual animations and transitions 4.2.1, sounds. We can then easily manage Bruno's behavior using a controller - grab an Animator component of Bruno's character, set a trigger to invoke the animation transition, and play the corresponding sound. The following example code defines the behavior of the character after waking him up. It changes the animation from sleeping to speaking by calling a method `ResetTrigger` and `SetTrigger`: it simultaneously plays the recorded of sentence prompting the game player to choose the correct answer.

4. IMPLEMENTATION

```
using System.Collections;
using UnityEngine;
//...

public class LevelGameController : MonoBehaviour
{
    private Animator _narratorAnimator;
    private SpeechClips _speechClips;
    //...

    private void OnEnable()
    {
        _narratorAnimator = Narrator.GetComponent<Animator>();
    }
    //...

    private void WakeupAction()
    {
        EnableGameButtons(true);
        EnableSleepTime(false);

        _narratorAudioSource.Stop();
        _narratorAnimator.ResetTrigger("sleep");

        var clip = _speechClips.Answer;
        var length = clip.length;

        _narratorAnimator.SetTrigger("speak");
        _narratorAudioSource.PlayOneShot(clip);
        StartCoroutine(WakeupActionStart(length));
    }

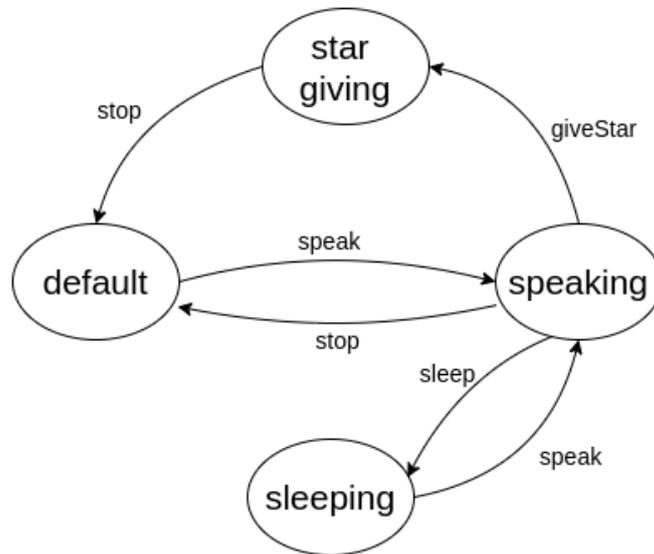
    private IEnumerator WakeupActionStart(float length)
    {
        yield return new WaitForSeconds(length);

        // after action finished
        _narratorAnimator.ResetTrigger("speak");
        _narratorAnimator.SetTrigger("stop");

        EnableNarratorBtn(false);
        EnableGameButtons(true);
    }
    //...
}
```

In the example above, we have used a Coroutine, a function that has the ability to suspend execution until the given yield parameter finishes [187]. In this case, it ensures the speaking Bruno animation is repeating while the record of speaking is playing. Right after the speaking record finishes, the animation of speaking Bruno changes to default Bruno animation.

Other of Bruno's actions are implemented analogously. In following automata, we can see which transitions between animations of Bruno's character have been implemented and are used the in scripts by resetting and setting triggers.

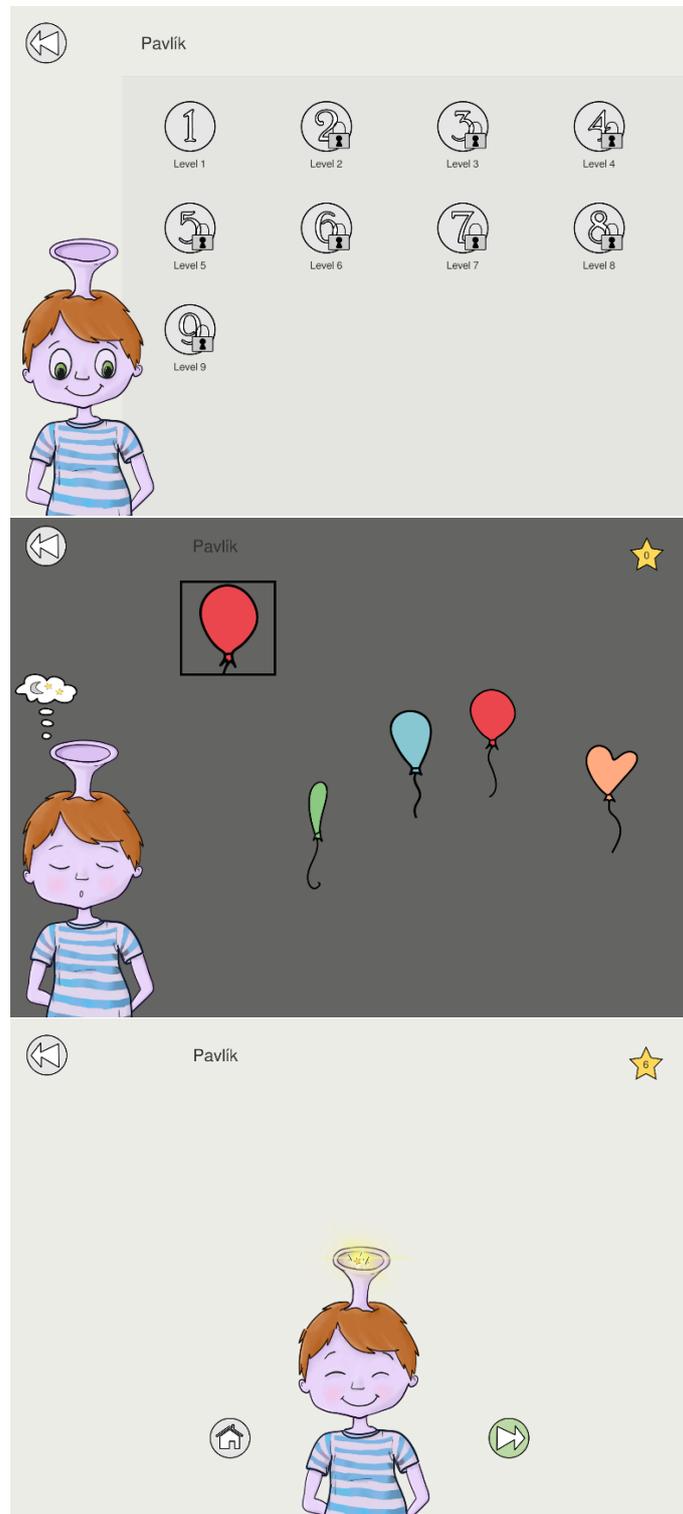


4.2.4 Build app for Android

The last step, when the game is polished enough to meet the developer's expectations, is to building the application and trying it on a real device. In Unity, the Build Settings window allows us to configure the build system parameters and generate the application output: Android Package Kit (APK) for Android SDK devices. The package can be published to Google Play Store or installed manually. [188] The manual installation is described in the following chapter. After installation, you can enjoy the prototype game, the following images are made from the final prototype.



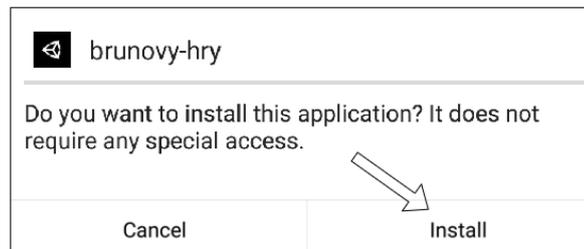
4. IMPLEMENTATION



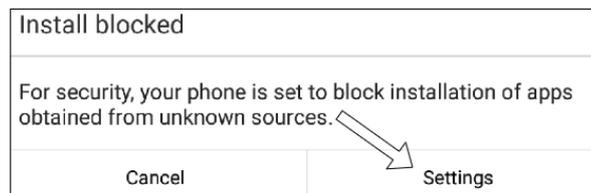
4.3 App installation

This chapter is a user manual to install the APK file to your Android device. There are two APK files on the attached medium, one is for tablets with screen resolution ratio 4:3, the other one is for mobile phones with resolution ratio 16:9. The installation process may differ a little for different Android versions.

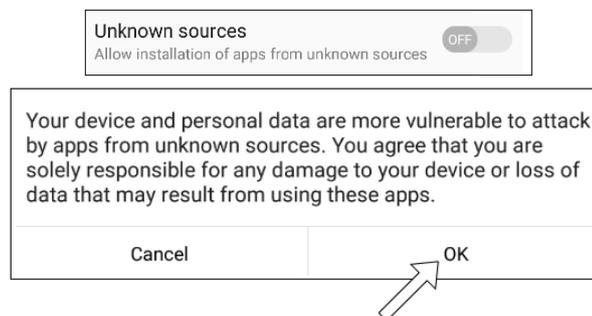
1. Transfer APK file from the attached medium to your device.
2. Open file explorer on your device, locate to the folder with APK file and click on the file.
3. The dialog for the installation confirmation should appear. Click install.



4. If the installation of unknown APK is not allowed on your device, the following dialog will appear. Click Settings.



Allow the installation of apps from unknown sources.

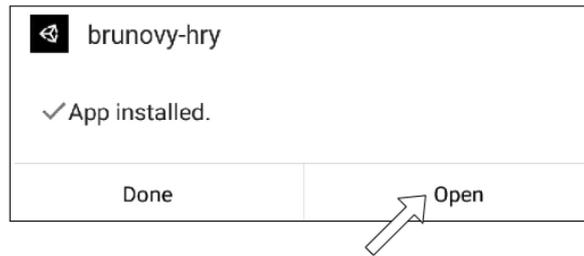


4. IMPLEMENTATION

5. Wait for the installation to finish.



6. Click open to open the application.



Usability testing

Usability testing is a user-centered functionality testing and is one of the most important types of all the software testing types. It is usually the first experience of the software by real users. The purpose is to know if we made an effective, efficient and enjoyable software by observing user's reaction and how easily they use the software and also to uncover opportunities to improve the software. [189] Since my target user group is so specific and it is hard to put ourselves in their shoes, it is immensely important to see their reactions in usability testing. What can see correct to us can actually be distractive or inappropriate to the target users. Usability testing tells me if I am on the right path. One usability test session was made as part of one of our faculty class MI-NUR (user interface design) at the end of the year 2018 and a second one, the final one, was made at the end of the year 2019. In this chapter, I will talk about the final testing, because the the result from first testing was used to improve the final prototype.

5.1 Usability testing method

There are a few possible usability testing methods, but I have decided on lab usability testing from the beginning. As the name says, the testing is held in a special environment, usually a simple isolated room (lab). The testing is supervised by a moderator that guides a user tester through the entire testing process. In the beginning, the moderator gives a user tester the input questionnaire with general questions related to the topic of the tested software to get a better insight into the user's experience. Then, the actual testing takes place. Moderator tells the to user tester what task should be done and the user tester attempts to accomplish them. In the end, the moderator gives the user tester the output questionnaire to get the feedback and the user tester's opinion and reflection about the software. [190]

We have a Usability lab for UX testing at our faculty and I have some experience from this testing method as a moderator and even as a user tester. It

is a small, separated quiet room equipped with desk and chairs for a user tester and a moderator, besides other things. Several video cameras are mounted to the wall around the room, they capture the user tester from different angles, so anyone, and especially the software development team, can later study the user tester's behavior and actions during the testing session in detail.

5.2 Testing Settings

Lab testing is a testing in a controlled environment, it is usually a new environment for the tester user. There is always a risk that the user tester will not behave realistically in the controlled environment. [190]

To get the most realistic testing result of children with developmental dysphasia, I decided to arrange usability testing in their environment, in kindergarten Litvinovska 300 with myself as a moderator. I was attending the kindergarten many times before the usability testing to make connections with children and to get children familiar with myself. It helped to reduce possible children's nervousness of being with myself as moderator alone in an isolated room.

On the testing day, I had available small separated room in kindergarten that is normally used for speech therapy. All children are familiar with this place as they have speech sessions there regularly.

I tried to mock-up the usability lab there as it is in the Usability lab at our faculty. I prepared a desk and two chairs, one for the user tester and one for the moderator. Tablet (Asus Z581KL 8", 2048x1536 px, Android OS 6.0.1) with the installed prototype application was placed on the desk. I placed a video camera above the desk to capture the tablet screen and user tester's hand, one camera from the side and a small GoPro camera on the desk to capture user tester's face from the front. Another recording was made using an application Screen recorder [168] in tablet to capture screen.



In addition to the technical settings I prepared testing scenarios, input and output questionnaires and subject's consents in advance. I made two versions of those, one for children testers and one for adult testers. Questionnaires and scenarios (in Czech and English version) are available in attachment D, as well as consents (in Czech version) in attachment C.

Consents were signed by adults testers and children tester's legal representatives before testing. Each tester was informed about testing in advance.

5.3 Testing Process

Testing was held with 3 adults (2 kindergarten teachers, 1 teacher's assistant), 4 children with developmental dysphasia and 5 children without communication impairment disability. Children tester's ages were between 4 and 6.

As children in kindergarten usually don't know how to read and write, I decided to ask the questions from input and output questionnaires in the form of an interview. I picked up each child individually in their classroom and interviewed them during the walk to the temporary testing lab. I added several unrelated questions outside of questions from input questionnaire just to make them feel relaxed and excited. During the testing process, the main task was to play the game and follow the instructions of Bruno's character. I had prepared a scenario, but I haven't interfered to the process when the children tester was able to continue without my guidance. In the end I interviewed children to get their feedback and gave them candy as a reward.

The testing process with adults was different, their main task was to test the user interface of the administration part of the application and, in the

5. USABILITY TESTING

end they also tried to play a game. Their testing was guided with the exact instructions provided.



5.4 Result

The good news is that all children testers successfully finished the both prepared levels. The difference between children with developmental dysphasia and without it was the time needed to accomplish the levels and their independence.

Healthy children testers went through the games in about 3 minutes, one child with ADHD in 4 minutes. They were able to go through the games intuitively, based on Bruno's instructions, without the need of my help.

Children with developmental dysphasia accomplished the same in 5 to 12:30 minutes. Bruno's instructions to tickle his belly and choose the balloon were not followed in the beginning, I had to repeat the instruction. They understood the part with tickling Bruno's belly to wake him up to be allowed to answer very quickly, however, the instruction to click the same balloon seemed to be harder to accomplish. After a few attempts they found out the correct answer and the next exercises were easier for them as they knew what was going on, even after the difficulty increased a little bit. The child tester with the longest testing time was repeatedly clicking the same incorrect balloon in the first exercise. Explaining the question and trying to get to the right answer together didn't help until I covered the incorrect balloon that he was fixated to. He was able to accomplish the following exercises in significantly less time after that. Another reason for longer testing time with dysphatic children was that three out of four dysphatic children testers

were interested in the recording devices and sometimes their attention was redirected to observing the cameras instead of test application. All children testers were used to the room, to the tablet, to me, but those video cameras were new and interesting for them.

Adult usability testing of administration part of application was very smooth, it exceeded my expectations. Two kindergarten teachers and one teacher's assistant accomplished tasks in 2:50 to 4:30 minutes. Small hesitation appeared in saving the new users with the diskette icon.

There are three sample recordings of testing the game process on the attached SD card. One of the game testing is with a healthy average child. Another one is with a child with developmental dysphasia with the longest testing time needed and the third one is an administration of game testing with a teacher with the shortest testing time. Records were edited to anonymize user testers identity.

Conclusion

The aim of this thesis was to analyze and design an entertaining application adjusted for preschool children with communication impairment disability. During the work on this thesis, the focus narrowed, especially on preschool children with developmental dysphasia. The outcome was a functional game prototype and usability testing of the prototype with children with developmental dysphasia.

The process and the text structure follow the software engineering standard structure - analysis, design, implementation, and testing.

For getting analysis data, I used four research methods: reading of academic and non-academic literature related to the topic, observation of children with developmental dysphasia, interviews of children with and without developmental dysphasia, teachers, speech therapists, and others; comparison of available software and hardware solutions. I used Interview and observation methods especially in kindergarten Litvinovska 300, which I attended one day a week for about half a year.

During the analysis part of my work, I decided to narrow my focus to preschool children with developmental dysphasia, I described the process and reasons in 1.2. In the first part of the analysis, I introduced developmental dysphasia and brain functioning, where I parabled the brain functions to CPU and computer peripherals to demonstrate the possible effect of developmental dysphasia on communication among people.

Using the mentioned methods for getting insight into the problem of developmental dysphasia, I found out and collected many possible constraints from the view of software development, which should be born in mind when creating a game for children with developmental dysphasia. They are written in the second part of analysis, followed by adjusted Nielsen's usability heuristic for the game for children with developmental dysphasia. Using comparison method, I compared and evaluated available software devices and platforms. The winner was an Android tablet for its perfect size, portability, and accessibility. I completed the analysis chapter with functional and non-functional

requirements.

In the design part, I set up a collection of specific features adjusting the game to suit children with developmental dysphasia better. I prepared more than 60 different types of small games to train the visual processing and support the passive vocabulary development of the children users. Those features and game's content reacts on most of the constraints 2.2 from the analysis chapter, the summary of constraints coverage by application features and the game's content can be seen in table 5.1.

For the future development of the full version of the game, I designed a software solution using the client-side architecture with REST API, allowing the android client application to download content from the server and send the data about user statistics there. The presented domain model and class diagram describe the needed structure for the database and system.

Most of the designed application features 3.2 was implemented into a functional prototype in Unity; some implementation details are described in chapter 4. It contains 2 levels with 4 training sessions. The usability testing of the prototype game was conducted with 4 children with developmental dysphasia, 5 children without developmental dysphasia, and 3 kindergarten teachers. All children accepted the game prototype well and successfully finished the assigned tasks. The total time needed to finish the same task was, however, two to four times longer in children with developmental dysphasia (5 to 12 minutes) than in children without developmental dysphasia (around 3 minutes).

Based on testing, I would add one important application feature to chapter 3.2: hiding the incorrect answer from the screen when the user repeatedly attempts to click that same incorrect answer, so it would be easier to find the correct one thanks to the lower number of possibilities. I think it is needed, especially in the beginning, when the child users need to find out what is going on in the game.

From the usability testing process, I can say the user interface and content of the game were well accepted and usable by all 4 children with developmental dysphasia, but it is a small number to state a generic conclusion about preschool children with developmental dysphasia. The success of the prototype usability testing revealed a good direction of achieving the goal and motivates me to continue in further self-education and realization of the full game.

Future work

In chapter Plan 2.3, I described three stages of speech development support with the idea of making an individual game for each stage. This thesis was focused on the first stage.

My wish and plan is to design new types of trainings sessions (now I have more than 60 different pieces of trainings), to implement the full client-side

game, to implement the server-side, and to publish the game on Google Play for the public. Those are the steps to complete the first stage.

My long-term wish is to complete even the second and third stage, it may, however, mean years of hard work.

CONCLUSION

	Covered by app features	Covered by trainings	Covered
C1	✓		✓
C2	✓		✓
C3	✓		✓
C4	✓		✓
C5	✓		✓
C6			✗
C7			✗
C8			✗
C9			✗
C10	✓		✓
C11	✓		✓
C12	✓		✓
C13	✓		✓
C14	✓		✓
C15		✓	✓
C16		✓	✓
C17		✓	✓
C18		✓	✓
C19			✗
C20		✓	✓
C21			✗
C22	✓	✓	✓
C23	✓	✓	✓
C24	✓	✓	✓
C25		✓	✓
C26	✓	✓	✓
C27	✓	✓	✓
C28		✓	✓
C29	✓	✓	✓
C30		✓	✓
C31	✓		✓
C32		✓	✓
C33	✓		✓

Table 5.1: Constraint coverage by application features and designed trainings

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Acronyms

CPU	Central Processing Unit
VR	Virtual reality
AR	Augmented reality
MR	Mixed reality
PC	Personal Computer
GUI	Graphical User Interface
HSB	Hue, Saturation, Brightness
UI	User Interface
UX	User Experience
UC	User Case
DRY	Don't repeat yourself
lo-fi	Low-fidelity
hi-fi	High-fidelity
RGB	Red, Green, Blue
REST	Representational State Transfer
API	Application User Interface
HDD	hard drive
RAM	Random access memory
ASD	Autism spectrum disorder

A. ACRONYMS

DD Developmental dysphasia

ADD Attention deficit disorder

ADHD Attention deficit hyperactivity disorder

Glossary of used terms

- Agrammatism** *inability to construct words in grammatical sequence to form phrases and sentences [56]*
- alalia** *speech delay*
- attention deficit disorder** *neurological disorder that causes difficulty attending to instruction (inattention) [191]*
- attention deficit hyperactivity disorder** *a neurological disorder that causes hyperactivity impulsivity [191]*
- auditory perception** *the perception of sound as a meaningful phenomenon [192]*
- autism spectrum disorder** *a complex developmental condition that involves persistent challenges in social interaction, speech and nonverbal communication, and restricted/repetitive behaviors. The effects of ASD and the severity of symptoms are different in each person. [193]*
- childhood apraxia of speech** *a motor speech disorder that makes it hard to speak [194]*
- cochlea** *the snail-shaped tube (in the inner ear coiled around the modiolus) where sound vibrations are converted into nerve impulses [192]*
- cogitation** *the action of deeply thinking about something*
- cognition** *Cognition can be defined as any form of information processing, mental operation, or intellectual activity such as thinking, reasoning, remembering, imagining, or learning [195]*
- communication impairment disability** *deviation from an accustomed (or codified) language norm in a certain language environment or on the basis of the communicative intentions of an individual [196]*

B. GLOSSARY OF USED TERMS

- comorbidity** *presence of one or more additional condition co-existing with a primary condition together [197]*
- diagnosis** *the nature or cause of some phenomenon [192]*
- differential diagnosis** *process of differentiating between two or more conditions which share similar signs or symptoms [198]*
- disability** *a physical or mental condition that makes you unable to function in some way [192]*
- disorder** *a condition in which there is a disturbance of normal functioning [192]*
- developmental disorder** *disorder of neurodevelopmental origin that develops in children during prenatal, perinatal and postnatal development up to 1 year old. [36], [37], [38]*
- developmental dysphasia/aphasia** *developmental disorder, where a child has dysfunction in the receptive and/or expressive communication*
- dysarthria** *impaired articulatory ability resulting from defects in the peripheral motor nerves or in the speech musculature [192]*
- echolalia** *the meaningless repetition of another person's spoken word*
- figure-ground perception** *differentiating the main object from the background*
- hearing impairment** *impairment of the sense of hearing [192]*
- intellectual disability** *lack of normal development of intellectual capacities [192]*
- language** *the cognitive processes involved in producing and understanding linguistic communication [192]*
- learning disorder** *a disorder found in children of normal intelligence who have difficulties in learning specific skills [192]*
- loanword** *a word borrowed from another language [192]*
- mental disorder** *any disease of the mind; the psychological state of someone who has emotional or behavioral problems serious enough to require psychiatric intervention [198]*
- motor-speech impairment** *struggle to produce speech because of problems with motor planning or muscle tone needed to speak [199]*

motor skills *movement and actions of muscles with the intent to perform a specific act, we categorise to two groups: gross motor skills (movement of large parts of our body) and fine motor skills (small movement bz hand and fingers)*

paraphasia *production of unintended word, a failure of selection at the phonemic level*

pedagogy *the profession and science of teaching [192]*

perinatal *occurring during the period around birth (5 months before and 1 month after) [192]*

personality disorder *inflexible and maladaptive patterns of behavior [192]*

prenatal *occurring or existing before birth [192]*

postnatal *occurring immediately after birth [192]*

psychology *The scientific study of the human mind and its functions, especially those affecting behaviour in a given context [198]*

perception *cognitive process by which organism become aware or interprets actual external stimuli through senses*

prosody *The patterns of rhythm and sound used in poetry [198]*

selective mutism *a complex childhood anxiety disorder characterized by a child's inability to speak and communicate effectively in select social settings, such as school. These children are able to speak and communicate in settings where they are comfortable, secure, and relaxed. [200]*

speech delay *delay in the development of mechanisms to produce speech*

speech motor *The system and strategies that regulates the production of speech*

speech perception *=reception, the auditory perception and comprehension of speech [192]*

speech therapy *a therapy intended to support overall development of individual, especially communication abilities*

symptom *sensation or change in bodily function that is experienced by a patient and is associated with a particular disease [192]*

visual closure *ability to imagine a missing piece in an image*

visual impairment *impairment of the sense of sight, decreased ability to see or differentiate, visual impairment is not fixable by using glasses*

visual perception *perception by means of the eyes [192]*

Consents

C.1 Litvinovska kindergarten

Vážený rodiče,

jsem studentkou posledního ročníku magisterského programu na Fakultě Informačních Technologií na Českém Vysokém Učení Technickém v Praze. Pracuji na diplomové práci, ve které jsem se rozhodla využít své znalosti z IT oboru pro návrh a vytvoření mobilní aplikace pro děti se specifickými potřebami. Abych dokázala navrhnout co nejlepší aplikaci, která by mohla dětem se specifickými potřebami pomoci, je pro mě důležité o nich vědět co nejvíce. Nejen vidět text od odborných pracovníků a speciálních pedagogů na papíře, ale především s dětmi strávit dostatek času pozorováním, společnou hrou, prací a dlouhodobým pozorováním jejich učení a pokroků v mateřské škole. Za Vaši pomoc bych byla neskutečně vděčná, bez vás by aplikace byla pouze výsledek načtené literatury a z pohledu technika bez prožité praxe.

Hana Kozáková

Souhlas se zařazením do průzkumu

Dávám souhlas, aby mé dítě , narozené, bylo zařazeno do průzkumu v rámci práce Hany Kozákové. To zahrnuje pozorování dítěte při běžném provozu mateřské školy, při logopedických a fyzioterapeutických cvičení se zaměstnanci mateřské školy, nahlédnutí do lékařských zpráv (psycholog, psychiatr, neurolog, klinický logoped, foniatr, ...), individuálních vzdělávacích plánů, popisování a zpracování získaných informací o dítěti do diplomové práce. Informace uvedené v diplomové práci budou anonymní, bez uvedení pravého jména dítěte.

V Praze dne

Podpis zákonného zástupce

Souhlas se zpracováním audio a video záznamů

Dávám souhlas, aby fotky, videa a audio záznamy mého dítěte, narozeného, mohly být zpracovány a zveřejněny v práci Hany Kozákové. V práci nebude uvedeno reálné jméno dítěte spojené s uvedenými záznamy.

V Praze dne

Podpis zákonného zástupce

Souhlas s testováním mobilní aplikace

Dávám souhlas, aby se mé dítě , narozené, zúčastnilo testování prototypu či reálné mobilní aplikace v rámci práce Hany Kozákové, včetně pořízení, zpracování a publikování audio a video záznamů z průběhu testování. V práci nebude uvedeno reálné jméno dítěte.

V Praze dne

Podpis zákonného zástupce

C.2 Litvinovska kindergarten, consent for teachers

Souhlas se zpracováním audio a video záznamů

Dávám souhlas, aby fotky, videa a audio záznamy mě, narozené/ho, mohly být zpracovány a zveřejněny v práci Hany Kozákové. V práci nebude uvedeno reálné jméno spojené s uvedenými záznamy.

V Praze dne

Podpis zákonného zástupce

Souhlas s testováním mobilní aplikace

Dávám souhlas, že se já, narozen/a, dobrovolně účastním testování prototypu či reálné mobilní aplikace v rámci práce Hany Kozákové, včetně pořízení, zpracování a publikování audio a video záznamů z průběhu testování. V práci nebude uvedeno Vaše reálné jméno.

V Praze dne

Podpis zákonného zástupce

Questionnaires and scenarios

D.1 Testing the application with adults, CZ version

Vstupní dotazník

1. Máte tablet? Pokud nemáte tablet, máte dotykový telefon?
2. Jste zvyklý/á pracovat s dotykovou obrazovkou?
3. Znáte nějaké hry pro tablet? Používáte je s dětmi ve výuce?
4. Máte zkušenosti s ovládáním her pro děti na tabletu?

Scénář testování

1. Vytvořte nový profil dítěte pro Josef
2. Změňte jméno dítěte na Pepa
3. Smažte uživatele Pavlík
4. Nastavte Pepovi hlasitost průvodce na maximum
5. Vraťte se zpět na hlavní menu se seznamem dětí
6. Spusťte hru pro Pepu
7. Následujte instrukce. V prvním cvičení odpovězte špatně a až poté správně. V druhém cvičení odpovězte správně.
8. Vraťte se na seznam her Pepy
9. Vraťte se na hlavní stránku.

Výstupní dotazník

1. Jaký máte pocit z testování hry?
2. Přišlo vám v aplikaci něco nelogické?
3. Vyhovovala vám grafická stránka?
4. Co se vám na hře líbilo nejvíce?

D.2 Testing the application with adults, EN version

Pre-test questionnaire

1. Do you have a tablet device? If not, do you have a phone with a touchscreen?
2. Are you used to working with a touchscreen?
3. Do you know some games for a tablet? Do you use them with children?
4. Do you have experience with the control and administration of tablet games for children?

Test scenario

1. Create a new child profile for user Josef
2. Change the name of the child to Pepa
3. Delete user Pavlík
4. Set the volume of the narrator to the maximum for user Pepa
5. Return back to the main page with the list of children
6. Run the game for Pepa
7. Follow the instructions in the game. In the first exercise, choose some wrong answer first, then select the correct answer. In the second exercise, select the correct answer
8. Return to the game list of Pepa
9. Return to the main page

Post-test questionnaire

1. What is your feeling about the game?
2. Did you find something illogical in the game?
3. Did the graphical design and interface of the game suit you?
4. What one thing are you most excited about in the game?

D.3 Testing the application with children, CZ version

Vstupní dotazník

1. Kolik ti je let?
2. Máte doma tablet? Pokud ne, tak dotykový telefon?
3. Hraješ na tabletu/mobilu hry? Jaké?
4. Která hra tě baví nejvíc?

Scénář testování

1. Poslouchej panáčka a udělej, co ti říká
2. Až dokončíš cvičení, jdi na další
3. Až dokončíš cvičení, klikni na domeček

Výstupní dotazník

1. Co se ti na hře líbilo?
2. Líbila se ti postavička?
3. Bavilo tě ji polechtat na bříšku?

D.4 Testing the application with children, EN version

Pre-test questionnaire

1. How old are you?
2. Do you have a tablet at home? If not, do you have a smartphone?
3. Do you play games on the tablet or on the smartphone? Which games?
4. Which game do you like the most?

Test scenario

1. Listen to the Bruno character on the screen and do whatever he says
2. After you finish the first level, continue to the second level
3. After you finish the second level, click the button with the house

Post-test questionnaire

1. What did you like about the game?
2. Did you like the Bruno character?
3. Did you enjoy tickling his belly?

Contents of enclosed CD

```
root
├── apk
│   └── Brunosgames.apk ..... Installation file of game prototype
├── src
│   ├── Brunosgames.zip ..... Unity project
│   └── thesis ..... Source code of thesis text
├── text
│   └── thesis.pdf ..... Thesis text in pdf
├── trainings
│   └── trainings.zip .... A collection of designed trainings to the game
├── usability testing ..... A records from usability testing
│   ├── User1 ..... Healthy child
│   ├── User2 ..... Child with developmental dysphasia
│   └── User3 ..... Teacher
```