Designing educational programming tools for the blind: mitigating the inequality of coding in schools

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1 Introduction

This dissertation aims at providing design considerations for developing educational tools for teaching programming to blind primary school students, as an effort towards more inclusive classrooms. The teaching of programming in early education is becoming beneficial in children’s acquisition of the fundamental knowledge necessary for posterior learning of coding. Failing to consider a broader spectrum of human capabilities, this practice seems to neglect specific needs of children with disabilities such as visual impairment.

Previous experiences in working with visually impaired people have given me the awareness of this specific group’s struggles, ranging from regular way finding in physical environments to navigating through Information and Communication Technology (ICT) devices, and through countless other challenging experiences that go beyond individual issues and concern human relations within social structures. The lack of conclusive research regarding the teaching of programming to blind children calls for action on investigative studies on this new educational paradigm in which digital technologies are not only becoming common tools for teaching, but are also becoming curricular content taught in schools. Acknowledging that this is a novel approach to children’s education, all research that may lead to better understanding of teaching programming to the blind will contribute towards fairer educational practices, opportunities and choices of being in tune with the world’s impressively fast changes and gains in complexity, shaping societies today. In the midst of this evolutionary complexity, social-political structures struggle to deal with the consciousness of ethical nature that become evident as never before, yet mercilessly omitted. When speaking of ethics, the negligence of minorities is common ground for discussion and a cause that I believe is in need of representatives, and is worth fighting for.

As a student of Interaction Design with a background practice set aside from computer technology, my own experience with learning to code was close to a failure. Living in a time where coding is becoming a basic requirement in the job market, not to mention its relevance in an Interaction Designer’s professional practice, made me question my suitability in a coding class. I was clearly missing fundamental understanding of programming to be able to learn coding. Solving my problem meant turning to tutorials, books, online courses, discussion forums, or in other words, the solution was right around the corner. If I were a blind student, this would not be as simple.

Personal experience and a strong sense of purpose are the main drives for researching for blind children’s rights to equal education when faced with inadequate learning tools used in programming classes. Last, but equally relevant, this is an attempt to shed light onto design considerations for programming educational tools for the blind, as my contribution for mitigating (ideally overcoming) this inequality issue, as well as contributing to Interaction Design and ICT Education research.

1.1 Research problem

Visually impaired children attending the first year of Primary School have special learning needs that differ from the needs of other students, regarding methodology and tools. The challenges faced in designing for the blind minority result in few slow advancements in theory and in practice. With coding as a new curricular learning goal, as discussed in the European Commission’s School Education Gateway (Gateway, 2015), an alarming need for action arises concerning the investigation
of its applicability in the education of blind students. Taking action means investigating a variety of factors, including teachers’ training, students’ learning parameters and the accessibility of tools, or in other words, analysing and evaluating the intended project thoroughly before its implementation, as a moral obligation of experts in Special Education, Inclusive Education, Human Rights, Interaction Design, and other parties. In this situation, solutions become urgent, for in several schools around the world the teaching of coding is already under implementation (Gateway, 2015).

As observed throughout the course of this study and as pointed out in an independent Survey conducted and published by a computer scientist in his blog I Shall Teach (Unknown, 2017), Scratch¹ is one of the main programming languages chosen by teachers to teach programming in classrooms. With an interactive digital interface that is primarily graphic, – in other words, visual - it is questionable whether Scratch can be manipulated and understood by a low, or no, vision person. Given this scenario, the following problem becomes evident: the choice of Scratch as the main resource used in primary schools to teach the fundamental logic of programming presents a potential threat towards human rights to equal opportunities in education faced by blind students, for the use of Scratch seems to rely highly on visual abilities.

1.2 Research aims

Having presented a brief overview of the research problem, the main aim of this study is to attempt to answer the following questions: Are Scratch and other tools used to teach programming in primary education accessible to the blind? If they are not accessible, then how can methods and approaches from Interaction Design apply to the process of developing adequate tools for blind primary school children to learn programming?

From a user-centred perspective, the objectives of this investigation are to:

1. Provokereflective thinking upon the need to refine schools’ capabilities for providing equal opportunities in education for blind children;
2. Evaluate the accessibility in the autonomous use of Scratch by the blind, with the blind;
3. Explore basic programming logic through Design research methods, with the blind at the centre of the design process, to produce insights for guiding Designers towards developing more adequate educational programming tools for the use of blind primary school children;
4. Present Design considerations and suggest methods for designers who wish to step into this domain of educational programming tools for the blind.

The scope of this project may present constraints of time limitation and resources availability, which may affect the feasibility of targeting primary school classrooms specifically. Broadening its outreach to consider blind learners of programming in general, independently of age or environment, may be necessary and should provide valid input for this study, given that every insight is currently valuable to foment critical discussions regarding this subject. Results here obtained may also become useful in a variety of other design projects related to blindness.

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¹ As described in its official website, Scratch is a ‘free programming language and online community where you can create your own interactive stories, games, and animations’. Source: https://scratch.mit.edu/ (access on August 10, 2017).
Another consideration regarding scope limitations is that this research emphasises the process and does not aim for an outcome in the form of a prototype or product. Additionally, this study should serve as a basis for a future follow-up project that focuses on delivering a prototype or a final product (an educational tool for blind primary school children to learn about programming).

2 Background

2.1 Coding as a subject in the contemporary school system

In the ever-growing scenario of technology, people are no longer mere users of tech companies’ creations. Users shape technology as never before, through its whole product cycle, from strategy, through design and development phases, all the way to its delivery and evaluation. Moreover, people have never before had so many tools at hand for acquiring the knowledge and the skills needed to interact with technology, be it through printed material, online or in classrooms.

According to The European Innovation Scoreboard of 2016, Sweden is the current EU innovation leader, followed by Denmark, Finland, Germany and the Netherlands (The European Innovation Scoreboard, 2017) - achievement historically grounded in its tradition of inventors, of commitment to gender equality, and its strong belief in the individual, as claimed in Sweden.se. Reference in research and development, Sweden has chosen to focus strategic investments on technology, leading in biotechnology research, developing tools for healthcare and in microelectronics. Looking into the future, youngsters have received tremendous incentive from the government to gain interest in technology. Several organizations have collaborated with schools across the country, to promote engagement through diverse experiences such as ‘inventors’ competitions.

Swedish schools are amongst the many schools around Europe that have adopted programming and coding as part of their curriculum. As Michael Grove (education secretary of the UK) expressed at the time when coding in schools was under discussion in England:

“ICIT used to focus purely on computer literacy – teaching pupils, over and over again, how to word-process, how to work a spreadsheet, how to use programs already creaking into obsolescence - , about as much use as teaching children to send a telex or travel in a zeppelin.

Our new curriculum teaches children computer science, information technology and digital literacy: teaching them how to code, and how to create their own programs; not just how to work a computer, but how a computer works and how to make it work for you.” (Dredge, 2014)

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2 The official website of Sweden, a source of facts regarding the country - Sweden.se (access on August 2, 2017)
3 Finn Up, Ung Företagsamhet and Snilleblixtarna are some of the schools’ partner organizations, as pointed out by the Innovation in Sweden webpage, found in Sweden.se (access on May 2, 2017)
4 ‘A study conducted in October 2014 among 20 European Ministries of Education, found that computer programming and coding is already part of the curriculum in 12 countries: Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Greece, Ireland, Italy, Lithuania, Poland, Portugal and the UK (England)’. Source: http://www.schooleducationgateway.eu/en/pub/news_events/computer_programming_and_coding.html (access on May 2, 2017)
Teaching coding is not an attempt to prepare children for becoming developers; it is an encouragement for them to become creative beings. At a primary level of education, it helps children to gain logical thinking, to solve problems, to articulate and test projects, to understand causality and effect. Programming can also help children to develop skills in literacy and numbers, where algorithms account to good examples of sentence structures (syntax). As Scientist Mitch Resnick said in his TED talk *Let’s teach kids to code*, “when you learn through coding and coding to learn, you are learning it through meaningful context and that’s the best way of learning things*. (Resnick, 2012)

However, teaching programming and coding are not exclusive to the school environment. There are other initiatives. In Sweden, it is common to find it as a *Fritids*⁵. Coder Dojo is an example of a *Fritids* attended by children from age 7 to 17, that started its activities in Malmö in 2012 as ‘a movement to teach children and youth programming’ (CoderDojo Malmö, 2017). Geek Girl Mini⁶, a version of Geek Girl⁷ – a women only IT community -, is another example of a successful initiative to draw young people’s interest towards IT.

There is an overwhelming amount of resources for learning to code independently, most of which are computer based in the form of tutorials structured in levels, such as Code Academy⁸, Udacity⁹, Coursera¹⁰, and Tree House¹¹. Other platforms allow for a more open and exploratory way of learning, of which Scratch¹² and Blockly¹³ are the most popular. Coding for children - be it in school or in the *Fritids* -, usually starts with the teaching of basic programming fundamental knowledge and skills, through the exploratory interaction with Scratch. In Scratch, creativity fuels projects for game development and interaction with numerous tools, such as character design and sound and video recording, played according to instructions programmed by the user. Scratch is an open-source platform that not only allows for creativity and logical thinking, but also foments peer communication and the sharing of projects between Scratch users around the world.

### 2.2 Inequality in learning coding

Laws seem to be created to be defied, similarly to the premise of popular saying ‘rules are made to be broken’. Protection acts of equality in education for children with disabilities exist, as that of Diskrimineringsombudsmannen¹⁴, the *Equality Mediators* in charge of assessing how higher education institutions and schools in Sweden work to prevent discrimination amongst other things. Although authorities are meant to monitor compliance with these terms, schools have not been fully attendant to the terms imposed when implementing coding in their curriculum. Taking Sweden as an

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⁵ ‘Leisure time’, in the Swedish language. *Fritids* are recreational, extra work or extra school, activities in Sweden.


¹¹ [https://teamtreehouse.com/](https://teamtreehouse.com/) (access on August 3, 2017)


¹³ [https://developers.google.com/blockly/](https://developers.google.com/blockly/) (access on August 3, 2017)

example, the following excerpt from the *Everyone’s right to development* section of *Towards an outstanding knowledge nation with equal education and world-class research* (Ministry of Education and Research of Sweden, 2016) reinforces this discussion:

“The government’s education policy aims to even out socioeconomic differences and offer everyone the chance to develop. All children, young people and adults should also be given the opportunity to test and develop their ability and their skills to their full potential, irrespective of age, gender or disability. In preschool, compulsory and upper secondary schools, the circumstances, needs and level of knowledge of each child or pupil should be taken into account. Authorities, education providers and teachers should strive to ensure their pupils achieve the knowledge requirements for the national goals of education, but have a large measure of freedom in determining how this is to be done.” (Ministry of Education and Research of Sweden, 2016, p. 5)

What is to be discussed here is not the policy in itself, for the intention of inclusion present in its discourse is aligned with principles of equality. Inadequate, or unacceptable, is the lack of commitment to abide to it, expressed in a governmental decision of implementing coding in schools’ educational activities without better previous assessment of all potential implications.

Visually impaired children, as well as children with other impairments, are entitled to study in inclusive classrooms with access to every special learning material and guidance needed for achieving the same learning goals as their fellow visually abled classmates. As stated by The European Agency for Special Needs and Inclusive Education15, “pupils in need of special support have the right to specialist provision. All education corresponds as far as possible to the national curricula, but with the emphasis on meeting individual learning needs” (National Organisation of provision, n.d.). It is Needless to say, the learning needs of blind children today include access to programming education in inclusive classroom settings. However, adequate learning tools for the blind are few and often inadequate. Blind children already have a knowledge gap in comparison with their regular peers because of reduced visual stimuli that add repertoire for the formation of knowledge, as identified throughout this study. With so much being invested in research and development, it is unacceptable to not work towards providing the educational means (methodologies and artefacts) for narrowing the inequality gap in inclusive classrooms attended by blind students.

Developing and delivering a project not thought for accessibility is a common global practice. When interviewing a former Swedish programmer with visual impairment (see 4.2 Observation), about the questions raised in this study, this statement gained depth, for who better to express common accessibility related frustrations than someone who deals with it on a daily basis. He criticises the managerial process of certain political sectors involved in the implementation of new projects regarding technology16, stating that these tend to specify and acquire certain tools based on market indicators rather than to carry out prior careful study of target users for informing precise supply

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15 “[...] an independent organisation that acts as a platform for collaboration for the ministries of education”, of which Sweden takes part. Member countries share a common vision for inclusive education systems where [...] all learners of any age are provided with meaningful, high-quality educational opportunities in their local community, alongside their friends and peers” [https://www.european-agency.org/about-us](https://www.european-agency.org/about-us). (Access on May 20, 2017)

16 This scenario is not only present in relation to technology, although for this study’s focus, this is the field of interest.
acquisition decisions. Uninformed actions can affect the lives of many visually impaired schoolchildren, as it happens so now with this raised issue of learning programming.

### 2.3 Designing for learning

Learning theories have been providing a starting point for researchers to build upon new ideas and evolved concepts in the field of education, progressing “from broad theories developed to explain the many ways that learning occurs to more specific theories that are limited in the types of learning they are designed to explain” (Halpern & Donaghey, 2002). According to Halpern & Donaghey, there are two main theories from which others derive: the Behaviourist and the Cognitive Learning theories. The first studies observable behaviours in reactions to stimuli; the second studies the internal processes leading to behaviours that include thinking and remembering (Halpern & Donaghey, 2002). Whichever the theory, and there are many, it helps to shed light on the understanding of the basic psychological processes of learning: the “lasting change in behaviours or beliefs that result from experience” (Halpern & Donaghey, 2002). The fact that these theories can be significantly divergent, therefore contributing to a more open understanding of the possible processes and outcomes in this science of building knowledge. For this study, learning theories contribute with perspectives that may help in designing for learning. For instance, the Associationist approach to learning, “models learning as the gradual building of patterns of associations and skill components. Learning occurs through the process of connecting the elementary mental or behavioural units, through sequences of activity followed by feedback” (Mayes & De Freitas, 2007, p. 15). Just as in programming, a given instruction infers generating responsive action, which gives the programmer feedback for validation or iteration. Every cycle of responsive action contributes to learning through new or reinforced mental processes, gradually scaling up the programmer’s knowledge and skills. This is how we make sense of things and are able to make assumptions and decisions: by associating actions to reactions, in mental processes formed by experience and memory.

The Instructional approach shares this Associationist understanding of gradual build-up of knowledge in the learning process, with an added concern for restricting (in other words, controlling) the amount of information per learning stage, as argued by American Educational Psychologist Robert Gagné (Mayes & De Freitas, 2007, p. 15). In his book called The Conditions of Learning (1965), Gagné introduced the ‘9 Events of Instruction’, based on internal cognitive factors (the learner’s prior knowledge) and external cognitive factors (outer stimuli) that contribute to learning. Differing from the Behaviourist theory, the Cognitive Constructivist theory of knowledge, as argued by Piaget, does not consider external stimuli (1970), “based on the assumption that learners do not copy or absorb ideas from the external world, but must construct their concepts through active and personal experimentation and observation” (Mayes & De Freitas, 2007, p. 17). Moreover, Vygotsky’s Socio-Cultural perspective of Constructivist learning (1978) emphasises the importance of social interaction for the development of higher cognitive functions.

This work is built on the theoretical approaches briefly mentioned above and the assumption that we make sense of things through action, whether internal or external. It is interesting to look closer into
the Instructional approach commonly used in the development of highly engaging e-learning experiences (Mayes & De Freitas, 2007), known as Instructional Systems Design (ISD). Gagné’s fundamental idea in ISD is that competence is built systematically from simple units of knowledge or skill and up, gaining coordination of a more complex structure as a cycle of learning (Figure 1) is completed. Gagné’s 9 Events of Instruction provide a useful framework for engaging users in design exploration techniques, such as workshops.


One must bear in mind that Learning Design - a discipline derived from instructional design, focused on providing solutions to problems related to learning activities – cannot fully predict behavioural aspects of learners and of situations (Beetham & Sharpe, 2007). As Beetham & Sharpe (2007) advert “[...] learning can never be wholly designed, only designed for (i.e. planned in advance) with an awareness of the contingent nature of learning as it actually takes place. This contingency demands constant dialogue with learners, recognizing that effective designs will evolve only through cycles of practice, evaluation and reflection” (Beetham & Sharpe, 2007, p. 8).

The following summary of considerations discussed above, found in both behaviourist and cognitive perspectives, are aligned with the topics within this study and may serve as research principles:

a. Gradual build-up of knowledge  
b. Sequences of activity followed by feedback  
c. Restriction of knowledge per learning stage  
d. Consider learner’s internal and external cognitive factors  
e. Active and personal experimentation and observation  
f. Learning Design evolves constantly

2.4 Examples of research in the field

A few examples of research regarding visually impairment in learning programming are available and although they relate to the aim of this study, none are aligned with its age group, the target of fully blind users and the attempt to deeper understand specific aspects of exploration in an invisible
world. Nevertheless, the shared concern for accessibility in learning programming is of great value in itself. Amongst these available examples, two stand out, as briefly presented next.

The first research worth commenting upon, is that which a group of scientists has conducted for creating a “custom computer programming curriculum specifically tailored for the blind and visually impaired” (Stefik, Hundhausen, & Smith, 2011). This work addresses the introduction to programming concepts by manipulating materials, prioritizing discussions and projects over lectures and providing a wide variety of projects for students to work on at their own pace, given that they work at varied paces. Creators of Sodbeans, a Jaws integrated coding platform accessible to the blind, the initial hands-on activities are a step into exploring screen based coding using their accessible IDE. This research targets middle and high school students.

The second is the Blind Arduino Project, launched in 2015 by Dr. Miele. It concentrates efforts onto understanding the barriers faced by blind people interested in learning DIY hardware prototyping. With the use of Arduino, blind people are able to be creative in building computerized devices. Dr. Miele’s mission is to record information regarding their accessibility steps during this process. With Arduino used to teach children the principles of computer science, findings from The Blind Arduino Project become valid contribution for accessible learning practices.

There are several tools available for different levels of programming. There are also several visually impaired programmers with different types of visual impairment in the market today. What we are lacking is research and tools regarding the specific case of visually impaired children learning programming from the basics.

### 2.5 State of the art educational programming tools

There is an array of tools available in the market, not specifically targeting visually impaired children. Below, a selection of these tools is presented, followed by a brief analysis.

#### 2.5.1 Osmo Coding

Intended for use with the iPad by children aged 5-12, Osmo Coding is a set of tangible blocks that are assembled, creating sequences of instructions for Awbie - main character of the game - to follow. Awbie’s main goal is to eat as much strawberries as he can in the virtual world of the game. The technology can also be used to play Coding Jam, another featured game. This toolkit is used in numerous schools around the world. The set of blocks encourages logic thinking, requires basic mathematical skills and enables shared play. Its main characteristics are simple and intuitive, magnetic for easy assembling and made with good materials for durability. It uses Reflective Artificial Intelligence technology, which consists of a reflector (a mirror) attached to the iPad’s camera and the computer vision algorithms that process the data to scan the surface beneath it (Osmo, 2014).

2.5.2 Cubetto and KIBO

Figure 3: Teacher and students using the Cubetto playset. Source: https://www.primotoys.com/resources/cubetto-teachers-guide/. (Access on April 24, 2017)

Cubetto is a wooden robot controlled by a board that executes programmes created by attaching sequences of ‘coding blocks’. Each block is an action identified by shape and colour. Cubetto comes with a map mat, which presents a modular grid correspondent to the robot’s standard movement pattern. This educational toy, used in schools worldwide, is for children as young as 3 years old and aims at helping them to “develop coding skills, problem solving, communication and creativity through adventure and hands-on play”. (Primo Toys, 2017)

Figure 4: Children play scan KIBO blocks with KIBO robot. Source http://kinderlabrobotics.com/kibo/. (Access on April 24, 2017)
For children of 4-7 years of age, KIBO’s wooden blocks are arranged into a set of instructions for the KIBO robot to perform. By scanning the sequenced blocks with the robot’s body, the instructions are read and performed, stimulating creativity through open play. KIBO does not require screens, mice or keyboards. All movements are controlled by a main board that is connected to a scanner, to sensors and to motors. (Kinderlab Robotics, 2014-2017)

2.5.3 Torino Beta

Figure 5: Children aged 9 play with Torino Beta. Source: https://blogs.microsoft.com/next/2017/03/15/project-torino-microsoft-creates-physical-programming-language-inclusive-visually-impaired-children/#sm.00002q1xmq174fe2wxbsezkbb2i8o. (Access on April 24, 2017)

Torino Beta, created by Microsoft researchers and designers, is a physical programming language that consists of connecting pods together to create programs as a way for primary school children to generate code, regardless of their vision. Originally white, assuming that colour does not matter in the case of visual impairment, colour was later added because children with low vision commented on how this could aid manipulation. The size of the pods also considered user’s input, resulting in bigger pieces for better handling. (Microsoft, 2017)

2.5.4 mBot and mBlock

Figure 6: Children program mBot together on graphical programming software mBlock. Source: http://www.makeblock.com/mbot-v1-1-stem-educational-robot-kit. (Access on April 24, 2017)
mBot is a robot kit with sensors that follows lines and avoids obstacles. Although there are pre-programmed modes that allow for using mBot straight from the box, the programming experience is in mBot’s graphical programming tool mBlock, with drag and drop function blocks, inspired by Scratch. As play becomes an extension of children’s everyday lives by making mBot move in certain ways or assigning it typically human roles such as that of a football player, emotional attachment may occur. As children carefully handle the robot, even though considerably resistant, they are often seen cheering and complaining as instructions given are performed, communicating all sorts of feelings verbally or with their full bodies. (Make Block, 2016)

2.5.5 Hello Ruby

Created for children aged 5 and up, Hello Ruby is a playful exploration of computers, technology and programming, through games, exercises and apps. Ruby, the main character, meets friends along her adventures and together they solve problems. Activities range from designing computers out of paper by fitting bits and pieces that constitute a computer, to activities that use only the body as a tool for interaction, with concepts such as ‘loops’ embodied by repeating a sequence of instructions that include hand clapping and jumping.


For Linda Liukas, programmer, storyteller and illustrator, and creator of Hello Ruby, there are 3 principles of play: Playfulness, Curiosity and Rules. With these 3 principles she provides play activities that teach children to understand computational thinking and see computers as not only the screen in front of them, but that it is also the remote control, the blender, the loudspeakers. She strives in helping children to build a relationship with technology without fancy interfaces and believes that “unless we give kids tools to build with computers, we are raising only consumers instead of creators” (Liukas, 2015). Linda’s ideas of taking children away from the screens in order for them to first understand what a computer is by exploring and experiencing its concept in their immediate surroundings serve as an example of how to teach programming with non-visual activities.
2.5.6 Scratch

According to its creators at the MIT Media Lab’s Life Long Kindergarten group (2007), “Scratch is a programming language and an online community where children can program and share interactive media such as stories, games, and animation with people from all over the world” (MIT Lifelong Kindergarten, 2007).

![Scratch interface](https://www.scratchfoundation.org/media/)

**Figure 8**: Scratch interface (2015). Source: [https://www.scratchfoundation.org/media/](https://www.scratchfoundation.org/media/) (access on August 22, 2017)

As technology journalist Fahmida Rashid (2014) describes it:

“Scratch feels a little like Lego, except on the computer. Each programming element, such as ‘move’, ‘if-then-else’ and the ‘while’ loop, is represented as a coloured brick that kids can drag from the tools palette into their workspace. Different pieces snap together to form a working program for a cat avatar on the screen. If the ‘move’ brick is dropped inside a ‘forever’ brick, for example, then the cat moves across a stream in an infinite loop. You can add other shapes to create an elaborate animation, and eventually games”. (Rashid, 2014, p. 125)

Following the philosophy of learning-by-making, Scratch aims for a hands on approach, targeting kids aged 8-16, with a more recent version for ages 5-7 (released in 2014) called Scratch Jr (MIT, 2017).

2.5.7 Analysis

What we can learn from the examples presented above is that the tools available today for the teaching of computational thinking for programming are not suitable for use by the blind, for the following reasons (which do not necessarily apply to all examples, but give an overview of the latter):

- **Visual communication**: Tools that perform based on visual elements do not communicate with the blind. Graphical interfaces or the use of light (ex.: Kibo), neither communicate nor provide interactive interfaces;
- **Intangible interfaces**: Programmable robots move out of reach and out of sight in case of the blind, meaning that the blind cannot follow the robot’s movement response to a given program. Moreover, if a robot goes in an unexpected direction, the blind may lose track of its position. The need to use a computer mouse to perform an activity presents the same challenge of losing track of reference elements;
- **Handling affordances**: Tangible elements that are equal in shape and differentiated only by visual elements, such as those present in Osmo Coding, are useless to the blind, for they end
up having to act upon guessing according to feedback from outcomes, instead of making informed decisions based on the overview of the processes.

From this analysis, some design considerations may be of use in designing for blind programming, such as:

- **Modularity:** a modular mesh for unit reference aids logic processes.
- **Sound:** auditory cues are a good method for feedback when tactile solutions are not viable. Linda Liuka’s idea of incorporating sound to the learning of programming by using the body as the interface (clapping and stomping) provides a simple and accessible form of learning;
- **Touch:** the importance and efficacy of tactile interfaces for the blind to ‘see’ the world is no novelty, but it is still in need of better Design, given that the examples analysed do not entirely fulfil the needs of the blind.

So far, Microsoft’s Torino Beta is the most promising example regarding designing educational programming tools for the blind, presenting Design considerations that result from user centred participatory research, such as bulky pieces and distanced positions. Although promising, it is still a project under development, therefore still unavailable for full assessment.

### 3 Methodology

#### 3.1 Design based research

Design-Based Research is the methodology of choice, with a focus on the Design process itself to produce contributions to the research community in the form of design considerations. The methodology is systematic but flexible, aimed to enrich investigative practices within the field of Interaction Design, with cyclical but evolving iterative practical explorations in a collaborative format, in which stakeholders participate actively. As Feng Wang and Michael Hannafin (2005) define it, Design-Based Research, is:

“[...] a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories.” (Wang & Hannafin, 2005, p. 6)

According to Kennedy-Clark (2013), there are three main phases in this approach to research: Preliminary research, prototyping and assessment. The given framework serves as a basis for this dissertation where the first phase consists of a proposal developed according to the research problem based on literature review. Two main areas of focus for the literature review are presented: one that provides understanding of the current context of coding education and Learning Design. In the second phase, mixed methods of data collection used include informal conversations, observations and workshops, together with their evaluations and conclusions, each accounting for one micro cycle of research. On the third and last phase, final results are assessed in relation to the problem initially exposed.
3.2 Methods of qualitative data collection

3.2.1 State-of-the-Art Review

As a first step in developing this research, and as a practice that follows the research throughout most of its process, literature review served as an informative basis. The search for published material related to equality in education, computational thinking, coding and blindness, available in media such as articles, books, online forums, videos and websites, helped to understand the current state of blind children’s access to coding education and gather evidence to support this study. Together with the selection and analysis of up-to-date teaching tools intended for learning computational thinking and coding at a young age, a panorama of the tools available today served as reference for the do’s and don’ts of Designing for the blind.

3.2.2 Unstructured and Semi-Structured Interviews

Edwards and Holland state that interviews range from structured to unstructured, through semi-structured interviews, with the first commonly used in surveys and resulting in quantitative comparative data (Edwards & Holland, 2013, p. 2). On the other hand, semi-structured and unstructured interviews have higher flexibility and lack of structure, according to the authors (Edwards & Holland, 2013, pp. 2-3). Aiming for generating discussion - which contributes to co-building a body of data within a given problem -, whilst still maintaining the activity within a certain constraint for the purpose of sustaining focus, semi-structured interviews are the method of choice in this research, although unstructured interviews in the form of informal conversations were also conducted. This form investigation provides space for insights, answers and questions to flourish from its open format, as opposed to the constraints imposed by the question-answer structure of questionnaires. Nonetheless, a brief and strategic pre-programmed set of steps consisting of questions and/or tasks is important to guide the conversation. The expected results from interviewing subjects using this method are those generated by memory recall, improvisation, peripheral insights and critical thinking, in the form of verbal and physical expressions; spontaneous manifestations of mind and body.

Coding educators and blind users of computer technologies were the target subjects in these informal sessions, with the aim of acquiring information regarding strengths and weaknesses in teaching children fundamental knowledge of programming. The sessions, conducted in person and through phone calls, and in locations where they carried out their daily routines, added to the informal character with the environment working in favour of pleasant and relaxed interactions.

3.2.3 Observation

To validate the here alleged claim of Scratch’s unsuitability for use by visually impaired people, two Scratch sessions with blind users were conducted separately in time and place, and with different subjects. Although the tests had the same purpose and followed equal instructions, the methods for collecting their results were different. One consisted of real-time observation, discussion and annotation by the researcher; the other by the tester in his own time, with memory recalled results passed on to the researcher verbally via phone call. Participant Observation is useful for validating
the study, helping to understand better the context, to answer research questions, and to generate and test hypothesis (DeWalt & DeWalt, 2002).

3.2.4 Sensemaking and Synthesis

According to Jon Kolko, “sensemaking is an internal, personal process, while synthesis can be a collaborative external process” (Kolko, 2010, p. 18). In sensemaking, the designer makes an effort to make connections between sets of information gathered, as a mental process. Synthesis, selects and organizes data in a visual manner, through an often messy process that requires “a big wall, a marker and lots of sticky notes”, as described by Kolko. Rounds of Synthesis and Sensemaking after each micro cycle of research generate conclusions.

Affinity Diagrams (also known as Affinity Clusters) were a useful method for helping to “gather large amounts of data and organise them into groups or themes based on their relationships”, as expressed by Rikke Dam and Teo Siang (Dam & Siang, Affinity Diagrams – Learn How to Cluster and Bundle Ideas and Facts, 2017), where elements and connections were put under categories, grouping information according to affinities. These clusters are flexible entities that allow for elements to be added or supressed, connections to be iterated, categories changed allowing for refinement and constant sensemaking.

3.2.5 Informal Brainstorming for ideation

Brainstorming, is usually described in literature as a method that “essentially relies on a group of people coming together with their prior knowledge and research in order to gather ideas for solving the stated problem” (Dam & Siang, 2017). Although theoretically a group activity, I frequently see this practice being used as a solo method for ideation.

Originally introduced by Alex F. Osborn (Osborn, 1953) as a strictly structured method for ideation, Brainstorming can also be informal, according to Jeffrey Baumgartner (Baumgartner, n.d.). Baumgartner states that, although the traditional formal structure of a Brainstorm is that in which “you post a problem on a whiteboard or chalkboard and invite a group of people to suggest ideas”, an informal type of Brainstorm may occur as an unstructured ideation activity, in a smaller group of participants, as a way to produce as many ideas possible to solve a given problem: Informal Brainstorming (Baumgartner, n.d.).

It is rare to perform a Brainstorm of any sort and end up feeling like the initial ideas remain the same. It inevitably produces new ideas or transforms old ones. For this study, the simple act of taking down notes of thoughts together with Sketching them out, letting the flow of ideas loose, recording and visualizing them, makes space for creativity and imagination to occur. This simple activity used throughout every step of this investigation is therefore, as Baumgartner named it, Informal Brainstorming.

3.2.6 Co-Design Sessions

Elizabeth Sanders and Pieter Stappers (Sanders & Stappers, 2008, p. 2) refer to Collaborative Design (Co-Design) as “the creativity of designers and people not trained in design working together in the design development process”. According to Catalina Naranjo-Bock (2012), Co-Design allows users to
be an active part of the creative process within a design exploration, interacting directly with the researcher, “grounded in the belief that all people are creative and that users, as experts of their own experiences, bring different points of view that inform design and innovation direction” (Naranjo-Bock, 2012).

From utilizing tangible interfaces (Naranjo-Bock, 2012) to scenario oriented activities (Brandt, 2006), data gathered from these collaborative sessions is usually visual and tangible, directly related to user’s ideas (Naranjo-Bock, 2012).

The active participation in exploratory activities of a key subject and a researcher, manipulating information and generating insights, opinions and ideas, is the most valuable data source for refining ideas within a given context, collaboratively. One can gather, understand and evaluate all the material available relevant to this user-centred study, but without input from its target users one is left with conclusions based on other’s findings, not from primary sources. It is crucial for the researcher to generate content to elaborate upon.

4 Design Process

Having conducted literature review and analysed the tools available for the learning of coding by children, it became evident that there is little study done regarding visual impairment, with no such tools as educational tools for the learning of computational thinking attending the specific needs of blind children. Further investigation appears relevant in face of this conclusion in order to search for basic guidelines that may lead to the adequate design of such tools. The Design process chosen for further investigation consists of gathering information from educational specialists of programming for kids, from blind users of technological devices, from an experienced blind programmer, and from a primary school blind child and respective assistant teacher.

![Figure 9: Visual overview of the Design process. Source: researcher's own archives.](image)

4.1 Unstructured and Semi-Structured Interviews

4.1.1 Coder Dojo Mediators

The first step into gathering information for this study was that of carrying out unstructured and semi-structured interviews within the field of education, with two people involved in the teaching of programming to children. Two visits were conducted, one in a one-on-one format with the coordinator of the program to further understand the topic and another with the mentors during class hours, where the dynamics within it could be observed too, so that the setting could be
understood better. All interviews were informal and took place within the premises of Coder Dojo in Malmö: the first as an unstructured interview (an open conversation) with no previous structure to follow and the second with a brief set of questions as a guide to follow, so to make sure to maintain in focus. As well as interviewing mentors, the children were observed without being interrupted, in their natural individual and group interactions with the program Scratch. All information collected from both visits was recorded in the form of written notes.

When presented the problem, Coder Dojo Malmö expressed surprise, having never come across this concern before or ever had so much as a call from a parent of a blind child asking for information. This first contact with one of Coder Dojo’s mediators, accentuated the programming educators’ need to clarify this new teaching paradigm.

Like this study, Coder Dojo’s participants are mainly children of between 7 and 14 years of age, with a few exceptions of younger participants, as young as 5 years old. At this Fritids, children learn through contact with various tools, digital and physical, assessed by adult mediators and with the freedom to explore programming according to their personal interests and pace (as perceived in the activities conducted by Sodbeans creators – see 2.4 Competitive Research). Although the possibilities of media accessible to the students is vast, the one main tool of choice, especially for the very beginners, is Scratch, just as one could expect from preliminary research on the topic.

Specifically addressing blind learning of programming during childhood in conversations with the children’s mediators, the challenge of visualization was emphasized from the perspective of those educators used to dealing with children, and with the tools and methods applied in teaching. In addition, they pointed out how unaware they are of the specific needs and processes required for blind learning and their handling of computers, and their belief in the potential sharper understanding and innovative ideas that a blind coder, not distracted or biased by image, may present in comparison with non-blind coders.

The one clue that these professionals assumed could be a way into investigating solutions to the problem was that of using audio cues to convey the information that the screen usually presents for visual capture. Maybe simple physical blocks, inspired in Scratch, can be assembled in a program that results in sound or haptic feedback?

As an example of coding tool with audio feedback the Sonic Pi live coding synthesizer, would be an option according to one of the mentors, where music is created in real time responding to code added to the API. Largely used as an input and/or output informative method when dealing with blindness, audio is a way through which to investigate coding for the blind. Sonic Pi is a useful tool for blind coders, not for individuals with no previous coding knowledge and experience; hence, it is not a solution and highlights the core importance of developing a tool that prepares for its use, from the teaching of basic computational thinking.

4.1.2 Maths, Science and Technology primary school teacher

Another crucial stakeholder in this investigation was a primary school teacher at Västra Hamnen Primary School, in Malmö, used to teaching computer programming to sixth graders. This meeting, although still informal, had a longer and more structured set of questions not used as a restrictive tool, rather used as a guide, with all answers recorded as written notes once again.
The teacher, learnt programming at the age of 66, self-taught, when asked to teach Arduino and Processing to 75 students. She believes that nowadays it is important to teach the subject early in schools, because “it is the future”. She further explains, “Before, bosses had secretaries. Now, leaders do their own presentations. In a couple of years you will have to do some programming too; at least you have to understand that an alarm clock goes off not by magic”. For her, it is important for developing logical skills, for understanding how the world works, understanding how to survive in different environments, and gaining the ability to understand the tech of today and of tomorrow.

Programming, as observed by the teacher, has made children learn how to “fix things”. This knowledge has given children the skills to be able to examine maths exercises more efficiently (looking for mistakes and correcting them), as she observed. Programming is not a subject of the curriculum in itself yet; it is taught as part of the subject of Technology, during a few weeks that were intended for Science classes.

Once again, Scratch was also a primary source for teaching programming to youngsters in her classes, where it was introduced to students using the body to express the idea of ‘move forward’, for example. Interacting with the body before moving blocks in Scratch helps to understand why it is important to learn to use it and what can be done with it.

The teacher suggests looking into Logic Blocks for inspiration for this project. She pointed out that children do not learn to read until 7 years old and therefore, they understand symbols better. Moreover, the teacher brought attention to peer-to-peer education as a method proven engaging and efficient.

4.1.3 Blind technology enthusiast representing SRF Skåne

The first visually impaired stakeholder to contribute with information – enlightening information – for this study was technology enthusiast, counsellor of SRF Skåne\(^\text{17}\), in Malmö. Two meetings with him were conducted at SRF: the first was for an informal conversation, which resulted in a second meeting (as described in the next topic) for the observation of his navigation of Scratch. The first meeting with him consisted of an open conversation with a few questions previously arranged, to be used as a guide. All answers were recorded as written notes, once more.

According to him, if you are blind in Sweden you are entitled to receive support from the government, which includes a computer with specific software installed, for example. When it comes to blind children’s assistance in schools, children can attend regular schools, with no need for specific schools for the visually impaired, where a specially trained teacher is assigned to assist the student throughout activities, and specific school materials are provided, such as books. According to him, although this is how the system is meant to work, reality does not fully correspond to what is planned, with teachers not fully prepared and a lack of adequate tools available, making the system fail in attending inclusion and equal rights.

With so many advances in Health Care along the years, the numbers in visual impairment amongst youngsters have decreased, leaving SRF with as few as 50 blind associates between 5 and 18 years

\(^{17}\) SRF (Synskadades Riksförbund) Skåne is the Visually Impaired Association of Skåne, in Sweden.
old, having a majority attendance of around 60% of associates above 60 years old. SRF currently has around 1200 members in Skåne and 12 local associations across Sweden.

Health Care has benefited immensely from advancements in technology, just as the world of digital devices of which he provided valuable information regarding accessibility. His experience as a blind user of computers, tablets and smartphones has led him to being a consumer of Apple products only, which he claims to be a common attitude given that Apple’s Voice Over is by far the best available screen reader today. Having said that is important to highlight that, as claimed by him as he demonstrated on his iPhone, the best screen reader still has a lot to improve; Voice Over does not describe images enough to make them understandable.

Navigation seemed intuitive to him, with the aid of Voice Over, heavily relying on sound to access information and communicate with others, while still coping with many functions and features fully or partially inaccessible to him. As problems are addressed, new problems naturally arise, and as navigation is being taken care of (slowly but continuously evolving), the use of mobile applications presents a new obstacle in the invisible world. According to him, for every 10 apps he downloads, only one is accessible to him.

When asked about his use of Braille or the use of Braille in SRF by its members, he responds that he is from a generation of blind youngsters that were taught braille and that although a universal and useful method, it is no longer talked about much anymore. The investment that it demands of time and of effort in learning, and of time and high costs for production of special materials, nowadays compete with the less demanding possibilities presented by technology, having sound and magnification as the main and best solutions available.

Further, I discovered that his children were starting to learn programming is school, and that the tool used by them was Scratch. I asked him if we could do a user testing session where he would try out the program for the first time.

he describes using the computer as “working on a black screen” and draws attention to the fact that everything (including classes) has become too fast-paced making the knowledge gap a reality between blind and non-blind students. Informative elements, such as colour, are becoming increasingly visual, leaving blind students with less stimuli, but still with better developed auditory and memory skills than their regular classmates: “you are forced to listen and to remember things much better”. When dealing with computers, students have to listen to what the teacher is saying and doing, to what the computer is saying or doing, and to what the student himself is doing, all at the same time and in a short time. It demands a lot of effort.

4.2 Observation

4.2.1 Blind Programmer’s Scratch experience

Two Scratch sessions each carried out with one visually impaired person, proved their inability to navigate through the program’s interface. The SRF’s Counsellor was the first participant with his visual disability of around 85%. He is a user of Apple products because Apple’s Voice Over tool is the most efficient gesture based screen reader that enables blind and visual impaired people to use
screen-based devices through audio descriptions of everything from basic icons to images. Although Apple’s Voice Over is the best screen reader available today, iOS is not compatible with Flash, the most common technology used to run multimedia programs such as Scratch. Without Flash, it was impossible to explore any of the demo works shared on the platform and to use its main feature of creating multimedia content through programming. Another challenge was the Voice Over read from the demo works, which did not say their titles, only their reference path numbers. The third and most insightful result from this exploration was that of visually impaired people not being mouse users; their navigation is with keyboard commands and shortcuts. Using the mouse does not provide any precise screen location references and Scratch’s drag-and-drop modality requires the use of a mouse. Furthermore, when the lines of a Scratch program are stacked up (Figure 8), they do not have a regular line-by-line position, such as the regular coding structure, making its open format lack in a formality that helps visually impaired people in wayfinding.

![Figure 10: Sample script from Scratch, with computational and mathematical concepts in evidence (2009). Source: http://web.media.mit.edu/~mres/papers/Scratch-CACM-final.pdf (access on August 14, 2017)](image)

Although not acquainted with programming himself, he knows blind programmers and confirms that it is possible to go beyond limits imposed by the lack of accessibility present in technology. The second exploratory Scratch session was carried out with a blind programmer who developed Apps for many years and has strong interest and understanding in technology. He uses Jaws as his screen reader. Even though he uses a Microsoft Windows OS with Firefox and Internet Explorer, both compatible with Flash, his experience with using Scratch was also one of great difficulty that confirmed the SRF’s counsellor struggle. The programmer reinforced the fact that, from an accessibility standpoint, Flash is not adequate since its support varies across browsers, making it a restrictive tool that generates problems in its operations. He was unable to provide more information regarding his experience in navigating through Scratch, for he could not use the program at all, and unable to point out the directions for how to develop a tool to teach children to program, but suggested experimenting further with someone who has never seen before – blind from birth -, using objects, instructions and sound.
4.3 Synthesizing and prioritizing findings

4.3.1 Synthesis for preliminary Design: considerations and constraints

Having reflected upon the main findings from the interviews and observations related the problem here discussed, it is with no doubt that Design for educational tools aimed at the teaching of programming to blind children presents itself as a challenging and complex task that requires thorough investigation with a large number of iterations. Given the demanding nature of this preliminary conclusion, together with the brief format of this study, the scope should therefore be limited to exploring the most basic aspect within the nature of programming: instructions. In exploring how instructions are given and how they are captured, the so far suggested paths of modularity, sound and tangible objects must be addressed, in the attempt to address the conflicting aspects brought to surface – visual information, drag and drop, incompatible operating systems. This said, it becomes necessary to work together with a blind primary school child in the next step of investigation, for obtaining the highest fidelity of results possible.

4.4 Co-Design Sessions

It took two months to be in contact, face to face, with a blind primary school child. There seems to be a reluctance from schools and institutions linked to visual impairment, to face this matter and offer help – the reason is unclear. In any case, a 12 year old blind girl (blind from birth), studying at a regular primary school in Upplands Väsby, together with her assistant teacher, were willing to participate in the planned co-design sessions (which will here be referred to as workshops).

Two workshops were carried out, one at the school and another at the Väsby Makerspace, a creative centre where children from pre-schools and schools within the municipality of Upplands Väsby can learn IT. Both workshops were intended for short duration to avoid fatigue and maintain the level of interest high for completing previously planned tasks while having fun and space for exploration and self-expression, and for open and continuous discussions. Instructions, through tangible artefacts, audio cues and modularity was the object of these workshops. The structure for both meetings was as follows:

- Informal conversation, where the purpose of the study was explained, as well as the relevance of the workshop (and so the relevance of their participation in it). In Workshop 2 this step is replaced with a review of Workshop 1 and discussion about it: thoughts, feelings, improvements, what worked and what did not work;
- Explanation of Activity x, Activity x and its discussion (repeated for as many activities as planned);
- Informal conversation, where the Workshop as a whole is discussed: thoughts, feelings, improvements, what worked and what did not work.

Previously to the workshops, the sensitizing of participants by briefly explaining the activities that they should expect to participate in was relevant for preparing them, but only briefly so that the activities’ surprise factor was kept for maintaining curiosity and expectation. Participants were also given a form of consent, especially given the participation of a minor. The form presented the
researcher and explained the activities to take place, informed of the anonymity to be kept regarding the participants’ identities and of their freedom to step out of the study at any given moment according to their wishes, and required signatures from both the teacher (representing the school) and from the student’s responsible parent. Both meetings were recorded in the forms of video, audio, photographs and written notes.

Workshops were kept analogue to discard any restrictions or biased responses that digital interfaces may impose upon the user. These may include and are not restricted to, predicted programmed behaviour of the digital artefact that may provide a response to an action, or by biased restricted behaviour imposed by artefacts of common use and triggering unconscious predictable reactions and actions from the user. In Workshop 1, two experiments took place: a Virtual Audio Reality (VAR) experience and exploration with a modular set of objects.

4.4.1 Workshop 1: Virtual Audio Reality (VAR) and modularity

In a VAR experience, the listener is positioned at the centre of a given scenario, with audio as an accurate informer of distances, positions and many other aspects of an environment. Equipment for recording VAR is so advanced that it provides a good substitute technology over screen readers for the blind to perform off screen and screen based activity. Binaural technology, used to record VAR material, has already been considered for the purpose of using directional hearing for orientation, converting visual information into audio interface, as supports the study 3D Audio Interfaces for The Blind (2003):

“Because of the sequential nature of commonly used technologies, it was found to be essential to develop a new interaction mode to increase the information flow between user and computer. While tactile devices like braille lines can only provide a limited amount of information per time, audio has the capability to provide a lot more information at once if made surrounding and spatial. Furthermore, hearing is a sense, which allows different levels of intenseness of perception, where the range reaches from background sound to speech. [...] The most obvious advantage over sequential techniques is the natural perception; humans are using their directional hearing for orientation at all times. Audio interfaces can be modelled in the space allowing multiple information sources.” (Frauenberger & Noisternig, 2003, p. 280)

In Workshop 1, a VAR sample was given to the student, on headphones. The aim was to understand her perception of space and of instructions through audio cues. The sample described a barber’s situation, where the main character (the barber’s client) was set at the centre of the situation while the barber and a helper moved around the client – an experience so real that transports the listener to the scene with high fidelity spatial perception.

Figure 11: Workshop 1 - Exercise 1 - Student given a VAR sample to listen to. Source: researcher’s own archives.
Listening to audio, the student had no reaction at all. Her facial and body expressions remained neutral. Nothing was explained to her about the audio prior to listening to it, in the attempt to get the most spontaneous reactions out of the experience.

Having listened to the audio she is asked about her first thoughts she says “it is really good, they talk a lot to each other, it seems real. It was fun.” Although a pleasant and real experience (a positive result for the study), she does not understand the situation played out by the characters, a situation of sitting in a barber shop, getting a haircut. It seems like she could have retained more information from the sample if given the context prior to listening to it.

The student then is asked about location and if she could imagine the position of people as they moved around and the answer is positive. She is further asked questions such as: Could that be a game? If a characters movements in a game were expressed to her through sound, would it be fun? Could she find her way around the game only through sound? Once again, she answers positively to all questions.

Later she is asked to tell the story she had just heard in as much detail as possible and as she describes it some elements seem to not have been captured or seem unclear. As conversation evolves, it becomes clear that the student does not relate to the audio using her imagination. Imagination, “the act or power of forming a mental image of something not present to the senses or never before wholly perceived in reality” (Merriam-Webster, 2017), seems to occur differently in blind pupils. Rather than a mental image, information retrieved from the audio sample appears to be converted into informative data of a more abstract form, the rational form. Information that describe the state of things such as far, near, fast, slow are prioritized over information that describe the appearance of things such as the shape of the room or of the characters. As a preliminary reflection upon this, it seems that information retained by a blind child who has never seen a scene in its macro format - for she relies heavily on touching close by objects to relate them to shape and texture, therefore differentiating forms and aspects -, is relevant directly conveyed, as if there is no space for subjectivity. Things are as they present themselves, and to somebody who does not see through vision, things are presented according to their repertoire of sensorial experiences other than visual.

“If I was to give you another audio like this one, telling another story where you would also be the main person in the story, which story would you like to be in?”, the student was asked. Following, she answered: “Maybe I was in a clothes shop. I could not find something good. I would ask the shop assistant. I maybe need a dress. Then I find a red dress, maybe. I think I would laugh a lot if I played that game.” Surprisingly, this quick mental sketch of a game follows an ordered sequence of events. More surprisingly, it refers to colour, when in reality colour is invisible to the blind.

Figure 12: Workshop 1 – exercise 2 - Wooden board (left) for experimenting with localization and modularity presented to the student (right). Source: researcher’s own archives.
The concept of Algorithm as a set of instructions was then introduced to the student, who nodded affirmatively at the explanation. She understood what it meant in relation to how computers function. This brief introduction served as a preparation for the next activity which used a square wooden board with 9 equidistant slots each occupied by a small wooden piece (Figure 6). The pieces could be moved between slots. With this instrument, the student is asked to pretend it was the room and that each of the slots (by this stage she is asked to feel it to recognize the board and its constituent elements) can be occupied by one element (object or person) from the story’s scenario in the audio sample. She was then asked to place 3 elements from the audio on the board, according to where they seemed to be in relation to the space of the room. Two elements were to be objects (such as scissors, guitar, telephone) and the third element would be herself as a listener (the client in the story). She was also asked to explain verbally the position of the items on the board, without an imposed format of description; to describe it as she wished, as if explaining to someone else the configuration arranged there. The resulting configuration was correct according to the audio and the description of the position of elements was precise and clear.

Figure 13: Workshop 1 - exercise 2 - student handles objects on a modular board, responding to instructions. Source: researcher’s own archives.

Furthermore, the student was asked to give instructions, verbally, to ‘take the guitar to the phone’, which was precisely accomplished referring to distances using the slots in the form of ‘steps’ and directions in the form of ‘right, left, up or down’ with the adjacent elements as anchor references. Her instructions contained only 3 straight forward sentences, as shown:

1- From the middle of the room, take a step to the left.
2- Then you take one step down and you are at the guitar.
3- Then to take the guitar to the phone, you take two steps forward/up.

To test how she responds to instructions, they were read to her for her to perform them using the objects from their initial positions and, once again, performance was exemplary. It seemed intuitive to use the modular slots as a unit of measuring distance from point A to point B and it seemed natural to her, to explain with such accuracy the location of elements to another person.

After this experiment, she was asked if she could recall any experiences with games that required instructions, to which she responded exemplifying a situation in which she played a game that she enjoyed very much but required her parent’s help to play it, since it was not accessible for blind users. Furthermore, asked to recall experiences with ‘coding’ games, the answer was given by her teacher, as follows: “We had in school Micro bits. They are like small, with LED lights to show you what to do, but it is hard because it is just visual. We could explain but she did not see what we were doing. […] It’s hard for her. You put them together in the computer, and she does not see. So maybe
if you could make them like this and put them together, it would be easier. But it’s hard on the computer”. As she answers, she points to the wooden objects and the headphones on the table, referring to them when suggesting how it could become accessible for her pupil.

4.4.2 Workshop 2: Debugging, and shaping and leveraging imagination

The main idea for Workshop 2 was to continue with exploring the giving and receiving of instructions with added complexity in comparison to the first workshop, and building upon the exercises already seen rather than creating unrelated activities. The reasons for insisting on previous exploration as an approach that may contribute to valuable insights, are: the tempt to validate, reinforce or review previous results; the attempt to enrich an effort already made, adding value to it; the belief that working with familiar elements makes participants comfortable and confident; and time and location constraints that limit workshop sessions to a number of two only at this stage of research.

![Image showing brainstorming and sketching for ideation](image)

**Figure 14: Informal Brainstorming and Sketching for Ideation. Source: Researcher's own archives.**

The first of three activities planned for this workshop was conducted as a recall of the first one, or as a warm-up exercise, where the student was asked to describe in as much detail as possible a place well known to her. Her place of choice was her bedroom. Her description of it was as follows:

“A desk is pretty close to the door. When you walk by it, you come to a bed sofa. If you walk past it, you come to a bed. Between the sofa and the bed, there is a nightstand. Then if you walk past the bed, you come to another table with a chair. After the table, you come to some closets and then you are back at the door. Between my bed and the table, there is a red chest of drawers. The room size is good. Not too small not too big. There are shelves over the sofa and over the desk.” (Excerpt from transcriptions of participant student’s speech at Workshop 2, 2017)

A detailed description of a systematic understanding and exploration of space, where one element is related to another. All elements are connected in a logic manner, with the logic here being order. It is also interesting to note that the description starts from elements at the height level of reach of the
The student is then asked: “do you ever think of your room as a whole thing, or do you only think of it in pieces when you go around it. Is it important for you to think of where things are in the whole, or is it more important to think of things in pieces?” To which she answers: “Things that are close are important. If walking towards something more distant I would then think of that. I don’t think if it is square or something.”

The second activity consisted of the student giving instructions as to how to get from one place in her house, to the bedroom that had just been described. The first description was as follows:

“From the kitchen to my room. You go through the living room, then you come to my little sister’s room, then there is a bookcase, and you go past it and then you are in my room.” (Excerpt from transcriptions of participant student’s speech at Workshop 2, 2017)

From the first description, she was asked to elaborate her instructions better, for one could get lost with it as it was, to which comment she agreed, and then went on to correcting herself:

“Maybe I can describe it better. My little sister’s room is... you go out from the kitchen... If you are by the kitchen table, then you go forward. When you come out from the kitchen, there is one red cupboard and you go past it and then you find my sister’s room.” (Excerpt from transcriptions of participant student’s speech at Workshop 2, 2017)

After listening to her own description by the researcher, the student was asked: “If I am by the kitchen table and I move forward, how do I know I am moving forward in the right direction? How do I know I am not moving in the other direction?” To which she answers:

“If you sit where I used to sit, when you stand up you stand behind the chair and then you turn around so the chair is behind you, and then you go forward, then you know you are in the right direction. And then you go past a red cupboard (maybe it is not red, maybe it is white) on the right.” (Excerpt from transcriptions of participant student’s speech at Workshop 2, 2017)

She was able to understand the gaps in her directions and correct them. This was a good example and exercise of testing and debugging. Testing and debugging, a common practice within the the

Figure 15: Workshop 2 - first exercise - student is asked to give instructions from point A to point B of a scenario well known to her, and to iterate process when finding flaws in the sequence. Source: researcher’s own archives.

spectator. After this layer of objects is complete, other information (of different types and at other heights from the observer) appear.
activity of programming computers, has proven to be one of the most important skills that students acquire from learning programming at a young age, for that skill is then applied as problem solving in their regular everyday activities.

As the second activity ends, the student is asked about colours, since the colour red appeared in the middle of her instructions in both Workshops 1 and 2, when describing certain objects. Her answer is that colour does not really matter, for she does not think of colours. The objects she added the identification of the colour Red to, were qualified to her in that manner by her mother when describing them to her.

Figure 16: Workshop 2 – second Exercise - generative exploration with Lego blocks. Source: researcher’s own archives.

The third and last exercise consisted of asking the student to build, using Lego bricks, her idea of the clothes shop as she envisioned it when describing her idea of a game, in Workshop 1. “What would the shop be like if you were walking around in it? It does not need to be a perfect shop, just give me an idea of what it would be like. No rush. Don’t worry about the time. Make it the size and shape you want. Feel free.”

The student seems to like the idea of this exercise and does not hesitate in starting building it. No recall of her description was conducted, she simply had it in her memory and brought it to surface and translated it into the physical format of a small Lego construction in 8 minutes, every now and then asked by the researcher for a brief report of her process.

Having finished she is then asked to showcase her shop, pretending to be walking around it and presenting it to someone, how it is and what there is. She presents it as “Here is a fitting room and there is a desk. Here are the clothes”. “And these blocks of different sizes. Are they all for clothes?” She promptly answers, “Yes, they are for different sizes”.

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The resulting built shop, even though made to the height of only two layers of Lego bricks, contains all the basic elements of a clothes shop, and details that are impressively represented: the fitting room has a door passage; one of the sides of the shop is free of bricks for that is the entrance and shopping window; different sizes of bricks, positioned in a line, are hangers for different sizes of clothes; there is a table that is also the cashier; and all elements inside the shop are placed distant enough from one another for the passage of people. What is intriguing is that, once more, priority was given to horizontality, leaving the vertical aspect almost as unimportant.

Finally, the student is then asked to verbally play out a scene, together with IT Strategist Per Falk, from Väsby Makerspace, who participated in Workshop 2 – according to her own script from Workshop 1, that spoke about looking for a ‘red dress’ in the shop, with her being the client and Per being the shop assistant. Her immediate reaction is that of excitement. The expectation with this exercise, from the perspective of the researcher is that imagination is facilitated, stimulated and formed when derived from her own creative process.

Since imagination from an external source, as experienced in Workshop 1 with the audio sample, apparently was not accessible to her in meaning, there must be other forms by which a blind pupil accesses imagination. And so, the practice triggers her imagination, as she creates more objects and events/situations, verbally expressed in her imaginary shop experience, with active responsiveness to Per’s stimulating roleplaying.
While they ‘virtually walked’ through the store, the student followed with her hands, positioning herself in the places where the story took her. At a certain point, the need to correct her position occurred, and she corrected it, once more iterating and ‘debugging’ her way through. That brief error was caused by an unexpected element, a mirror in the fitting room, added by Per. “I could not figure out where the mirrors where, it was very hard”, she said. It should also be taken into consideration that this student has never seen a mirror before and that this may add a level of difficulty to imagination.

The exercise clearly builds up the student excitement, humorously interacting with Per. As the exercise ends, she shows contentment, confirmed when asked if she had enjoyed it. She also seemed to be more energetic and communicative than at any other moment during both workshops.

4.5 Invisible Exhibition experience

During my stay in Stockholm for conducting the workshops at Upplands Väsby, I had the chance to visit a permanent exhibition called Invisible Exhibition. The Invisible Exhibition is an interactive exhibition that takes the visitor on a walk inside completely dark spaces, where common environments are carefully recreated and one can navigate them through smell, touch, auditory and even palate senses.

The experience started with using a braille typewriter, without being in the dark or blindfolded, to type one’s name on their ticket. This warm-up set the tone for how challenging the experience would be. Entering the dark rooms was in itself distressing. The noise was distressing. The silence was distressing. A poke in the eye by another disoriented visitor was distressing. Everything about it generated anxiety, even though I knew I was in a safe and controlled space.

There were new challenges to deal with, relying on guesses and sometimes even on luck, on others’ instructions and on what my memory could recall in order to cooperate with me. No power cut or blindfold can truly recreate life without sight, and although this particular exhibition succeeds in providing this experience, as non-blind visitors our experiences are not representative of those of the blind.

In the end, one finds the way out, but it is not without a skilful balance of tremendous effort (attention) and relaxation (trust). Nothing that a good cup of coffee, sitting in an invisible bar, did not ease. A momentary wonderment to me, a lifelong reality to others. There has to be a lot to explore for the understanding of the experiences in this invisible world. My personal experience enhanced all that I encountered and learnt in the course of this investigation and it helped me to better understand my findings from Upplands Väsby.
4.6 Conclusion from the Design Process

Scratch, the main tool for teaching programming to primary school children is not accessible to blind children unless aided by someone sighted, as proven through experimentation conducted with two blind individuals, separately. Not only Scratch is not accessible, but also other common tools used for teaching programming do not present adequate design, according to how blind people experience and understand things. Based on the outcomes of the various research activities in my Design process (as presented previously in this Chapter), I learnt that the major problems presented by Scratch to the blind are:

- Information and interaction require, mostly, the ability of visual capture;
- Its main interaction requires drag and drop movements, which the blind are unable to perform;
- Apple’s Voice Over, the best screen reader available today and main reason why visually impaired people choose to acquire Apple products, does not read successfully the features of Scratch;
- IOS is not compatible with Flash, the technology used to run multimedia on Scratch.

This study suggests, through findings in state-of-the-art analysis and in design exploration, that one cannot perceive adequate design results aimed at blind users from the standpoint of what one assumes to be relevant. A major learning outcome of my studies is that blind users must be positioned in the centre of the design process, involved from preliminary explorations to the testing of a final design. Only then, can design for the blind be called as such. Engaging people who can share their non-blind convivial or collaborative experiences with blind people is also an efficient and high fidelity source of information. Moreover, it is important to select and prioritise specific aspects of Design exploration to address, in order to keep aims clear throughout exploration, for it produces large amounts of data dense in content.

Along the design process presented in this study, many were the times when I predicted a given outcome, which then resulted surprisingly different. I would have never thought, for example, of being so careful when dealing with imagination, as imagination is not perceived by the blind the same way as it is by me as a non-blind being. It is logical that there are many aspects to this specific design field that differ from general design aspects. How I have experienced things in the course of my life, gives me a repertoire that differs from that of someone who has never used sight. My perception is not the same, and for this reason the blind subjects with whom I have conducted this study somehow added to my repertoire, revealing a little of how they experience life and how we differ.

This research presented an approach to Interaction Design Research that produced valuable design considerations to help us develop adequate tools for blind primary school children to learn programming. The approach consisted of positioning blind primary school subjects and subjects closely related to this user group at the centre of the design process, for active participation (collaborating) in the exploration of the chosen research topic, through common methods of design research adapted to the context of visual impairment in primary education. Constant iteration of the process was crucial for ensuring high fidelity results, shaped according to environmental input. Added to iteration, deeply exploring one specific aspect of programming (in this case, the
management of instructions) using various media accessible to the blind is, without a doubt, adequate and fruitful. The following chapter presents the results obtained with this approach, in the form of design considerations.

Figure 19: Categorizing findings by affinity to synthesize results. Source: researcher’s own archives.

5 Results

There are several interesting insights that account for design considerations obtained from this investigation. My assessment of the resulting outcomes here presented is that of a non-blind researcher of Interaction Design, therefore it points to behavioural patterns and does not attempt to analyse them from other perspectives, such as the Psychology perspective, for example. These design considerations for developing educational programming tools aimed for use by blind children, result from exploring ‘instructions’ as its main logic operation, to discover physical and mental patterns that deserve special attention. As presented in Chapter 4, these result from experimenting with navigating programming environments through different interfaces: screen based (computers and mobile phones), audio based (VAR and verbal communication) and touch based (manipulation of physical objects), having blind subjects as participants. Conducted with combined elements, such as ‘instructions in audio and verbal communication formats, translated into manipulated physical objects’, this exploration produced interconnected results, as presented below.

5.1 Design Considerations

Accessibility must address navigation of environment and communication of content. Its success depends on the right choice of methods and tools for navigating a carefully planned environment, and on the right choice of methods and tools for facilitating the communication of carefully chosen content. Accessibility provides Autonomy.

5.1.1 Time
It takes longer than usual to complete regular tasks when one cannot see. Getting acquainted with an interface and performing an action are not as immediate when it does not engage sight, for it requires engaging other, more limited, senses. This may result in the need to break down an activity into groups of smaller numbers of tasks to ensure that the total time for an activity does not exceed that of children’s attention span.

5.1.2 Tools

Interacting with diverse mediums may be the best way to target the understanding of basic programming logic, leaving screens for more complex coding practices in later stages of learning. Interacting with the body before interacting with other interfaces helps to understand the logic of instructions, through more tangible associative connections. This is important for developing the skills needed to survive in different environments. Non-blind survival relies highly on visual parameters, to the point of anticipating something as trivial as a traffic jam further down the road. For the blind, survival depends more on tangible parameters. The body offers many tools in itself for the exercise of exploring the understanding of basic programming logic, with vocal chords, tactile and auditory senses as examples.

Hearing, as much as touching, is crucial for orientation in the invisible world. For instance, VAR (Virtual Audio Recording) is a good substitute technology over screen readers, being an excellent tool for the blind to perform not only screen-based activities but also off-screen activities. Binaural technology, used to record VAR material, can reproduce the soundscapes of environments and provide an audio interface for orientation through directional hearing. Binaural technology, therefore, is an efficient tool for compensating the inability to explore the world visually.

On the topic of tools for navigating screen-based environments, the need to use a mouse disables interaction: blind people are not mice users, for mice do not provide any precision in screen location. Their use of computers is through voice or shortcut inputs, utilizing a microphone or a keyboard.

The issue of mice usage, just as it happens with touchscreens, is nowadays tackled with the aid of Screen Readers. Screen readers are efficient in enabling the capture of visual digital information in audio format. The tool presents the advantage of being adaptable to different devices, reusable and portable. Nonetheless, it is important to point out that although it is a great tool, the screen reader frequently fails to provide the expected outcome, as noticed when tested with Scratch. Aware that not all programs are compatible with screen readers, screen-based activities must be compatible with Voice Over and Jaws screen readers, providing accessibility for MAC OS and Windows users. Another problem with screen readers is its inability to describe images – it is important to understand that this description is not recreated in an image format; rather it delivers information in a raw data format, of details as well as of the general context.

5.1.3 Multimedia

Compatibility between interactive digital content and its enabling multimedia software, such as Adobe Flash, also presents problems. Flash is not reliable in its performance. It is not compatible with MAC OS, as well as with a variety of browsers, and given that it is the operating system of choice in the invisible world, it must be avoided.
5.1.4 Imagination

What can also be suggested regarding describing images to a blind person is that even if a successful algorithm could perfectly describe any given image, the assumptions of the non-blind in regards to how the blind use imagination may be full of utopic and uninformed expectations. Reason being that imagination is processed differently by the mind with no activity of visual nature, due to the lack of visual repertoire and of stimuli. In this case, interaction that requires imagination to occur (as it happens in game scenarios) must be addressed accordingly to the specific case of blindness. This topic of imagination related to a mind banned from visual image capture is one yet to be explored in depth, theoretically and practically. Acquiring scientific knowledge on how imagination occurs in the human brain, including recent discoveries such as that of the condition of Aphantasia, is needed.

5.1.5 Content

As already pointed out, a blind person does not recall a given scenario (a ‘bigger picture’), rather retrieves elements of it from their memory, in the form of selective data, not as pictorial data. Purely visual elements, such as colour – elements that cannot be smelled, felt, heard, tasted or sensed -, do not exist in the non-visual memory, they only exist as descriptive information conveyed by a visually abled informer. Colour does not mean anything to a blind person because this knowledge is not useful to them. Apparently, as it does not contribute to survival in an invisible world, it is discarded. Having said this, it is relevant to briefly comment on another interesting insight that this study presents: communicating colour may be used as a tool for building a sense of belonging in a non-blind group, through common language.

There seems to be a natural tendency for reality over fantasy, when speaking of blindness. It is not as big an issue as imagination, but they are linked, for fantasy also demands repertoire, and does not seem to mingle with the rational thought processes of such mind. Need is the prevalent criteria for filtering information, over any other criteria unrelated to providing useful data, and its relevance is often measured by the emphasis that it presents – loud speech over background sounds within a soundscape, for instance.

The ability to precise sequential thinking, to spot mistakes and to correct them, are to be taken into account. The lack of sight does not discourage confrontation or disable the solving of challenging tasks. Formality, order, precision, consistency, these are all qualities that contribute to a work in favour of sequential thinking. Systematic detailed description of the constituent elements of an interface, presenting clear links as reference anchors that enable wayfinding should provide a solid environment for autonomous exploration. Moreover, a consistent feedback system seems effective in sustaining interest in an activity and in enabling critical cognitive associations for knowledge retention.

In such ordered cognitive activity, the thought process may be disrupted by seemingly harmless interruptions in its flow. The unexpected introduction of a new element to a story, such as a new instruction or object, for example, may briefly interrupt a thread of though; it is wise to plan this aspect carefully, to enable cooperation with an ongoing thread of thoughts, avoiding disturbance. This is important for avoiding conflicting information, aiming for a stable level of motivation in a progressive learning process.
5.1.6 Context

When thinking spatially, elements that are not at a ‘reach’ distance automatically become secondary or unimportant, just as what matters for a transition from one point to another: what matters is the information needed in between the start and the end of a journey. Blind people navigate by sensing their immediate surroundings, with a horizontal focus (on what they can reach out for, as a default setting developed for life’s everyday tasks), making all that is above their height secondary in importance. It is always important to provide a thorough explanation of the context of an activity, in as much accurate detail as possible, to compensate the fact that the bigger picture is not captured, thus facilitating piecing together a context and making meaning out of the individual bits of information captured.

5.1.7 Modularity

Modularity is a good asset in programming activities as it provides a reference unit to communicate with, adding order and aiding instruction based learning. Just as distance is often communicated in an urban setting using roads or blocks as a reference unit, or number of steps when playing a board game, the use of units of reference is also useful for guiding non-visual activities.

6 Discussion

6.1 Critical Reflections

With so many obstacles which this design process faced regarding placing the user at the centre of the design exploration, because of the difficulty encountered when searching for teachers and blind students able to participate in it, the potential for design exploration contained in this topic was harnessed. Nonetheless, it enabled common methods of Design Research to be tested and validated, given its insightful outcomes. How these methods became malleable without coming apart, changing and evolving in synchronized progression with the activities executed, proved that every process is unique.

Commonly applied methods of Design Research such as those inherent to the practice of academic research (and usually conducted individually), such as Literature Review and State-of-the-art Analysis are methods of great importance to grounding any Design investigation. These Methods are characteristically formal, but it appears to me that design researchers tend not to abide to strict linear ways of thinking, and they must acknowledge that they possess a special ability to weave unexpected multidisciplinary connections within the fabric of a research structure, and that this often enriches the process as well as the results. As for the collaborative methods applied in this study, I like to call them ‘game changers’; these collaborative methods add new players (stakeholders) that intercept ongoing research with their experiences and knowledge, adding new layers to it. This collaboration continuously made use of the resources available (existing questions, findings, tools and stakeholders) to defy and leverage its outcomes. I believe that this approach to
design investigation defines the level of success in the fidelity of a design consideration in relation to the reality of its context. The more collaboration in the process – engaging stakeholders within the context of the study conducted –, the better validated a resulting design consideration is.

Managing stakeholders required multitasking and this led to many faults along the process that, although acceptable, may have caused some negative impact on the project as a whole. One way in which I feel the project was affected is in being so presently involved in interacting with participants that I would forget to record the activities in photographs, for instance. I have to say that all the mental and written recordings that I collected are of immense value, but that this reminds me of Jon Kolko’s (2010) ideas regarding synthesis and the impression of ‘magic’ that it gives to someone not exposed to its full process. I feel that my design process, as presented, would benefit from more elements of visual content (photographs), to enrich its description and to tame a possible impression of ‘magic’. I also believe that it would have been more efficient if the workshops were conducted between two researchers, to make sure that all the important aspects and elements of the design process are covered – execution and collection of information.

On the topic of Learning, it is important to keep intended learning goals coherent with those already existing in the schools’ curricula, in order to have them clear and achievable. This said, considering coding as an advanced level of programming is a distinction that has to be made to avoid misinterpretation, facilitate the planning of activities and of goals intended at each completed level of instruction. The learner should be able to code when the knowledge and skills of basic programming are fully retained, and only then can complexity be added. The difficulty level must scale up gradually, to avoid frustration and ensure thorough solid learning.

Although this was a difficult project to execute, because of all that held it back from moving forward (lack of existing research; difficulties in finding blind participants; adapting existing methods), my belief in its importance kept me motivated. Just as the design process that shapes itself according to need, the broader infrastructure of projects do not always fit a pre-determined framework. One must be prepared to deal with the unexpected in a design process and, most of all, to know how much every small contribution to knowledge is of value to a given context. At the early stage of discussion in which the context of this research finds itself today, every small contribution may become a big step to an important discovery.

6.2 Future Opportunities

This research presents only the beginning of a much larger project that I envision; a project that engages larger numbers of stakeholders and of micro cycles of research, including ideating, prototyping and testing. Ideally, this work will be of use to other researchers aiming for a final design result of at least one programming educational tool for blind children, to be of use in inclusive primary schools that have implemented coding as part of their curriculum. It would also be good to have this investigated in relation to peer-to-peer education, to support and accelerate initiatives of inclusive education.

In addition, the topic of Imagination is in need of further exploration and better understanding, which raises my interest in investigating more thoroughly the specific condition of Aphantasia. I see
this as fertile ground for producing valuable insights for game developers to create accessible interfaces carefully tailored for the imagination of blind users. Games account for a significantly high portion of tools used for teaching different subjects to primary school children, including programming, and it is a potential possible solution to the research problem here exposed.

Overall, the issue discussed in this dissertation is important and urgent. Not only researchers and designers will have to address this, but authorities will also have to acknowledge their existence and step forward to foment this discussion, and encourage, keep track of and verify further development, manifesting and offering their support throughout its unfolding.
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