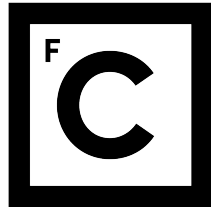


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***TACTOPI: A Playful Approach To Promote
Computational Thinking to Visually Impaired Children***

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MESTRADO EM INFORMÁTICA

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To the children who need more accessible play.

Resumo

O uso de atividades lúdicas é comum em configurações introdutórias de programação. Visualmente, estas atividades tendem a ser estimulantes o suficiente no entanto, não são acessíveis para crianças com deficiência visual. O objetivo deste trabalho é apresentar o sistema *Tactopi* - que consiste num ambiente tangível que proporciona o treino de competências de navegação e enriquecer experiências sensoriais utilizando elementos sonoros, visuais e tácteis; Permite a aprendizagem de conceitos introdutórios de pensamento computacional, para além de atividades lúdicas com narração de histórias que promovem a educação ambiental. O mapa é modular, personalizável e tem um sistema de encaixe para colocar os elementos permitindo uma interação táctil divertida. Outro elemento importante é o leme impresso em 3D com contendo um joystick e botões que permite controlar e pré-programar as instruções a serem reproduzidas pelo robô.

No entanto, as abordagens e adaptações para crianças com deficiência visual ainda são reduzidas. Algumas destas adaptações podem ser menos estimulantes para as crianças com deficiência visual normal, comparativamente à riqueza dos materiais para as crianças normovisuais. Neste trabalho, o nosso objetivo é responder a este problema com uma abordagem mais compreensiva para crianças com deficiência visual, não só para introduzir o pensamento computacional, mas também para estimular os seus sistemas sensoriais com atividades lúdicas e envolventes.

A introdução do pensamento computacional na educação precoce está a tornar-se benéfica na aquisição pelas crianças de uma base valiosa para a motivação e aprendizagem da programação a posteriori. O que distingue este sistema é o acrescentar uma camada lúdica, que tem vindo a faltar, especialmente concebida para crianças cegas e de baixa visão que acomodam atividades de estimulação cognitiva e computacional.

As crianças com deficiência visual podem sem dúvida ser grandes aprendizes, no entanto têm falta de acesso a conteúdos adaptados na educação. A maior parte da informação é recolhida através da visão, em alternativa deverá ser conseguida utilizando outros sentidos e métodos. Os objetos tangíveis são importantes porque a criança pode explorar as suas dimensões e apreender sobre os seus detalhes. As mãos são uma ferramenta primária na recolha de informação para crianças cegas. Por esta razão, as crianças com deficiência visual precisam de ter o maior número possível de oportunidades para experimentar objetos sensorialmente [26].

Desenvolvemos um sistema com as seguintes propriedades:

- Um ambiente tangível capaz de proporcionar a aprendizagem de competências de navegação e experiências sensoriais ricas utilizando elementos sonoros, visuais e tácteis;
- Aprendizagem de conceitos iniciais de pensamento computacional;
- Atividades lúdicas e interativas;
- Fácil personalização, modificação e design extensível;
- Alternativa a brinquedos com necessidades especiais que podem ser caros e muitas vezes limitados a uma única habilidade de estimulação.

No decorrer do presente trabalho, apresentamos três contribuições:

- TACTOPI - um ambiente tangível acessível a crianças deficientes visuais com elementos interativos e atividades lúdicas;
- Uma ferramenta para introduzir o pensamento computacional e inspirar outros ambientes de aprendizagem acessíveis;
- Opiniões e sugestões de profissionais recolhidas através de um questionário qualitativo;

Os resultados preliminares foram publicados na conferência da ACM - ASSETS em 2020 [28].

Um repositório [25] está a ser construído contendo um tutorial e uma coleção de referências, código, materiais para impressão 3D e máquina de corte a laser, tais como ficheiros STL e vetores, cartões de histórias e ficheiros áudio disponíveis para educadores e entusiastas interessados em fazer ou redesenhar o protótipo *Tactopi*. Esperamos contribuir para que a comunidade tenha acesso e inspirar para a diversidade e inovação em projetos de acessibilidade e educação.

Os componentes deste protótipo são compostos por um grupo de elementos tangíveis: o leme com um joystick, o robô, o mapa, os animais, os cartões, um módulo de identificação - leitor NFC e um módulo de reprodução de som. A maioria dos elementos foram desenvolvida através de processos de fabrico digital, corte a laser e impressão 3D. Impressão, corte e colagem foram outras técnicas utilizadas para criar o protótipo funcional. Os animais têm uma etiqueta RFID incorporada na base que permite a associação do som com a identificação de cada animal. Os cartões também contêm etiquetas RFID para permitir a reprodução das diferentes histórias sonoras através do módulo de reprodução de som.

O mapa é um elemento essencial com grande relevância na educação dos deficientes visuais, especialmente para aprender a navegação espacial. O mapa neste jogo tem duas

representações diferentes. Em primeiro lugar, temos uma representação macroscópica e conceptual do mapa mundial que contém o conjunto de missões a explorar. Estas missões são apresentadas como cartas de jogo com etiquetas RFID para identificar e ouvir cada missão. Cada carta contém um relevo de um animal e uma história em texto e áudio.

A segunda representação do mapa é formada pelo conjunto de peças modulares sobre as quais o robô irá viajar. É uma representação imaginária que tem lugar num determinado oceano, de acordo com a atividade. Estas peças são exploradas com tacto pela criança cega. Este mapa é acessível como um elemento tridimensional e onde elementos como os animais e possíveis obstáculos ou prémios podem ser anexados. O mapa contém pontos perfurados em cada célula do mapa, criando assim uma matriz de pontos onde é possível anexar um elemento à célula do mapa.

Neste sistema, pretendemos ter um elemento central interativo, capaz de seguir as instruções dadas pela criança.

O robô viaja sobre as células do mapa em várias direções (norte, leste, oeste). Foram atribuídos símbolos para as direções Norte, Este e Oeste, triângulo, círculo, e quadrado, respetivamente. Estes símbolos pretendem promover a lateralidade e a navegação espacial, um desafio que é complicado para a criança cega mas importante como tarefa de treino [41].

Foram atribuídas funcionalidades para dois modos de navegação diferentes (ver figura 3.12). Para o primeiro modo de navegação estruturada, a principal funcionalidade é pré-programar passo a passo as instruções, de acordo com o número de células a percorrer, guardar estas instruções e reproduzi-las repetidamente, se necessário, até a criança encontrar a sequência correta para completar a missão. O modo de navegação livre (ver figura 3.13) dá à criança a liberdade de mover o robô de uma forma exploratória.

Foi realizado um estudo através de um questionário qualitativo com professores e investigadores de diversas áreas e na sua maioria com experiência na acessibilidade com crianças cegas, de modo a avaliar o sistema onde foi possível concluir que este sistema é uma ferramenta, que apesar de algumas limitações, se mostrou eficiente na introdução ao pensamento Computacional para crianças cegas. Foram recolhidas sugestões dos inquiridos experientes com crianças cegas, investigadores e educadores, as qualidades do sistema, as vantagens e desvantagens de cada um dos elementos, a adequação para crianças cegas, e a estimulação e aprendizagem da criança. Foram entrevistadas um total de 14 pessoas, 12 investigadores e dois educadores de diferentes áreas, experientes em educação, Interação Homem-Máquina, robótica, psicologia, educação e acessibilidade.

A *playfulness* (“brincadeira”) está presente e é valorizado no contexto da aprendizagem, o sistema TACTOPI tem elementos interativos que suportem atividades noutras disciplinas e contextos e por fim uma ferramenta que assegura a acessibilidade e suporta o treino de tarefas espaciais e navegação para o desenvolvimento da criança cega.

“Um jogo muito interessante. Permite muita manipulação por parte das crianças e com estímulos da componente tátil, aos sons e não esquecendo as luzes. Porque muitas das crianças mesmo sendo consideradas cegas têm visão residual e para as crianças com baixa visão, as luzes são muito importantes. Este jogo pode ser um Mário Kart lá de casa para estes meninos!”

Professora de educação especial no domínio da visão de alunos do pré escolar ao ensino secundário

Palavras-chave: Brincar, Pensamento Computacional, Acessibilidade, Tangíveis, Robôs

Abstract

The use of playful activities is common in introductory programming settings. Visually, these activities tend to be stimulating enough. However, these are not accessible for visually impaired children. This work presents TACTOPI - a system that consists of a tangible environment that provides navigation skills training and enriches sensorial experiences using sound, visual and tactile elements; It allows the learning of introductory concepts of computational thinking embedded in playful activities with storytelling that promote environmental education for children with visual impairments from 4 to 7 years old. The map is modular, customizable and has a docking system to place the elements allowing a fun tactile interaction. Another essential element is the 3D printed helm containing a joystick and buttons for the child to control and pre-program the instructions to be played by the robot. A study was carried out using a qualitative questionnaire to evaluate the system. Suggestions were collected from respondents experienced with blind children about the suitability, relevance and accessibility of this system for these children. From the results, it is possible to conclude that this is a tool that, despite some limitations, is efficient to introduce computational thinking; interactive elements that support activities in other disciplines and contexts; a tool that ensures accessibility and supports task training for the development of blind children.

Keywords: play, computational thinking, visually impaired children, tangibles, robots

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- Special Education practitioner - Experienced with VI children; and a
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Chapter 1

Introduction

1.1 Motivation

In recent years, we have seen the rapid growth of tools for children to learn basic programming concepts. This step for education is undoubtedly important because, in the future, it is expected that programming will be a new form of literacy. However, approaches and adaptations for visually impaired children are still reduced. Some of these adaptations can be less stimulating for children than the richness of the materials for normal visual children. In this work, we aim to respond to this problem with a more comprehensive approach for visually impaired children, not only to introduce computational thinking but also to stimulate their sensory systems with playful and engaging activities.

Visually impaired children can undoubtedly be great learners, but they lack access to visual content for education. We are aware of how the majority amount of information is gathered via vision must be achieved using other senses and methods. Tangible objects are important because the child can explore their dimensions and grasp their details. Hands are a primary information-gathering tool for blind children. For this reason, visually impaired children need to have as many opportunities as possible to experience objects sensorially [26].

We want to create a richer interaction, similar to a playground balancing the fun and immersive level in this context. The main challenge of this research is how to create a fun interactive, and accessible experience. Although it can be challenging in a world where visual information is dominant, and our own experience so far would be addicted to that visual world, there are more tools to facilitate the design of solutions crucial in the learning and play of these children.

1.2 Goals

The introduction of computational thinking in early education is becoming beneficial in children's acquisition for a valuable basis for posterior coding learning. What distin-

guishes this system from previous systems in the state-of-art is adding a playful layer, which has been missing, specially designed for blind and low vision children that accommodate cognitive and computational stimulation activities.

This work presents TACTOPI - a system that consists of a tangible environment that provides navigation skills training and enriches sensorial experiences using sound, visual and tactile elements. It allows the learning of introductory concepts of computational thinking embedded in playful activities with storytelling that promote environmental education for children with visual impairments from 4 to 7 years old.

We propose to achieve this by analyzing the state of the art of educational tools for teaching computational thinking, the main properties to create a physical environment that the blind or low vision child can explore and what will need a set of materials and prototyping tools.

This work focuses on stimulating children through a playful approach, not uniquely designed for computational thinking purposes, and as a tool for special needs educators that frequently use activities with physically augmented materials.

We conduct an online study, a questionnaire to evaluate our prototype, investigating the benefits of our approach and which improvements can be made in the future, according to a group of teachers and researchers specialized in the field of accessibility.

We developed a system with the following properties:

- A tangible environment capable of providing the training of navigational skills and rich sensory experiences using sound, visual and tactile elements;
- Learning early concepts of computational thinking;
- Playful and interactive activities;
- Easy customization, modification and extensible design;
- Alternative to special needs toys that can be expensive and often limited to a single skill of stimulation.

1.3 Contributions

In the course of the present work, we present three contributions:

- *TACTOPI* - a tangible environment accessible to visually impaired children with interactive elements and playful activities;
- A tool to introduce computational thinking and inspire other accessible learning environments;
- Professional's opinions and suggestions gathered through a qualitative questionnaire;

1.4 Publications and Outreach

Preliminary results have been published at the ACM ASSETS conference in 2020 [28], a that presents research on the design, evaluation, use and education of computing accessibility.

A repository [25] is also being built containing a tutorial and a collection of references, code, materials for 3D print and laser cutter machines, such as STL and vector files, story cards and audio files available for educators and enthusiasts interested in making or redesigning the *Tactopi* prototype. We hope to contribute to the community having access and inspire for diversity and innovation in projects for accessibility and education.

Chapter 2

Related Work

2.1 Inaccessibility for blind and low vision children

“Visual Impairment means an impairment in vision that, even with correction, adversely affects a child’s educational performance. The term includes both partial sight and blindness.” [26]

Even though blind children represents a minority, the prevalence of childhood blindness varies according to socioeconomic status. The majority of children with blindness worldwide live in the poorest countries, with high mortality rates in children younger than five. The prevalence may be as high as 1.5 per 1000 children, in contrast to high-income countries where the majority is five times less. Designing for blind children is a challenge. These children often present coexistence with additional disabilities [35]. An inclusive design for a broad spectrum, from low vision to blind and attending different cognitive levels, can be a flexible approach to accommodate most of the needs. This approach can also include a set of regular practices that can stimulate other senses and train them to be more efficient and independent. Later we present two studies on Design Guidelines for accessibility, with the good practices to create a tangible environment for blind children.

2.2 Introduction to Computational Thinking

Learning computer science is nowadays important to pursue a future career in the STEAM field. It is fundamental to inspire children from early ages to be creative with technology and not merely tech-savvy consumers. Computational Thinking (CT) as a set of foundational problem-solving skills is an essential step towards this goal. Pires et al.[46] found that educators were particularly avid to find overlaps between the CT concepts or activities and what they already try to foster for the development of their younger students. Bers, an important researcher and creator of the KIBO project [49], to be mentioned later,

proposed that when introducing computer science and computational thinking into early childhood education, the approach must be playful [32].

A simplified programming language for novice programmers is a block-based language. These languages are highly visual, which makes them inaccessible to blind and visually impaired students. A common approach is using a tangible user interface, physical coding blocks that children can manipulate.

2.2.1 Learning CT through Play

Play is fundamental in the early development of young children. Children are engaged to explore, develop skills and learn to socialize with their peers.[36] Early childhood education has long recognized and agreed upon the benefits of using constructivist methodologies to help young children learn by manipulating materials, engaging in active inquiry, and creating playful experiences. This tendency is now more pronounced in the last decade [32]. Introducing computers in early childhood education settings has been a challenge. Bers defends that robots can support integrating computers into the constructivist practice by engaging children and teachers in the functional design of meaningful projects, combining manipulative materials.

2.2.2 Discussion

We support the approach “Coding as a playground” [32] to engage children in learning to code through fun, play and creativity. Children can use a series of computational thinking processes - such as abstraction, algorithm and procedures, debugging, problem decomposition, and pattern recognition [30] - in an engaging and immersive way. While creating this environment, we presuppose a richness of multi-sensory elements such as an audio narrative and sound cues, sounds of the sea, wind and animals, akin to a video game. Beyond the graspable elements of navigation and collectable stars, the textures on the map will contribute to an immersive experience and the child’s engagement and playfulness.

2.3 Tangible Programming Environments

Tangible programming toolkits support coding projects and even not being accessible, their physical and graspable elements can inspire the design of tangible environments for blind and low vision children.

LittleBits- LittleBits [31] is an open-source library of modular electronics, which snap together with magnets. (see figure 2.1). Beyond the democratization of electronics, they thought of electronics as material that can be combined with other traditional ones such as paper, cardboard and screws. *LittleBits* consists of small circuit boards with specific

functions built to snap together with magnets without soldering, wiring, or programming. Each bit has its specific function, such as light, sound, sensors, or buttons. “*The LittleBits mission is to put the power of electronics in the hands of everyone and break down complex technologies so that anyone can build, prototype, and invent*” as said by the founder *Ayah Bdeir*. *LittleBits* units are available in more than 70 countries and used in more than 2,000 schools. In 2019, *Sphero* [23], A leading STEM learning company with interactive robotics STEM education kits completed the acquisition of *LittleBits*. These kits, although promising and attractive, are not accessible to blind children.

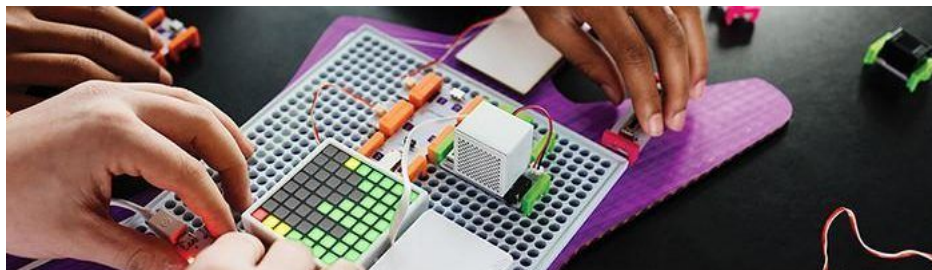


Figure 2.1: *LittleBits* example of a circuit with plugged components.

Project Blocks (see figure 2.2) inspired by previous academic work and then supported by *Google*, was a research program aiming to create tangible programming experiences for kids. Their goal was to help young learners to develop computational thinking and “coding experiences that are playful, tactile and collaborative” [18].

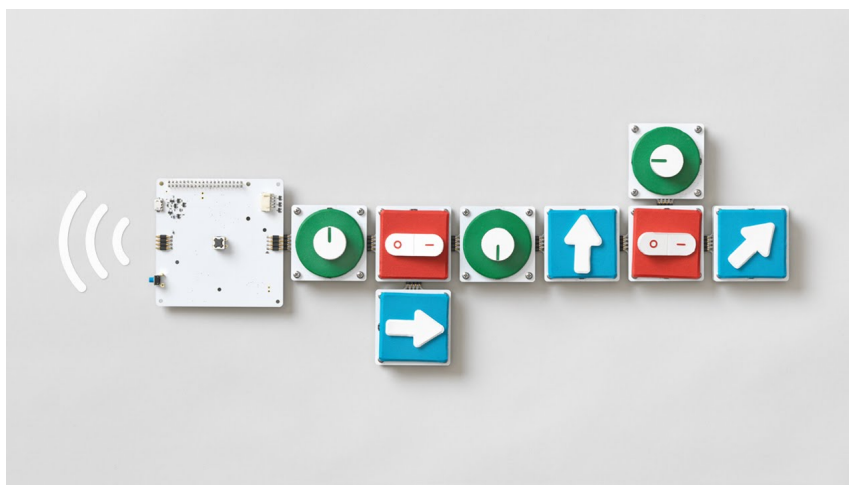


Figure 2.2: textitProject Blocks.

Algobrix4 - Instead of writing scripts, the kids have blocks to arrange in a tangible way that is true to actual coding.

The *Algobrix* [3] team wanted to make coding accessible and tangible for kids by building code with LEGO® (see figure 2.3). This would be a promising system with Lego compatibility. However, the project appears to have been discontinued.

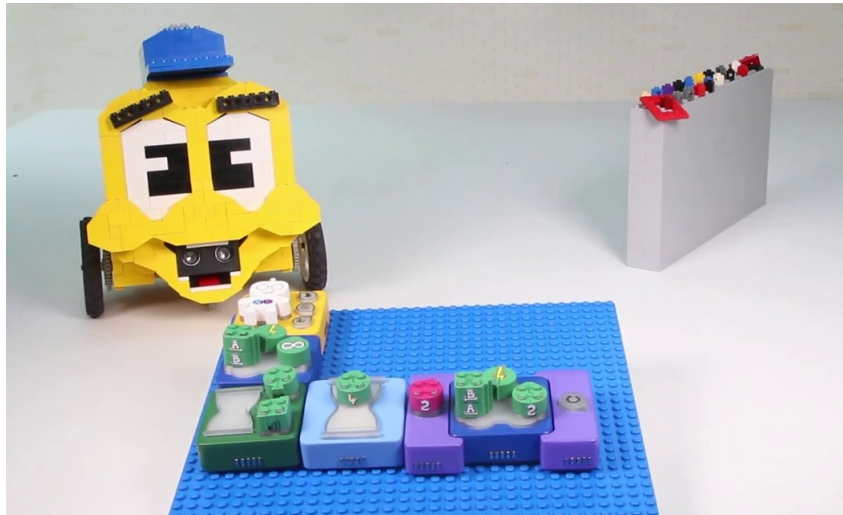


Figure 2.3: *Algobrix* programmable blocks and robot with LEGO®.

Kibo

Kibo [49] is a robot programmed with tangible wooden cubes, using a barcode reader that identifies the instructions of each cube, eliminating the need to use a computer (see figure 2.4). The robot can later be personalized by the child, creating a character and program its actions. It is an excellent example designed in collaboration with children and teachers over several years of iteration and redesign. *Kibo* is recommended for ages 4 to 7.



Figure 2.4: *Kibo* Project.

Concerning programming projects that involve tangible elements, compromises are made in their democratization, for various reasons such as access to the hardware itself. In contrast, projects that involve only software, such as visual programming languages (VPL), can be dominant and accessible to a larger number of children.

2.4 Accessible programming environments

Story Blocks [43] is a tangible block-based game that enables blind programmers to learn basic programming concepts by creating audio stories using the combination of code blocks (see figure 2.5). Story Blocks offers an alternative approach that provides equal access to blind and sighted learners, it also focuses on audio stories as an output format.



Figure 2.5: Blocks used in the initial *StoryBlocks* prototype include characters (mouse, turtle, cat, snake, cheese), actions (explode, talk, run, dance, eat) and control structures (repeat, branch).

Project Torino [19] is an accessible programming environment that uses custom hardware “blocks” that can be connected via cables to create audio-based programs. *Torino* is a very interesting project to introduce computational thinking to blind children, it has colourful and well-designed elements to manipulate. However one of the main problems with this project is the high cost which reduces the availability and opportunity for many children to use it in their schools (see figure 2.6).



Figure 2.6: Blind children interacting with *Project Torino*.

Project Torino and **StoryBlocks** uses physical components to create audio programs. **StoryBlocks** uses low-cost components and computer vision rather than custom electronics.

2.4.1 Digital Fabrication and Physical Computing

Do-It-Yourself and 3D Printing are useful in the design process because it allows anyone, user or caretaker, to build, create, iterate or personalize devices, it is also fundamental to improve the design process of assistive technologies [39]. Digital fabrication techniques, such as 3D printing is a DIY approach that presents good benefits for assistive technologies and the design of tangible artefacts. There is a growing body of work investigating the use of 3D printing for/by the visually impaired [37]. Kim and Tom have studied the usability of several forms of 3D printed tangibles. Kim and Tom [42] have investigated the use of crowdsourced 3D models in the design of personalized tactile books.

MapSense [34] is a multi-sensory interactive map for visually impaired children that proposes reflective and ludic scenarios and allows caretakers to customize it as they wish (see figure 2.7). It is made of a raised-line map overlay, on a touch-sensitive surface. It uses colours and ludic audio cues, for children with low vision or with residual colour perceptions.

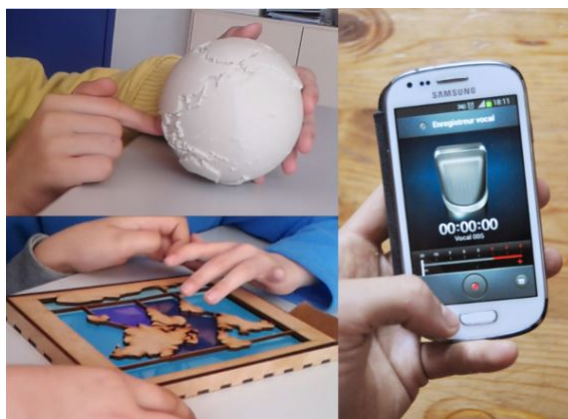


Figure 2.7: TactiGlobe, a tactile 3D printed globe; WoodMap, an interactive map with a laser-cutter overlay, using ludic audio cues; SoundRec, an audio recorder Android app.

Studies on the use of tangibles in teaching have reported that interaction with tangibles encourages engagement, excitement and collaboration, promotes discovery and participation, and makes computation immediate and more accessible. [40]







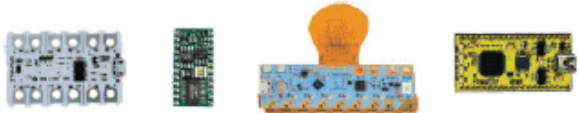

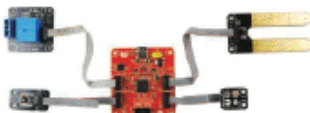

Applications of tangibles with computer interfaces have also been explored in the “Tangible Desktop” a project headed by Baldwin et. Al [29] to explore a method of desktop navigation using 3D printed tangible objects tagged with RFID markers that represent taskbar icons.

Micro:bit

The *BBC Micro:bit* [14] is a micro-controller, a tiny programmable computer that was developed to help children easily learn the basics of programming. Including inbuilt sensors for movement, light and temperature detection and a screen with a matrix of LEDs *BBC Micro:bit* also contains a compass and Bluetooth connectivity. In the table (2.8) we can see *BBC Micro:bit* categorized as a board-level embedded device that needs a computer or mobile device to program, however, it can operate as a standalone device and be battery-powered, it can be interesting to create small interactive projects without the need to be connected to a computer.

2.5 Discussion

Computational thinking is an important subject that has a set of tools for children. Nonetheless, children with visual impairment cannot be left behind by the lack of adapted tools, especially for earlier ages that we analyse in this work. After reviewing existing work, we found that there are accessible systems and a good base of conceptual frameworks that assist in designing play systems for these children. There is still some lack of available systems in open source form for TVI or SNE to use and adapt in their classes. On the other hand, the Playful component is not always present in these systems and is essential for the engagement of the blind or low vision child.

Categorization	Type of product	Examples	
1. Packaged electronics; no programming	Kits of packaged components and modules	Snap Circuits, basic LittleBits, Circuit Stickers	
2. Packaged programmable products (not boards); programmable via PC or phone; often battery-powered	Robot turtles	Sphero, Ozobot, Kibo, Dash and Dot, BeeBot, Cubetto	
	Programmable construction sets	Lego WeDo, Lego Mindstorms, Pico Cricket, Vex Robotics	
3. Board-level peripheral devices; need PC during use	Integrated input/output devices for PCs	Makoy Makey, PicoBoard, BlinkM, Sense Board	
	Modular input/output devices for PCs	Phidgets	
4. Board-level embedded devices; need PC to program but can operate as standalone device; can be battery powered	Microcontroller boards with integrated input/output devices	micro:bit, Light Blue Bean, Arduino Espora, Circuit Playground, Calliope	
	Microcontroller boards with low-level input/output	Crumble, BASIC stamp, Arm mbed, Chibi Chip	
	Microcontroller boards with support for modular input/output	Arduino variants	
		.NET Gadgeteer, TinkerKit, Hummingbird	
5. Board-level general-purpose devices; often use wired power	Often used without PC; input/output available through accessories	Raspberry Pi, BeagleBone, Intel Galileo	

Some images courtesy of AlesiaKan/Shutterstock.com; Chester Fitchett/phidgets.com; Bunnie Huang; and Greg Norris.

Figure 2.8: Categorization of Commercially available physical computing products. Retrieved from [38] Some images courtesy of AlesiaKan/Shutterstock.com; Chester Fitchett/phidgets.com; Bunnie Huang; and Greg Norris.

Chapter 3

Design and Implementation

In this chapter, we give an introduction to the concept of *Tactopi*, and reflections on the preliminary design experiments.

3.1 The concept of *Tactopi*

*“What she taught me is to feel that you are part of this place.
Not a visitor. And that’s a huge difference.”*

Craig Foster from the documentary My Octopus Teacher [16]



Figure 3.1: *Tactopi* - conceptual name.

The name *Tactopi* is the combination of the words Touch, in Latin as *Tactus*, and octopus, as it arises from the search for a tactile experience that would be enriching for visually impaired children (see figure 3.1). *Tactopi* is the name of the main character, a curious octopus with an excellent sense of touch. A documentary called *My Octopus Teacher* [16] from the Sea Change Project [20] also inspired me to think about this fascinating animal as a connection element, as a friend, between the child and the robot. A cooperative effort is reached between the octopus *Tactopi* and the child who have the agency to give instructions to *Tactopi*, using a helm, to command the robot, a boat, and accomplish the missions of saving marine species from external threats, such as sea waste - plastic and also global warming consequences.

The main purpose of this project is to develop an integrated platform that can potentiate the learning and playfulness between teachers, family and children with visual impairments to increase children's cognitive stimulation, communication and interaction.

Tactopi is an inclusive exploratory nautical game to engage children in a playful experience while acquiring computational thinking skills (see figure 3.2). *Tactopi* is a kit composed of:

- 25 modular pieces, with perforated dots to enable customization, allowing to construct different paths;
- the helm that is controlled by the child in two different modes;
- a set of five 3D printed animals [48], [17], [22], [2], [1] with smart tags;
- mission cards with tactile figures with smart tags;
- a magic stone for reading mission cards and animals;
- an Mp3 and speaker to reproduce the sounds.

The environment presupposes a richness of multi-sensory elements such as sound cues, textures and 3D printed elements that can also be interactive using *Micro:bit*.

The map is modular, customizable and has a fitting system to place the elements allowing a fun tactile interaction.

Another important element is a 3D printed wheel with a gamepad (joystick and buttons) that allows controlling and pre-program actions on the robot.

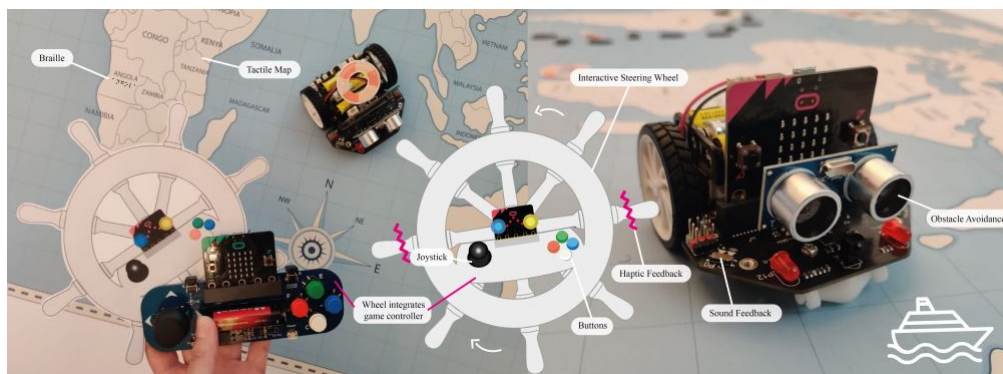


Figure 3.2: *Tactopi*'s initial concept.

3.1.1 Design considerations for accessibility

The following guidelines were fundamental as a basis to ensure the playfulness but also the accessibility of the system. We followed the design considerations of these two studies [27], [34] that present in their findings design guidelines for the design of tangibles accessible to children with visual impairments:

- “Bright and contrasting colours, to be consistent with residual visions;
- Artefacts should not have **sharp relief**, as it is uncomfortable or frightening during exploration (i.e. children would avoid some part of the object in order not to hurt their fingers);
- surfaces should be at least “**two fingers large**” so children can feel the differences between the volumes;
- specific objects that could be compared during the class should respect the differences of **scale**, to provide a correct mental image;
- Taking great care of visual, audio and tactile **aesthetic quality**, is beneficial for inclusion and reflective learning, as it evokes past experiences and triggers positive emotions;
- When designing for the classroom, one should be designing for **inclusion and collaboration**, using **multi-sensory interactions** as they accommodate **different cognitive and perceptive needs**;
- **Tangibles** seem to be particularly beneficial as they can be used in multiple ways;
- Scenarios of use should be **ludic** and engage children in storytelling. It stimulates engagement and reflectivity, thus improving access to **symbolic representations**;
- **Do-It-Yourself** methods enable high-level customization by children and caretakers, which reinforces satisfaction and engagement;
- Not to restrain the imagination of children rather improve their **imaginary world and creativity**;
- Parts are as **simple** as possible. Parts are as **durable** as possible;
- Simple, enjoyable and **fun** to play;
- Appropriate to **play alone** and **play with others**.
- Improve **sociability of children**;
- Appropriate to play in **alternative plays**;
- Appropriate to **play by both girls and boys**;
- Should be designed and produced according to the **safety regulations** ”.

3.2 Implementation

In this chapter we discuss the design of *Tactopi*, the activities we have developed, technical background on the solutions used, we also contribute with open-source code to further inform research for the visually impaired (see figure 3.3).

3.3 Overview

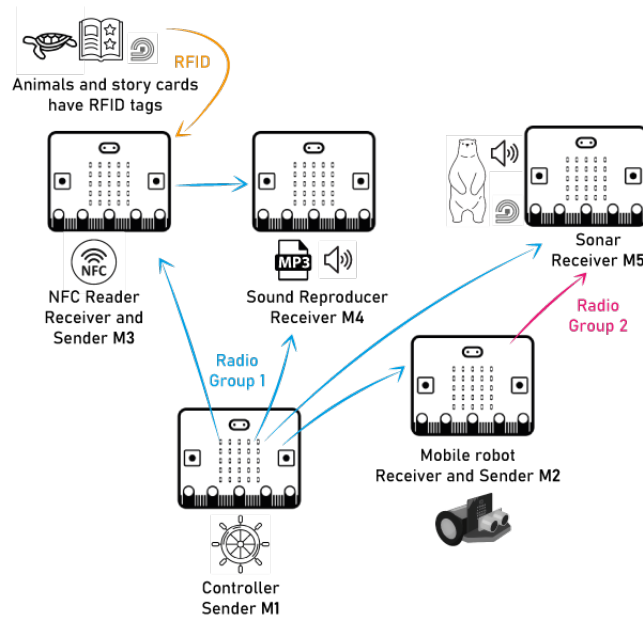


Figure 3.3: Overview of the system, essentially composed of 5 *Micro:bit* that communicate through different groupings by radio, sending and receiving data. There is also an identification module by NFC (Near-Field Communication) and a sound reproduction module.

3.3.1 Requirements

When designing the system, we defined the following requirements:

- A tangible map capable of providing the training of navigational skills and early concepts of computational thinking;
- A central interactive element, able to follow the instructions given by the child - a mobile robot;
- A module for the child to control, tangible and playful - the wheel;
- Provide means to explore the map allowing the child to freely explore the map or to explore in a structured way;

- Playful activities with storytelling for environmental education;
- Allow all stories and instructions to be played using audio;
- High contrast colours and lights, tactile cues and text written cards and simple illustrations;
- Easy customization, modification and extensible design;
- Allow the system to be extended with additional story elements;
- Allow the system to be extended with additional audio elements.

3.4 Components

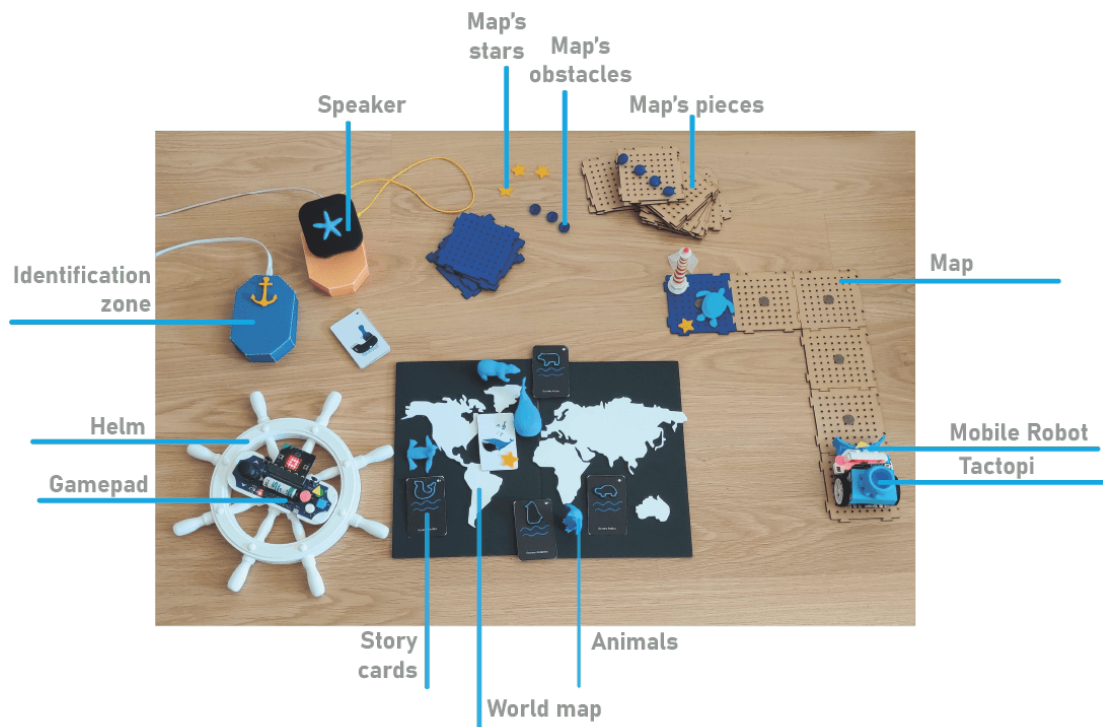


Figure 3.4: Main components of *Tactopi*.

The components (see figure 3.4) in this prototype are composed of a group of tangible elements: the helm with a gamepad and joystick, the robot, the map, the animals, the cards, an identification module - NFC reader and a sound reproduction module. Most of these were created through digital manufacturing processes, laser cutting and 3D printing. Printing, cutting and pasting, and some crafting were other techniques used to create the functional prototype. The animals have an RFID tag embedded in the base that allows the association of the sound with each animal's identification. The cards also contain RFID

tags to allow the reproduction of the different sound stories by the sound reproduction module.

3.5 Map and Story Cards

The map is an essential element with great relevance in Visually Impaired education, especially to learn spatial navigation. The map in this game has two different representations. Firstly, we have a macroscopic and conceptual representation of the world map that contains the set of missions to be explored. These missions are presented as playing cards with RFID tags to identify and listen to each mission. Each card contains a relief of an animal and a story in text and audio (see figure 3.5).



Figure 3.5: Story card with the animal relief in 2D and the correspondent 3D animal.

The second representation of the map is formed by the set of modular parts on which the robot will travel. It is an imaginary representation that takes place in a certain ocean, according to the activity. Here, the TVI - Teacher for Visually Impairment or SNE - Special Needs Educator organizes the map according to an activity guide. These pieces are explored tactfully by the VI child, which would help the child to integrate the set of steps necessary to accomplish the mission's goal.

Firstly, this map is accessible as a three-dimensional element and where elements such as animals and possible obstacles or prizes can be attached. The map contains perforated dots in each map cell, thus creating a dots matrix where it is possible to attach an element to the map cell.

A second requirement is a modular map - the multiple map cells allow the construction of different paths. As these are paths that the robot will travel on top of, it is crucial to ensure that the interlocking system is efficiently fixed (see figure 3.6).

A third requirement is the presence of contrast (see figure 3.7) - some pieces of the map have a contrast colour concerning the remaining pieces and should be used to identify the terminal piece of the goal. The reason for this differentiation is an attempt to give low vision children the opportunity to have a residual visualisation of this goal. There is also

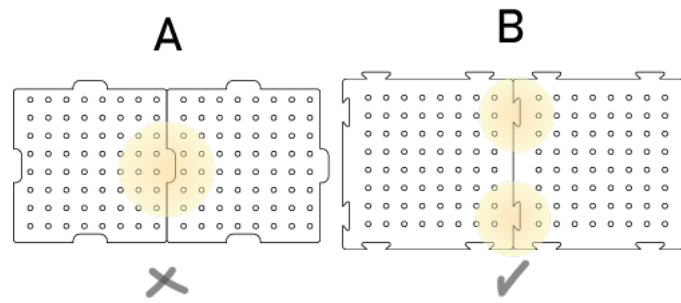


Figure 3.6: Interlocking system illustration of first version A and improved version B.

a 3D print lighthouse [4] with striped red and white colours to attach to the goal piece to accommodate these low vision cases;



Figure 3.7: Lighthouse and fitting system.

A fourth requirement is that the pieces should have a way to be tracked and counted by the child. In this case, each piece's centre has a soft felt circle that the child uses to count the number of pieces (see figure 3.8); The fifth requirement is a frictionless surface for the robot to circulate efficiently in a path with a coherent size of each cell, compatible with the dimension and conceptualisation of the step by step movement.

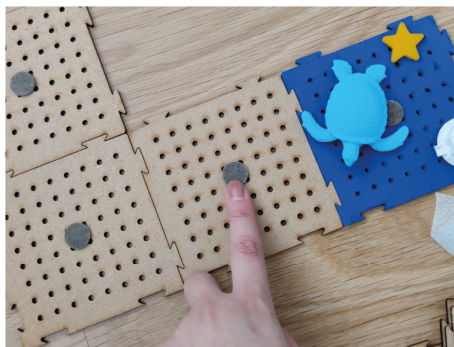


Figure 3.8: Tactile clue - a circle in filter at the centre of each map cell.

3.6 Robot

In this system, we intended to have a central interactive element, able to follow the instructions given by the child. Within the nautical theme, one of the requirements was to have a boat controlled by a rudder.

Many of the robots on the market do not offer a high level of programming and customization (see table 2.8).

The set of sensors that the micro: Maqueen [12], a *Micro:bit* [14] Educational Programming Robot Platform for STEAM education, presents is impressive, for its low cost of about 20 dollars, inherits playability and simple operation of the *Micro:bit*. The small size, interesting features and plug-and-play allowed us to design a tangible environment to program and interact with this robot.

In the image below 3.9, we can observe some of the sensors and actuators of this mobile robot. Although we did not use all the sensors in our activities, having this spectrum of possibilities is essential to allow greater customization regarding children's needs and preferences. The proximity sensor allows to avoid obstacles, and the greyscale sensors in the bottom allow for line following.

The robot travels above the cells in several directions (north, east, west). Symbols have been assigned for the North, East and West directions, triangle, circle, and square. These symbols intend to facilitate laterality and spatial navigation, a challenge that is complicated for the child but important as a training task [41].

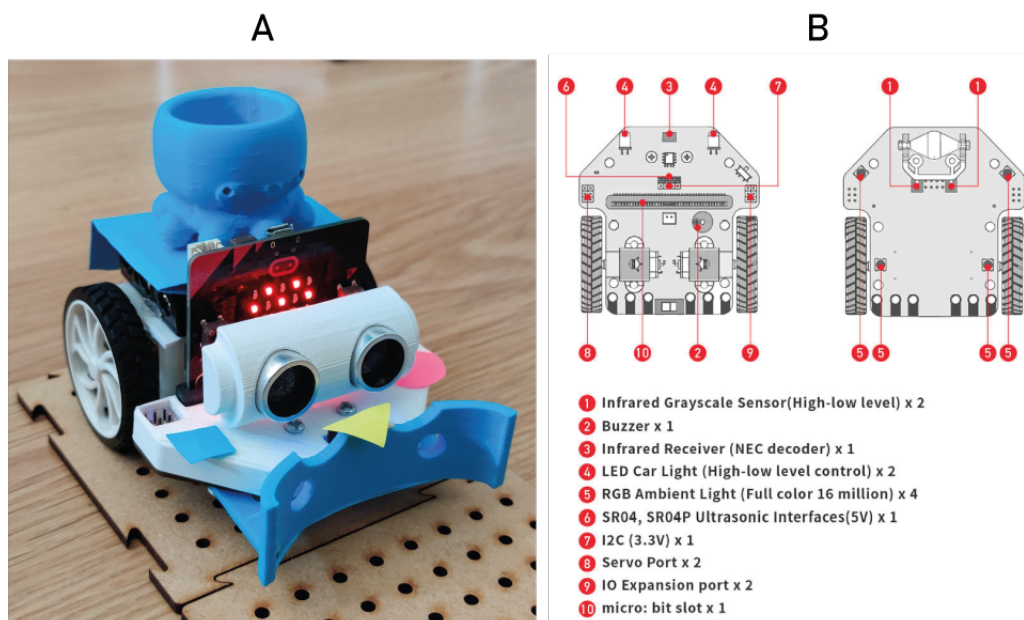


Figure 3.9: A - Robot customized for *Tactopi*; B - Function diagram of Micro:Maqueen. Retrieved from Dfrobot [13].

This use of symbols for the directions that depend on the perspective of the robot

was an adaptation of Turtle Robot [48], a game that, despite being a simple card game was proven to be engaging and easy for children to play. To prototype this concept, we used paper, but for an actual testing environment, we aim to 3D print these shapes and button caps, applying different textures. The 3D printed octopus [9] is our main character, *Tactopi*, and he has a small container to fill with a star after completing each mission.

Another solution to reinforce laterality is to have incorporated in the helm a small boat, with a servo motor connected via radio with the *Micro:bit* in the robot and changing direction at the same time as the robot does. Another requirement is the presence of RGB ambient lights, and we could program-specific colours for different states of direction, as shown in the figure 3.10.

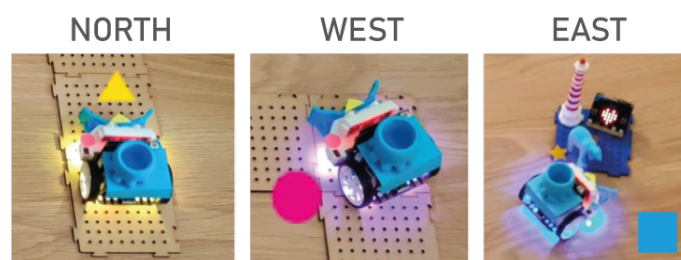


Figure 3.10: The colour changes according to the direction; North or front is yellow; West or right side is pink and East is blue.

Considering that this robot comes without encapsulation, we have printed some parts in 3D to protect electronic components and also against impacts [15], [11]. Thanks to an avid online STEAM community, it is possible to access some of these open-source models. Here we managed to combine parts of 4 different models.

3.7 Helm and Navigation Modes

For this system, another essential requirement is a control element. In introductory programming training, adaptations tend to lose the playful layers, becoming all about the blocks and the actions, leading to less immersion and reduced engagement and motivation. The helm is primarily a symbol of agency, a means of control for the child that also incorporates playful possibilities in a nautical adventure.

With *Tactopi*, we intend to provoke this *status quo* and prioritise playfulness. We designed it to be an interactive element that would provide an immersive and rich embodied experience as it uses both body and mind. Thanks to the *Micro:bit* ecosystem and the possibilities of using the accelerometer we had the possibility of using it attached to a wheel, and to allow a more tangible control with buttons, we added a compatible gamepad [8]. This element was incorporated into a 3D printed helm, thus obtaining a realistic and interactive object for the purpose. The helm is a 3D printed model that contains the control board, a joystick and six buttons - customized using 3D printed elements [21], [7].

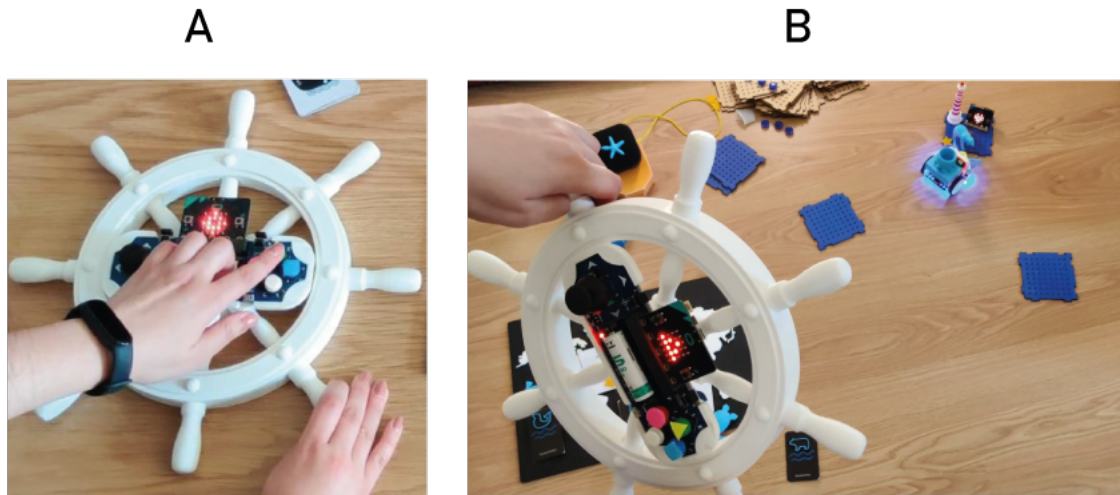


Figure 3.11: A - Navigation mode 1 as a structured navigation mode using the buttons; B - Navigation mode 2 as a free mode using the helm.

In this, functionality has been assigned for two different navigation modes (see figure 3.12). For the first navigation mode the structured navigation, the main functionality is to pre-program step by step the instructions, according to the number of cells to travel, save these instructions and reproduce it repeatedly, if necessary, until the child finds the correct sequence to complete the mission. The free navigation mode (see figure 3.13) gives children the freedom to move the robot in an exploratory way. However, it still addresses a learning goal, as we detailed explained in the subsections below.

3.7.1 Navigation Mode 1

The grid navigation mode presupposes (see figure 3.12) a grid-based movement, i.e. the ship movements are restricted to move inside the cell units. Initially, they can use small arrows on the map to plan a set of instructions, to travel from point A to B, to fulfil a specific goal on the map. The challenges progressively increase, adding obstacles to avoid or missions that challenge them to find strategies and plan sequences of instructions.

3.7.2 Navigation Mode 2

The free navigation mode (see figure 3.13) gives children the freedom to move the ship in an exploratory way by freely moving the wheel to command the ship. It also presupposes reaching from point A to B but in real-time with constraints such as limited time or obstacles at sea, such as continents, islands or pirate's ships. In this mode, we implemented a SONAR functionality, possible to be used independently by the blind child. To illustrate this, we have the example of the activity with the polar bear, which is lost in an ice glacier that may melt; the goal is to save the bear by finding him. The place where the bear is has a *Micro:bit* with a speaker which emits a continuous sound that becomes louder and

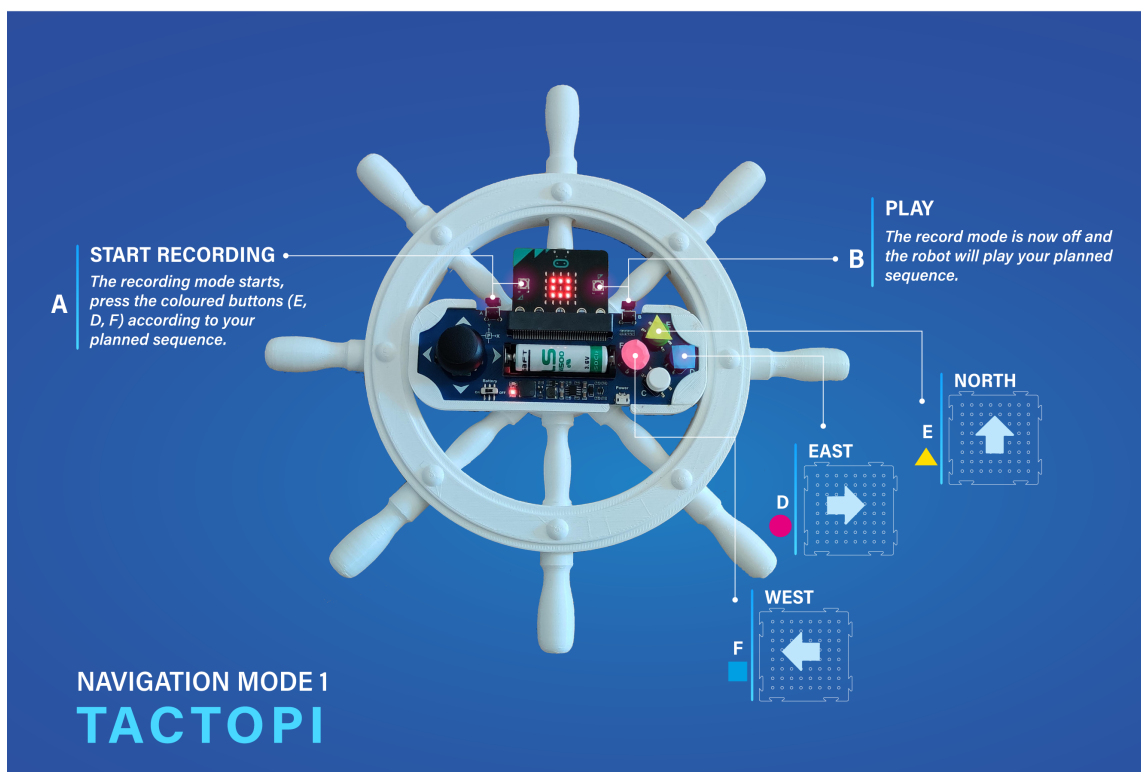


Figure 3.12: Navigation Mode 1 as a structured navigation mode using the buttons, each button has a specific instruction for direction, start recording and play the sequence.

intense as the robot, controlled by the child with the helm, gets closer and lower and less intense if the robot moves away. This mode has the added value of working with spatial concepts through sound, which is also important to be stimulated in blind children.

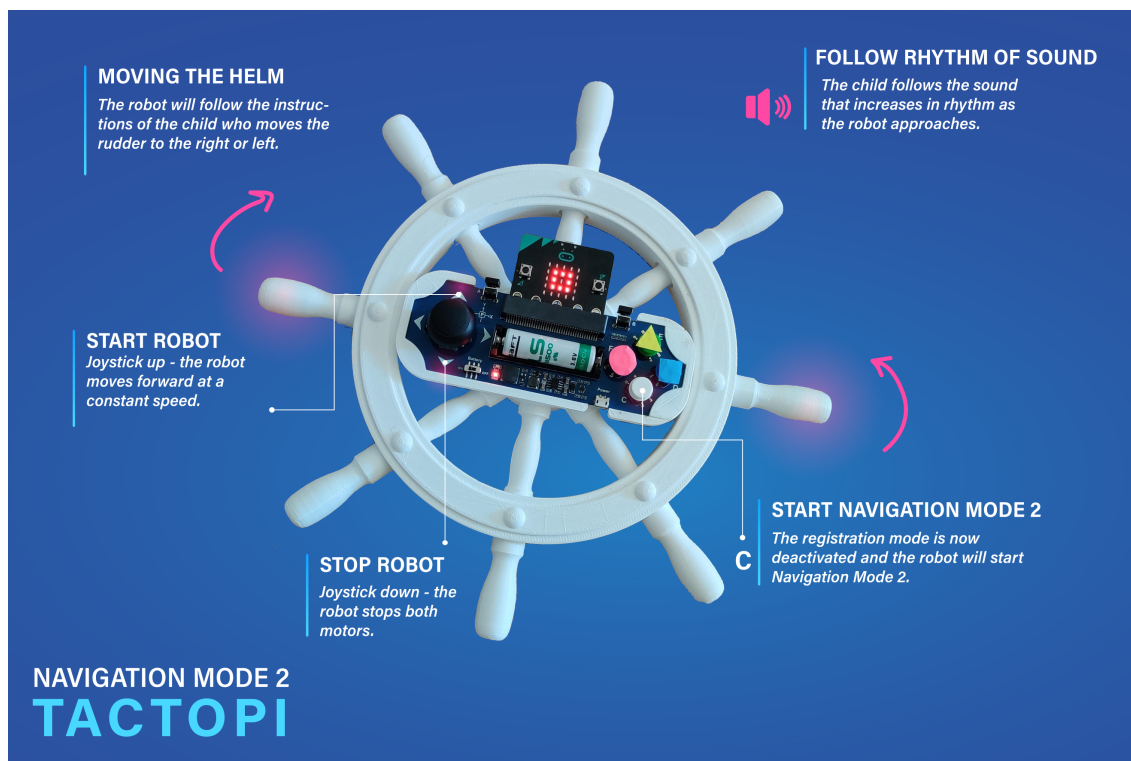


Figure 3.13: Navigation mode 2 as a free mode using the helm to control the direction and the joystick to start moving the robot or stop.

3.8 Sound and NFC

Sound has an essential role as a means of interaction for the blind child. It was fundamental in this environment to be able to incorporate this element. The *Micro:bit* allows the reproduction of certain sounds in 8 bits. However, this would be limited for our purposes. For this reason, we had to find an alternative to be able to reproduce sounds. After some research, we came across a solution where it would be possible to make this adaptation for the *Micro:bit* by acquiring a small mp3 module and a breakout board. In the figure below 3.14 it is possible to see in detail the hardware and the necessary connections. A speaker is also used for sound output.

After that, it would be necessary to have intelligent objects that could be identified. For this, a module was created that incorporates NFC through a similar approach, using an NFC module and connecting it through a breakout board (see figure 3.15).

With these approaches, it was then possible to have a sound reproduction module and an NFC (Near Field Communication) module to identify story cards or animals containing RFID (Radio-frequency identification) smart tags in the course of the activities. The smart tags were stickers placed on the base of the animal print, and the RFID cards themselves with the text attached in a small booklet also have a tag identification.

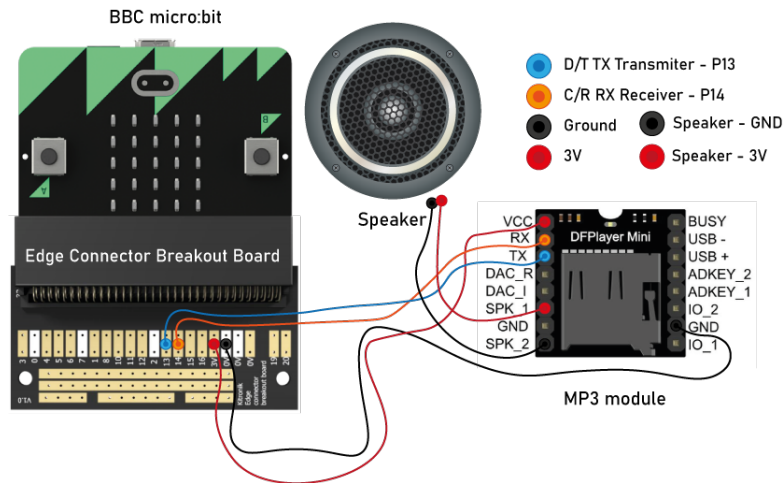


Figure 3.14: Functional diagram on sound.

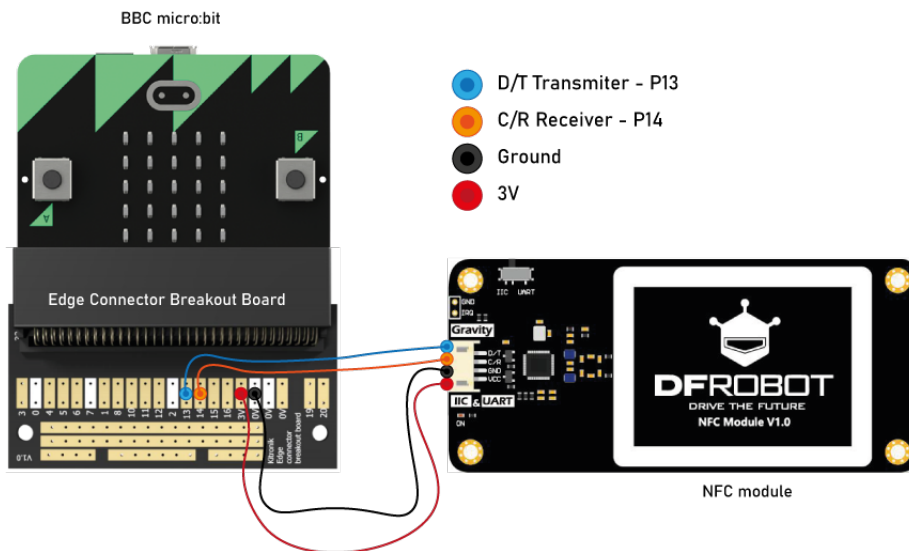


Figure 3.15: Functional diagram of the smart tag reader.

3.9 Activities

Computational thinking is an abstract and demanding concept to be tackled in a stand-alone way. Therefore, it makes sense to incorporate it with playful activities. As soon as we realized that we could think of a story to connect to the objectives, we came up with the possibility of talking about the environmental issue, and given the importance of this theme, it would be an opportunity to promote more awareness.

The activities for this system are presented in detail in the story cards. These cards contain descriptions of the missions for the child. The activities have a mission. However, the course of the activity can be shaped by the educator, whether adding more cells on the map, the route directions or even the existence or absence of obstacles, to be adapted to the child's level and training needs.



Figure 3.16: Modules of Sound and identification with NFC. The prototype is made in blue and orange cardboard, and inside, it carries the corresponding hardware components. The smart tag is a sticker on the animal's bottom part, identified by proximity when placed above the NFC reader.

3.9.1 Storytelling

In this subsection, the story of the little octopus *Tactopi* is presented. *Tactopi* will embark on this adventure, but he needs the child's help to control the boat (robot). These activities also aim to educate children about environmental awareness and the dangers marine species face due to excessive plastic pollution and global warming. In the Indian Ocean activity, the child can help *Tactopi* rescue the turtle before it confuses its food with plastic. In the Arctic Ocean activity, the child also has to help the polar bear, the ice is melting, and with the help of sound, following the sound that becomes more intense as the robot gets closer, the child will then find the polar bear.

Tactopi - an adventure in the ocean

Tactopi is a curious little octopus that one day found an abandoned boat at the bottom of the ocean.

As soon as he put his tentacle on the boat, he realised that the boat was unique, but he did not know how to move it.

Do you think you can help the octopus to navigate? (Child replies)

Yes? Good! To do this, we will need the helm, explore with Tactopi the boat's movements using the helm!

(Child tries out the rudder and the possibilities. Can be helped to understand the functions of the buttons in general).

Did you succeed? Yes!

Oh, there seems to be a box at the bottom. Tactopi needs your help to find out if there is a treasure! This time use the direction buttons on the helm to guide him to the box!

(Child uses Navigation Mode 1 and trains until he/she reaches the treasure box)

You did it! Open the box. What have you found? It seems to be a message. Use the

magic stone to listen.

(The child places the message on the NFC module, and the audio message is played).

In each ocean, you will have a mission. Use the magic stone to listen to the challenge of each card. When you complete the mission, you will receive a star! Place it on your map to complete the treasure.

To start this adventure, look at the map carefully and identify the Indian Ocean!

(The child may be helped to identify the ocean. The Indian Ocean activity will then begin).

3.9.2 Use Scenario

In this subsection, a scenario of using the Indian Ocean activity will be presented to illustrate the sequence of an activity and its possibilities:

1 - connect all the game's electronic components: robot, rudder and magical reading and sound reproduction stones.

2 - open the contrast map and place the separate booklets (Audio Stories) on the map's corresponding oceans.

3 - the child will explore the map tactfully and be guided towards finding the Indian Ocean.

4 - the child places the respective ocean card on the magic reading stone and listens attentively to the challenge mission - "Turtles are very curious marine animals, and their diet includes jellyfish. Unfortunately, jellyfish resemble plastic bags. Foreign objects, such as plastic, can often be mistaken by animals as food. Quick! We have to save the turtle! Help *Tactopi* to meet the turtle before he tries to eat the plastic! Use the helm's buttons to guide *Tactopi*."

5 - Meanwhile, the educator prepares the activity elements, follows the instructions, and chooses the difficulty level. For example, in the activity about rescuing the turtle, they will lay out the map with the following configuration for a beginner level and place the animal in the last dark blue cell area to visualise or feel.

6 - The child can then use the buttons on the helm - navigation mode 1 - where they will have to start a sequence, record the robot's steps, and then reproduce it.

6.1 the child, together with the educator, will check if the objective has been fulfilled.

6.2 if not, the child should ask what could have been the error. The sequence? They are encouraged to debug it.

7. If successful, the child then picks up the turtle and places it on the high contrast map area corresponding to the ocean, together with a star.

8. the child can also listen to the corresponding audio of the turtle on the magic stone.

9. After this, the aim is to move on to the next challenge on the map, to complete the five cards. The child chooses the next card and places it on the identification stone.

10 According to the activity, the educator/collaborator, prepares the game map, assuming a level of difficulty appropriate to the child's level and performance or difficulties.

3.10 Personalisation

Reusing the *Tactopi* system is also possible. It already has an infrastructure with the *Micro:bit* in which a teacher assistant (TA) can add MP3 audio tracks, customize the robot, maps and elements with RFID or add new ones and thus build on another thematic. Our intention is that a TVI or SNE would have the autonomy to modify and add other elements. It did not reach an ideal level of autonomy, especially for those who are not familiar with a programming language, but since everything is being built on a block-based language with the *Micro:bit*, it facilitates this customization task. We aim in the near future to create a set of guidelines that can effectively guide educators with a non-proficient knowledge in technology, this system may allow the continuity of training studies in this area thanks to the customization and reuse of artefacts, which in turn will help educators or parents interested in improving essential aspects in a particular child with visual impairment. The personalisation aspect has always been a necessity aiming to accommodate to the diverse range of comorbidities associated with visual impairment.

Chapter 4

Evaluation

To ensure that the developed solution effectively addresses real problems, we presented it to both stakeholders - researchers and educators. We wanted to determine how *Tactopi* can improve activities related to the introduction to computational thinking if they find it useful for visually impaired children and what new improvements or functionalities could be added.

4.1 Research Goals

- *RQ1*: Can *Tactopi* be an efficient tool to introduce Computational Thinking to blind children?
- *RQ2*: Can Playfulness be valued in the learning context?
- *RQ3*: Can *Tactopi* have interactive elements that support activities in other disciplines or contexts?
- *RQ4*: Can *Tactopi* be a tool that ensures accessibility and positively supports navigation skills and spatial training for the development of blind children?
- *RQ5*: What benefits, disadvantages and suggestions can be listed by the experts?

4.2 Methodology

This section discusses the methodology used to evaluate the prototype through a video demonstrating the *Tactopi* system's functionalities followed by a qualitative questionnaire.

In the impossibility of a face-to-face study with the children, due to the pandemic restrictions, we chose to create a video demonstration of the prototype, followed by an individual qualitative questionnaire. This study's aims are to evaluate with specialised researchers and educators the system's qualities, advantages and disadvantages of each of

the elements, appropriateness for blind children, and the child's stimulation and learning within the age. The questionnaire form and the user agreement are available in appendix A at the end of this document.

4.3 Participants

A total of 14 people, 12 researchers and two educators from different areas, experienced in education, human-computer interaction, robotics, psychology, education, industrial design and accessibility. Of the 14 participants, 8 had already had experience in working directly with visually impaired children. The charts detail the participant's different areas and whether they have experience or not, with visually impaired children and for how long (see table 4.1).

ID	Research Area	Experience with VI children	Years
R1	Educational Technology	No	-
R2	Educational Technology	No	-
R3	Human and Social Sensing	No	-
RE1	Accessible Technnology	Yes	6
R4	Human Computer Interaction	No	-
RE2	Cognitive Psychology	Yes	1
RE3	Industrial Design	Yes	2
RE4	Human Computer Interaction	Yes	2
R5	Human Computer Interaction	No	-
RE5	Accessible Technnology	Yes	2
SE1	Human Motricity	Yes	1
R6	Robotics	No	-
RE6	Accessible Technnology	Yes	1
SE2	Special Education Teacher	Yes	5

Table 4.1: Identification of the participants and corresponding IDs:

R - Researcher; **RE** - Researcher - Experienced with VI children; **SE** - Special Education practitioner - Experienced with VI children; and a number of years of experience with VI children.

4.4 Procedure

4.4.1 The Questionnaire

The questionnaire was online with a Jotform link sent by email to the participants. It was composed of five questions on the characterization of our population and five general qualitative questions on the benefits and limitations of the system, contexts of use. Then a group of fourteen more specific questions on the system components, namely the map,

the helm, the navigation modes and Computational Thinking, the robot and the card's activities, the 3D animals and the importance of playfulness. For respondents who have experience working with blind children, specific questions were asked about their suitability, relevance, and accessibility. In this questionnaire, respondents were allowed to answer the more extensive qualitative questions verbally or in text form. The questionnaire form and the user agreement are available in Appendix A at the end of this document.

4.4.2 Video Description

Creating a video [24] was the most appropriate format to demonstrate the prototype's functionalities at a distance and to enable participants to understand its interaction mechanisms with greater reliability.

At the beginning of the video, the system name and description of *Tactopi* are presented. The Audio Stories are visually highlighted, consisting of the card, the reader, the blue beacon and the speaker in orange. The video shows how to put the instruction's card over the reader, so the sound is played with the initial story "*Tactopi* an Ocean Adventure" and visually represented with the text and an illustration. In this narration, the rules and how to proceed in the adventure are also explained. The raised-line cards of the oceans are identified, the Indian Ocean card is selected and again placed over the identification zone so that the respective narration is reproduced, with the same procedure at the visual level of the represented text and illustration. The mobile robot, the modular map, is presented with a legend. The narration and demo explain how the child needs to use the rudder buttons to guide *Tactopi* to the turtle. Next are the instructions for Navigation Mode 1, starting by pressing the A button, the sequence of buttons with the north and west directions, and finally pressing the B button so that this sequence is played back. The robot then plays the instruction set, and the audio is heard each time the robot changes direction. Then is the Navigation Mode 2, the instructions and a demonstration of its use as a free roam mode, in which the child follows the sound until it reaches the goal to find the lost polar bear. In the end, the credits and some images about the digital fabrication process, namely 3D printing and laser cutting, are presented.

4.5 Findings

4.5.1 General feedback

Researchers and caretakers (TA Teacher Assistants) considered the system empowering and successful for blind and low vision children. The interactivity of the system, the diversity of elements, the design and the suitability of the system for blind children were highlighted.

Introduction to CT

Participants mentioned the presence of typical computational thinking tasks. *“Engagement. It seems to present a very rich environment, full of places, characters, and different activities. The interaction looks simple and attractive, affording typical computational thinking tasks.”* - RE2

4.5.3 Limitations

Computational thinking tasks

One of the observations was whether the objective was to stimulate computational literacy or raise awareness of environmental problems. Most participants understood that there was a component of computational thinking training through a theme they could integrate. Within the computational thinking component, the system was designed for an initial intervention to create instructions using the helm buttons. The system in this way is not developed for complex programming settings. This system was thought to enable a set of activities that transcend several disciplines, reinforcing that computational thinking is necessary to be present but not just as a central element. Other ways of expressing and working on a set of instructions to solve a problem are through sound, following the sound and tempo to get to the problem’s solution.

The challenge and complexity

Several participants mentioned the complexity of the number of elements and a TVI also added the challenge that it can be for a child to complete activities highly dependent on the map exploration, still, it can be a learning opportunity. *“A blind child from birth has many difficulties in reaching different concepts. Reading maps is one of them. So having the map can be a limitation, but it can also be an opportunity to develop knowledge in map exploration. But just to point out that if there are activities that are highly dependent on the interpretation of the map, they can be difficult.”* - SE2 This observation was essential to reflect on the complexity of the challenge and facilitate it avoiding excessive frustration for blind children.

Replayability - sustained practice

Two participants wondered about the replayability: *“It seems that different objects and characters are designed to meet narrative demands. They look great, however, I wonder what will happen after some repetitions of the same activity. Will children get tired of the same game. My concern is about sustained practice. Probably different challenges could be included.”* - RE2 This system has a game included, that can be limited after some repetitions. However, it is also a tool, as it allows the addition of new activities

or characters and adaptations for other disciplines, something we also identified to be important for TVI and parents, due to the lack of resources.

Some participants also pointed the use of a button's sequence could be hard to memorize the sequence, some hints or cards could be provided.

4.5.4 Design for Accessibility

Throughout these observations, a set of recommendations were also mentioned, which gave rise to our this subsection, where the aspects listed by these experienced professionals with blind children were considered.

Boundaries, a dedicated space for each component

“The lack of boundaries for the workspace and a dedicated place for each component of the system might make it difficult for children who are fully blind to find the various elements on the workspace.” - RE5

The map contrast and bigger buttons

The map contrast and bigger buttons were also mentioned as an important change: *“Children with visual difficulties sometimes have low vision. Since they still see colours and some shadows but unable to capture the images clearly. In this way, I think the brown squares are not a good choice because if the child is playing on the floor (as the game demonstrates), there will be no colour contrast, making the dynamics difficult. Another point that I think would be interesting to change would be the size of the rudder buttons; I think they should be bigger.” - SE1*

Braille inclusion

“I think it should also include braille. A keyword on the oceans card, a letter in charge and, if possible, the pamphlets also in Braille. Blind children do not have contact with braille writing in the same dimension as other children with reading in ink.” - SE2

“Yes very much. It could if it were possible to include braille on the cards - key words. And the stories could contain a separate book with the story in braille.” - SE2

“Probably, although it's hard to tell. Including braille at the bottom of the card where the name of the ocean is might also help tactile learners.” - RE5

Arm reach

“The space required to use the entire system imposes the requirement of having a wide and uncluttered table. If the child is very young the maximum arm reach may not be sufficient to use the map and other parts around it, which could require that it be used while standing, or on the floor.” - RE3

Spatiality

“in the case of blind children, recognizing where each thing is can be a significant challenge. The location of the cards on the map could have clues, to reposition each one in its original place.” RE3

Rudder symmetry

“The symmetrical shape of the rudder can make it difficult to recognize the north direction if only grasped from the outer edge. Joystick knowledge may suffice, but a little hint in the shape of each rudder grip could reinforce haptic front/back recognition.” - RE3 “I don’t foresee limitations other than picking the wheel upside down, or from the wrong side.” -R3

Map hints

“The map could have more relief on the continent, I also believe that there could be a differentiation between the material of the ocean and the continent, for example, the continent being rough or the ocean has a cellophane paper that is smoother and makes a noise when touching.” - RE6

Activities

Benefits of these activities were also mentioned, important for the development of the blind child:

“This game, in addition to the environmental awareness component, combines a component of map analysis, cardinal points - very important in orientation and mobility. Analysis and problem-solving. Auditory development in the remote control car game.” - SE2

4.5.5 Scenarios of use

The participants had to reflect on possibilities for use in settings at home and school.

At home

When envisioning the use of Tactopi at home, participants imagined scenarios either on the floor or on a table, a collaborative family-friendly activity. The vast majority also mentioned the need for guidance or supervision of parents or adults. Some mentioned a question and answer trivia about species, storytelling, or even quick games in terms of ideas for activities.

“I imagine it could be used in a multiplayer way, where random tile setups could be made, and the players had to navigate through the puzzle as fast as they can, in order to

discover all the species and place them on the map. Or in a more didactic way, with an adult supervisor, that guides or asks trivia about each species.” - RE3

At home, it was also thought from a more playful and fun point of view and also included activities that incorporate fundamental elements, such as lights: *“A very interesting game. It allows a lot of manipulation by the children and with very nice stimuli, from the tactile component, to the sounds and not forgetting the lights. Because many children, even if they are considered blind, have residual vision, and for children with low vision, lights are very important. This game can be a Mario Kart at home for these kids!” - SE2*

At school

In turn, collaborative scenarios were imagined in schools, where different roles were assigned in an interactive activity or games, organised by teachers:

“In the classroom I imagine collaborative activities guided by teachers. Some children could be using the map and others the rudder, taking turns and then changing. It could be put on a large table and two to four children around. The map itself can be an interesting activity for younger children.” - R3

“I see a strong potential for collaborative environments where sighted children and children with VIs work together.” - RE4

“Collaborative games in small groups, helping to visualise computing concepts in a tangible way.” - R2

4.5.6 Map

Participants pointed advantages as the modularity and flexibility to create several arrangements and complexity levels. One participants also pointed one disadvantage on the location of the robot in the map:

“The advantages are that it is modular, and can be arranged as pleased to reach the goals. The players or organizers can make it simple for beginners, or more complex for more advanced users, to (similar to a spelling game) spell each step the robot has to take to achieve the goal. The disadvantage may be the size, as larger maps may need to be played on the floor. Another disadvantage may be the error of the robot in locating himself after many turns, as the errors accumulate and he may end up lost outside the map.” - R3

“It is not noticeable how easy it is to identify each module. These modules have to be easily identifiable to understand how many times you have to press in one direction. (...) Perforation seems to me very well elaborated.” - SE2

4.5.7 Helm and Navigation Modes

Regarding the navigation, modes participants found mode 1 to be suitable for computational thinking activities and mode 2 particularly suitable for blind children.

Playfulness

“Benefits are the toy aspect and the real steering of the boat by turning an actual boat wheel, and the didactic way of having to “spell out” each specific movements in the correct order, as for long sequences that may be a challenge, or a competition element between players if one gets it wrong.” - R3

Buttons

A TVI mentioned the suitability of buttons for VI children to program the instructions for the robot. *“Buttons are a very suitable solution for these children. Each button is in a certain position and has a different shape to be easily identified by the child.” - SE2*

4.5.8 Mobile Robot

Through a picture of the robot, some participants pointed out positive features to the robot, several mentioned the aesthetic aspect being interesting besides being a friendly character for children. Thanks to the video, we could also have feedback regarding the accumulation of errors of the robot, something that is a problem of several systems in mobile robots. We can give it more attention to correcting, probably by using the infrared sensors at the base of the robot to follow a dark, central line in each cell of the map.

Form and function

Some mentioned that the robot didn't look like a boat. We thought a solution could be a redesign adding a bow, making it more similar to a boat and the forward direction easily accessible for VI children by touching the robot.

Accumulated errors

“The robot is very eye-candy and cute, however, from the video and the left turn I saw it make, I would be concerned about its accumulated errors if has to turn 4 or 5 times, it may run off the cells in the pre-programmed mode.” - R3

“The robot seems appropriate to me, the front and rear (wheels and shovel) are easily recognizable. As an alternative, I would explore that the front of the robot could reinforce the idea of “forward”, for example changing the concave shape for a convex one. And in this case, the robot could have a magnet on the front that attracts the animals to rescue.” - R3

4.5.9 Story and Tactile Elements

Most participants agreed that the presence of storytelling was relevant, as long as it was not too long, for the engagement and motivation of the child, besides the educational component:

Stories

“Yes, the story in a game always gives players a sense of playing towards a goal, otherwise it is just for fun, and the player may lose interest quickly if he doesn’t make his own goals.” - R3

“I believe so. They just can’t be very long stories. I believe the one presented is just the right length.” - R6

Animal’s cards

About the reliefs on the cards, an important observation was that the child would not be able to identify the animals without learning the meaning of each of the shapes: *“The child can learn that this relief represents a certain animal, but it is practically impossible for the child to know in advance that this relief is a bear, for example. If you close your eyes and sense the relief, you will realize the difficulties in identifying what it represents. However, children learn. The waves I can’t see well if they have the same relief as the animals. They should be a little further apart if possible.” - SE2*

3D Animals

The 3D elements were seen very positively by all participants, also as a complement to the symbols on the cards and as a motivating and relevant element for VI children: *“I find that they are motivating. I think it is a good thing to map the abstract 2D representation with the 3D characters. Adding too much complexity can be counterproductive, but in this case, I think it’s good.” - RE3* *“Yes, because it facilitates the creation of a mental image.” - SE1* *“Super motivating, they really enjoy groping objects and finding out what they are.” - RE6* *“A lot. The child perceives certain characteristics of animals” - SE2*

4.5.10 Playfulness and Audio

Learning Through Play

Playfulness was seen as crucial in the child’s learning and creativity: *“This approach of using playful elements that comes from Seymour Papert, who was inspired by educators such as Piaget, collaborates in the greater learning of any person, not only blind people.” - RE6* *“Learning is only possible if the child is having fun.” - SE2* *“Playfulness is important to ensure engagement and stimulate creativity.” RE5*

Audio

Audio was seen as a good complementary element with the tactile component: *“I think that these audios help children but I couldn’t say if they are enough to ensure accessibility. This question might be probably answered by running user studies with VI children.”* - RE4

“The audio feedback is definitely positive but I think that a bit more tactile feedback when it comes to exploration of the map or haptic feedback suggesting the direction in which the robot should move if the child gets stuck could increase accessibility and reduce frustration.” - RE5

4.6 Discussion

Experts’ feedback in different intervention areas, from robotics and design to psychology and direct educational contact with blind children, is fundamental for the continuity of the project and the system’s redesign. The set of information from the benefits to the limitations and suggestions is of great value for this system’s development. Below we present our research questions answered and discussed.

- *RQ1: Can Tactopi be an efficient tool to introduce Computational Thinking to blind children?*

Our results indicate that the system could be an efficient tool for an initial phase, where simple concepts of instructions and algorithms are introduced. However, some researchers pointed out limitations such as not being susceptible to more complex programming concepts.

- *RQ2: Can Playfulness be valued in the learning context?*

The playful component was unanimously validated among the participants, referring even to be fundamental for the child’s learning keeping them involved and motivated. The play represents the universe of expression and understanding of children, and it is in this sense, we can captivate their attention for this theme, the environmental consciousness and computational thinking exercises.

- *RQ3: Can Tactopi have interactive elements that support activities in other disciplines or contexts?*

Participants considered the potential of *Tactopi* to be used in other contexts and this hypothesis was appreciated in terms of contexts and activities such as trivia games about species or environmental preservation, family games, classroom games and also collaborative activities with a division of tasks between children and also as an element of fun for the child as the robot that is controlled by a rudder.

- *RQ4*: Can *Tactopi* be a tool that ensures accessibility and positively supports navigational skills and spatial training for the development of blind children?

We found that participants found the system accessible and that supported navigational skills and spatial training. However, they also suggested providing tactile from the tactile indications on the helm, the textures on the map, the zones being delineated by fixed limits and the contrast.

- *RQ5*: What benefits, disadvantages and suggestions can be listed by the experts?

Some of the benefits have already been mentioned, but others were also mentioned, such as the importance of presence, lights, map analysis and cardinal points, the importance for orientation and mobility and auditory development, which was confirmed by an educational assistant SE2, which happens in the Navigation Mode 2. Limitations are linked to a sustained practice; there is room for improvement and more activities to add. Still, this is not the easiest of the tasks for parents or even educators. A guide should be provided. We received detailed feedback from different experts and good suggestions to keep thinking about, such as the design suggestions for accessibility mentioned above, the children's challenges with navigation and maps, the accumulated errors of the robot when a change of direction occurs are essential issues to address in an improved version of this system and for future developments.

Chapter 5

Conclusion

We have developed and evaluated an approach for introducing computational thinking with a tangible environment and providing playful experiences for visually impaired children. The results suggest that our solution is viable, although it can be further ameliorated. In the present work, we have contributed with the *Tactopi* prototype for developing and designing playful environments for visually impaired children. *Tactopi* appreciated by the participants and listed qualities such as interactivity, accessibility and benefits for the development of the blind child.

5.1 Limitations

The pandemic changed the course of the project and brought new challenges. The direct experience with users is almost irreplaceable, its importance for the design of the approach and accessibility. Unfortunately, it was not possible either for initial workshops or for a final evaluation. However, it was possible to obtain useful feedback from TVI and researchers in the accessibility area with online video demo followed by a feedback questionnaire.

In addition to the suggestions for improvement recommended by the experts, the map, would be something to redesign in the future as is an element that needs more attention and detail in the construction of a fitting system that can be efficient and easy to use for visually impaired, to allow for more stability of the objects attached on top, regardless of the robot's movements. The area delimitation could also be defined with a type of fence to facilitate the identification and limitation of different areas by touch.

The pre-conceived activities allow a certain degree of creation by the children, such as using the buttons to store a sequence of instructions and reproduce it. We are using a platform that in itself allows endless programming possibilities but depends on tools like *Makercode* [10] a Visual programming language (VLP). However, there are still limitations with this approach for a deeper level of creation and learning of computational thinking but that is something we want to address in the future, exploring more the adap-

tation of VPL to a tangible interface. Starting by a popular accessibility tools such as *Makercode* developed by *Microsoft*.

5.2 Future Work

In future work, we plan to use *Tactopi* as co-design instrument with visually impaired children and as an informative tool for interaction studies in the future.

Interest has also arisen in reusing the *Tactopi* system for teaching Biology and Evolution of Species, something that will be explored with the support of a researcher in the field who aims to improve tools and teaching methods for visually impaired children.[44]

Appendix A

Appendix - Qualitative Questionnaire

Tactopi - A Playful Approach to Promote Computational Thinking for Visually Impaired Children

We invite you to participate in a research study about an accessible system for promoting computational thinking to visually impaired children by programming a robot. The study consists of viewing a short video and filling out a questionnaire, which will be presented below, if you give your consent.

A demo of the system and playing scenarios is provided in the video below. It aims to promote introductory computational thinking and executive functions skills through activities that combine sounds and tactile interactions for an engaging and playful experience.

We are part of the LASIGE research unit of the Faculty of Sciences of the University of Lisbon and work under the guidance of Prof. Doctor Tiago Guerreiro and Doctor Ana Pires. This study is part of my master thesis which aims to promote computational thinking and executive functions in children using a tangible and accessible environment.

If you have any concerns about any aspect of this study, you can speak to Prof. Tiago Guerreiro, who will do his best to clarify and answer your doubts by e-mail, tjvg@ciencias.ulisboa.pt.

If you agree to participate in this study, you will be asked to complete a questionnaire on the next page. We will follow all ethical and legal practices and all information about you will be treated in an absolutely confidential manner.

The questionnaire aims to collect feedback information related to the system TACTOPI.

Description of the System

A demo of the system and playing scenarios is provided in the video below. It aims to promote introductory computational thinking and executive functions skills through activities that combine sounds and tactile interactions for an engaging and playful experience.

TACTOPI is a kit composed of:

- 25 modular pieces, with perforated dots to enable customization, allowing to construct different paths;
- the helm that is controlled by the child in two different modes;
- a set of 5 3D printed animals with smart tags;
- mission cards with tactile figures with smart tags;
- a magic stone for reading mission cards and animals;
- a mp3 and speaker to reproduce the sounds.

Demographic Characterization

This page collects data to characterize the population of our study.

1. Role you play:

- Father / Mother / Legal Representative
- Family member
- Special Education Teacher (a)
- IT Teacher / Robotics
- Researcher (b)
- Other

(a) Briefly describe your experience as an educator.

(b) What is your research area?

2. Have you had contact with or work with visually impaired children?

- Yes
- No

3. Indicate your time experience (in years) with visually impaired children.

4. What is the age group of the visually impaired children?

- 1-3
- 4-6
- 7-9
- 10-12
- 13-14
- Other

General System Questions

5. 1. Which age group do you think the system is most suitable?

- 1-3
- 4-6
- 7-9
- 10-12
- 13-14
- Other

Note: For the following questions, you can either make an audio recording of your answer by pressing the orange button **”Record”**, or if you prefer, you can write your answer in the corresponding text box. The impossibility of carrying out a live assessment with educators and children due to the current pandemic has led us to give you the option to record your answers, taking into account the length of open-ended questions, in order to facilitate your time management and ease of being able to give us feedback on the presented system. As stated previously in the consent, we will follow all ethical and legal practices and will treat all information about you in a confidential manner.

6. Which qualities do you appreciate the most in the presented system?

7. Which limitations do you identify in the presented system?

8. How do you imagine this system could be used at home by children and family members?

9. How do you imagine this system could be used in the classroom?

The Map

Modular Map - The map has 25 modular pieces allowing to construct different paths, with perforated dots to enable **customization**, for instance the lighthouse to assist in locating a destination or animal, or to create pieces that serve as obstacles to avoid.

10. What are the advantages and disadvantages that you can enumerate on this type of map?

11. Do you imagine that other scenarios or concepts can be explored with this type of map?

Computational Thinking

On this page, we ask questions about the helm and the two navigation modes that allow the training of computational thinking tasks.

Navigation Mode 1 - The child can create a sequence using the buttons of the rudder, as can be seen in the image below. In this way, the child can acquire spatial concepts and computational thinking by pre-planning the robot's path step by step until the mission is accomplished.

12. What are the benefits and limitations that you identify in this rudder solution with buttons to pre-program the robot's actions?

Navigation Mode 2 - To find the animal in danger (e.g. the ice is melting and the polar bear needs to be rescued) the child follows the sound that increases the rhythm as the robot approaches the goal, using the rudder (helm) in a more conventional and natural way, moving it to the right or left.

13. Could this navigation mode help the visually impaired children to train spatial concepts? Do you find it useful to learn other concepts or cognitive skills?
14. Do you see benefits or limitations by using a free roam mode?
15. Do you consider both modes equally suitable for the visually impaired children? Why?

Mobile Robot

16. Do you consider this robot suitable for the activities? Any suggestions / observations about its size or tactile characteristics?
17. In terms of customization, would it be motivating for children to be able to use plasticine or other materials to customize the robot and create their own characters or elements for the scenario?

Story and Tactile Elements

The activity presupposes the existence of short stories, in particular a narrative about the ocean and the preservation of marine species. There is a set of small books with text and audio versions that present the challenge of each activity.

18. Do you consider that using a story to complete the missions has benefits for the child's motivation?

19. Do you consider the raised-line representation in the mission cards appropriate?
Can the child relate the card to the corresponding animal in 3D?
20. Do you find the use of 3D prints to represent the characters motivating? Why?

Playfulness and sounds

Playfulness is a concept present in this approach, we aim that children can play and imagine while acquiring concepts of computational thinking, motor skills and executive functions. The possibility of sound reproduction aims to improve the accessibility and interactivity of the system.

21. What is your opinion regarding the benefits of activities with the playfulness component?
22. Do you consider the presence of audios for the robot's direction and descriptions of the missions adequate to ensure accessibility?
23. If you have any comments or suggestions you want to share, use this field "Suggestions/Observations".

Thank you for taking the time to answer this questionnaire!

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