Math Melodies: Supporting Visually Impaired Primary School Students in Learning Math

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ABSTRACT

For children with visual impairments, learning mathematics entails significant difficulties. This is partially due to the fact that both traditional and digital didactic tools for teaching mathematics to children often integrate visual elements into explanations and exercises in order to improve children's engagement and comprehension. These visual elements, however, are not accessible to students with visual impairments. Approaches that substitute visual information with audio or haptic stimulation exist, but they incur in several problems, including the need of a supervisor or expensive specialized hardware.

To address this issue, we propose *Math Melodies*, a didactic software for the teaching of mathematics to primary school children. The application is freely available for iPad devices, and it presents 19 different exercise types, each with multiple levels of difficulty. The exercises are immersed within an adventurous story organized into 10 chapters. *Math Melodies* enables exploration of audio-visual elements on a touchscreen and provides multi-modal feedback that entertains and engages both visually impaired and sighted children simultaneously.

CCS Concepts

•Social and professional topics → Assistive technologies; People with disabilities; Children; •Human-centered computing → Accessibility technologies; *Touch screens; Haptic devices; Auditory feedback; User interface design; User centered design; Participatory design;* Tablet computers; **•Applied computing → Computer-assisted instruction;** *Interactive learning environments;*

Keywords

People with visual impairments, didactic tools for children, assisted teaching of mathematics, touchscreen devices, audio-visual feedback, multimodal interaction

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1. INTRODUCTION

Individuals with visual impairments habitually access written information using braille or voice recordings of the written information being read. Recently, thanks to the availability of digital supports, blind people can also access written information by the means of text-to-speech synthesis and refreshable braille displays.

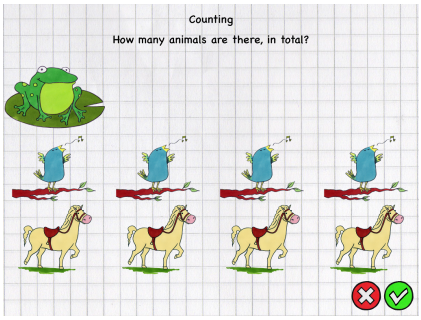
These solutions are convenient for accessing text, but they are not effective in conveying information containing visual elements. Mathematics workbooks for primary school students are particularly difficult to access due to three main reasons: First, they include many images, with the aim of engaging the student. Second, math exercises involve graphical elements (e.g., sets operations) or elements that need to be explored along two dimensions (e.g., operations in columns). Third, solving exercises often relies on non-trivial forms of spatial interaction, such as drawing or inserting digits in a table. Similarly, didactic software that supplement or substitute traditional workbooks in teaching maths to children, are not accessible to blind students as they often leverage sophisticated visual stimuli to immerse the educational purpose in an entertaining environment.

Didactic software often use auditory interaction paradigms to be accessible by visually impaired children [Stefik et al. 2011, Mendels and Frens 2008]. However, conveying spatial information through audio interaction also entails a high cognitive load [Stanley 2008], which makes it incompatible with the teaching of maths that already requires high attention and good memory skills. Haptic interfaces have been used to construct mental representations of spatial data [Gutschmidt et al. 2010, Raisamo et al. 2007, Kuber et al. 2011]. This approach can be used to convey sophisticated spatial information with reduced cognitive effort, but the haptic hardware is generally prototypical and not sufficiently widespread to be used for math and geometry didactics in practice.

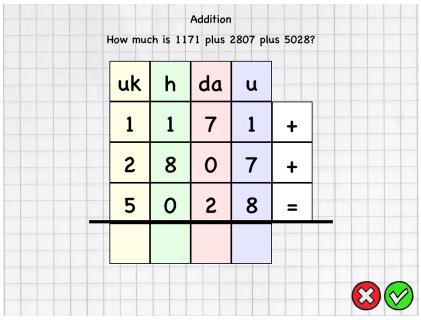
To address these issues, we present *Math Melodies* [Gerino et al. 2014], a tablet app that lets both sighted and blind students practice math. Using touch screen enables proprioceptive exploration of the interface elements which can improve spatial understanding and stimulate the comprehension of mathematical and geometry concepts. The software immerses the educational activities in an entertaining environment with an adventurous story that motivates children to keep on playing. *Math Melodies* is designed to be engaging for all students using multi modal (audio, visual and touchscreen) interaction. Our application, first developed as a university prototype, has been engineered thanks to a successful crowdfunding campaign and is now distributed as a free iPad application[1].

[1] https://itunes.apple.com/us/app/math-melodies/id713705958

(a) A story page with an audio-icon. Multimodal feedback is used to entertain children.



(b) A counting exercise page. Audio-icons of various animals serve as a mnemonic stimuli.



(c) A sum exercise page. Digits, operations and result audio-icons are ordered in a grid.

Figure 1: *Math Melodies* is organized in chapters, each composed of pages describing the story or proposing exercises.

2. MATH MELODIES

In order to engage the students, *Math Melodies* presents a tale in which the main character needs to face various challenges, such as finding a treasure. The story is organized into 10 chapters, two for each grade of primary school (in many countries primary school has 5 grades). Each chapter is further divided into "pages" (see Figure 1) that either forward the story or propose mathematical exercises. The software uses 19 different types of math exercises as puzzles that the player needs to solve to proceed in the quest. For example, solving an addition exercise will provide the player with the key needed to unlock the treasure' chest. The exercises are accessible to blind students through screen reader and a simplified on-screen keyboard to insert digits or provide answers. There are about 30 exercises for each chapter, with the exercise difficulty increasing over the course of the story through 10 difficulty levels. For example, the "easy" addition exercise consists in adding two single-digit numbers, while at a harder level, the aim is to add three numbers, each one with up to four digits (See Figure 1(c)). Stimulating children to play the same exercises at increasing difficulties several times benefits the comprehension of exercises by the means of reinforcement learning.

The story proposes different narrative contexts, ranging from an environment more familiar to the student (i.e., the apartment), gradually moving to others that might be less familiar, like the city, the seaside, the mountain. The story can be either read by sighted students or automatically voiced through text-to-speech synthesis. Large fonts and high contrast between the front objects and the background are used for access by visually impaired users.

All the visual elements included in the story are associated to an easy to recognize and entertaining sound, like a frog's call for the frog icon, or the noise of an approaching car for a car icon. We call these images with their associated sound "audio-icons" [Gaver 1986]. During exercises, audio-icons are organized into a grid layout that helps to reduce the time and mental workload required to explore the exercises. Similarly to the approach adopted in most children's books that heavily rely on colorful images, the tale and the audio-icons have as the objective to pique children's interest. Given the dual audio-visual nature of all graphical elements in *Math Melodies*, this approach works for both sighted and visually impaired children. A reward mechanism is also provided to further involve the children, and gifts the child with a visual reward and a short piece of music when a correct answer is provided.

During the development of *Math Melodies* we followed the participatory design methodology to define the interaction paradigm and the exercises. For this purpose we involved 4 teachers experts in education for blind students and 3 primary school blind children. The design process is presented in details in [Gerino et al. 2014].

3. EVALUATION

Math Melodies has been evaluated with 2 sighted and 3 blind primary school children. After at most two minutes of supervised training, all the participants were capable to interact with the system, and all of them found the application accessible and entertaining.

Since the publication, *Math Melodies* has been downloaded over 14,000 times. Usage data has been collected remotely to evaluate and improve the system, and provide generalizable knowledge for the design of didactic applications for the children.

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