WordMelodies: an Inclusive Mobile App Supporting the Acquisition of Literacy Skills

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ABSTRACT

We present WordMelodies, a mobile edutainment app designed for inclusive teaching of literacy skills to visually impaired and sighted primary school children. WordMelodies is a cross-platform mobile application, and it can be accessed visually and through screen reader.It is available in Italian and in English, and it includes over 80 different exercises, with diverse interaction modalities and configurable difficulty levels. It is designed to be extendable with new exercises, and localized to additional languages with specific and appropriate linguistic exercises. We describe the design process of WordMelodies, consisting of two iterations, which included formative studies and tests with visually impaired participants and experts in education for children with visual impairments.

CCS CONCEPTS

• **Social and professional topics** → **People with disabilities**; • **Applied computing** → *Interactive learning environments.*

KEYWORDS

Visual impairment, Literacy education, mobile edutainment apps.

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1 INTRODUCTION

To support students with visual impairments or blindness (VIB), who cannot access printed teaching material, accessible solutions such as braille books or tactile drawings are used [8]. These solutions, while effective [7], are rarely available outside special education classes. Furthermore, their interactivity is limited and the inclusiveness with other children is disregarded [24], potentially leading to social exclusion [21].

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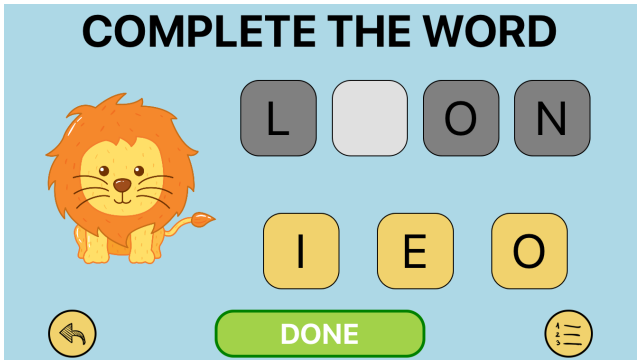
In particular, primary school teaching materials, including those aimed at developing literacy skills, often rely on images and visual cues to engage students and to support the understanding of more complex concepts. Such images are difficult to render non-visually [9] and therefore they are not available for children with VIB [6, 7, 14]. Educational apps often adopt the same approach, using animations and drawings to stimulate learning, which makes them inaccessible as well [20, 22]. The lack of accessible digital teaching materials for developing literacy skills is particularly relevant in situations that require for teaching activies to be conducted remotely, without being able to use solutions available in class, as during the school lock-down following the COVID-19 pandemic.

To address these issues we developed *WordMelodies*, an inclusive mobile app that supports children with and without VIB in practicing basic literacy skills. *WordMelodies* includes 80 exercise types with multiple difficulty levels, and new exercises can be easily added. *WordMelodies* was localized in English and Italian, an it was engineered with a universal design approach [23], which improves the learning outcome for all students [4]. It was developed with cross platform development tools [25] to run on both iOS and Android devices, without writing separate code for the two platforms, in order to reach widespread diffusion among all potential users [2].

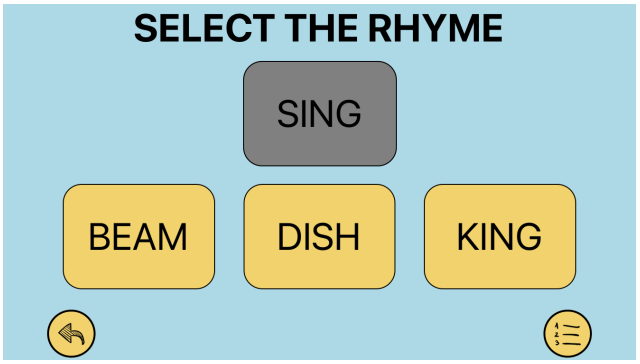
This paper describes the iterative design of *WordMelodies*, including key design choices and challenges faced during implementation. In the first iteration the app was designed based on feedback from three experts in accessibility & education, and teachers of children with VIB. The implementation was evaluated by two of them, showing promising results, but also some limitations: namely low exercise variety and absence of multilingual content. These limitations were addressed during the second iteration, which also introduced new functionalities, such as remote logging and tutorials.

The app accessibility was evaluated with three adult participants with VIB, who reported poor color contrast issues and clarity problems with some of the verbal messages. Once the app was improved, we were asked by one of the domain experts to publish it, as such tools were needed due to school lock-down following the COVID-19 pandemic in 2020. Thus the final app is currently available on Google play store[1] and Apple app store[2] for free. The app was publicised by word-of-mouth, during classes with children with VIB, and through blogs for accessible learning for people with VIB [3].

[1] https://play.google.com/store/apps/details?id=com.wordmelodies
[2] https://apps.apple.com/it/app/id1495831516
[3] Perkins Learning Blog on WordMelodies: https://www.perkinselearning.org/technology/blog/word-melodies-emerging-reading-and-writing-app



(a) "Listen and complete" (lion)



(b) "Rhyming words"

Figure 1: Some of the exercises implemented during the first iteration of *WordMelodies*.

2 SYSTEM DESIGN AND IMPLEMENTATION

The idea behind *WordMelodies* was suggested by a teacher for children with VIB from the USA who reported the lack of accessible applications to practice literacy skills. Guided by this observation, the research team started analysing the problem, in particular with the aim of identifying which exercises could be more effective in supporting the learning of children with VIB. A list of 56 possible exercises[4] was created by examining teaching standards [5, 15, 18], existing apps (most inaccessible), and by conducting informal interviews with three domain experts: the same teacher who reported the problem, a congenitally blind expert in assistive technologies (a co-author of this paper), and a primary school teacher from Italy.

Each exercise in the list was presented to two of the domain experts, also providing an example of how a blind child could interact with the app while performing the exercise. Then, we asked the experts to specify, for each presented exercise, a subjective evaluation of the exercise usefulness, and optionally to provide additional comments. The results of this formative activity were used, in the following development phases, to select which exercises to implement. Informal interviews with the two domain experts were also conducted to define the following list of design goals for the app:

- **Inclusiveness**. The app should be usable by both sighted children and children with VIB.
- **Entertainment**. To engage and keep the children interested the app should be entertaining.
- **Independence**. Children should be able to use the app also without supervision by adults.
- **Consistency**. Interactive elements should have the same position in all screens, possibly close to the screen corners.
- **Beyond tap**. The app should help children to exercise common yet complex interaction gestures, like drag&drop. This is the opposite of the "simple gesture" principle adopted in similar applications [1, 12].
- **Scalability**. New exercises should be easy to create.
- **Multi-platform**. To reach all potential users, the application should be available for all mobile operating systems (iOS and Android) and device form factors (smartphones and tablets).

[4]https://wmel.netlify.app/

2.1 First iteration

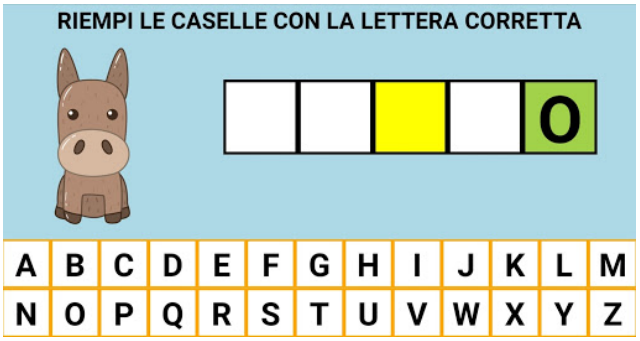
During the first iteration (which was previously demonstrated in [17]), we implemented the 9 exercise types with the highest usefulness scores achieved during the initial analysis stage. For example "Listen and complete" (see Figure 1(a)), in which the child needs to complete a word, hinted by a figure and an associated sound (*e.g.*, lion and its roar), with one of the given letters. Instead, in "Rhyming Words" (see Figure 1(b)) the child needs to select a word which rhymes with a given word, from a set of words provided on the screen.

The design and the implementation of the application addressed four main requirements, related to the design goals which were previously defined:

R1 **To design inclusive and entertaining interactions for the implemented exercises.** We used audio-icons [11], interface elements which combine visual and auditory aspect and interactions. Indeed, all interactive elements in *WordMelodies* are accessible by hearing and sight. Consider the example in Figure 1(a): when a blind child uses the app with the screen reader, upon touching the lion image, its call is reproduced. Then, when the child moves among the letters, the screen reader reads each letter and a corresponding word to support the comprehension of the letter (*e.g.*, "I for ice").

R2 **To support children in learning and exercising with the drag&drop gesture used on mobile devices.** With screen reader, this gesture is performed by double tapping and holding the finger on the screen after having selected an item; afterwards the selected item can be dragged while the screen reader describes the traversed target positions. To support children in learning this gesture, we defined a tutorial exercise that explains how it is performed step by step. Furthermore, we added additional verbal messages during the execution of the gesture itself. So, for example, when the child double taps and hold on the letter "I", the following message is read: "You are moving I for ice". Similarly, when dragging the items, the app informs the user about elements on which the dragged items can be dropped (drop targets), like "Empty box 1".

(a) "Word Grid"



(b) "Fill the letters"

Figure 2: Dynamically created exercises added during the second iteration.

R3 **To streamline the creation of new exercises.** We defined different **exercise families**, each with its own implementation and interaction design ("drag&drop" or "multiple choice" questions). Different **exercise types** belong to the same family and therefore share the same implementation, but address different teaching topics (*e.g.*, "select the rhyme" and "select the opposite" are different exercise types in the same family). The content for a given exercise type is defined in a static definition file, subdivided into different **exercise instances**, *i.e.*, specific configurations of exercise elements to display. For example, it is possible to create an exercise like the one in Figure 1(a) where, instead of the lion there is a dog, by editing a static definition file without writing additional code.

R4 **To reach all potential users.** We developed *WordMelodies* to be accessible on Android and iOS platforms, using *React Native*, a cross platform development framework [10]. However, additional effort is needed to manage accessibility issues which are often associated to cross-platform development. For example, as detailed in our previous work [3], React Native does not allow to trigger events when screen reader focus changes, which is required to implement audio-icons that can play a sound when touched. As a result, it was necessary to develop native code for both Android and iOS platforms to enable this functionality in *WordMelodies*.

During the first iteration, two domain experts tested the app functionalities and reported three key limitations: 1) only a small number of exercise types and instances were present, 2) the app only had exercises specific to English language, and 3) the screen reader focus in React Native does not follow the logical UI elements order when the flick screen reader gesture is used (left/right flick should move the accessibility focus to the next/previous UI element).

2.2 Second iteration

The second iteration focused on new functionalities, including those requested by the domain experts, and on fixing issues detected during the first iteration. GUI elements were re-designed for easier access. For example, buttons were placed in the interface corners (compare Figure 1 and 2). To mitigate the screen reader focus order issue, elements were ordered top-to-bottom as they should be read.

In particular, we addressed four new challenges:

R5 **To increase exercise variety and automate their creation.** We created new exercise families such as "Word Grid" (See Figure 2(a)), in which all words associated to a given concept need to be selected, and "Complete the Word" in which a word has to be completed using a simplified virtual keyboard. Differently from prior exercise families, many instances for a given exercise type can be created dynamically from a common definition. For example, for the "Word Grid" exercise family, we can create an exercise type (*e.g.*, "Select verbs") and a set of possible words. An exercise instance is then generated by randomly selecting a subset of words. It is also possible to create different "Difficulty Levels" by varying the number of selected words, which further expands exercise variety.

R6 **To support app localization and language-specific exercises.** We implemented a method for presenting the app interface and content in different languages, selected by the user, with the default set to the system language. For the exercises, we chose to enable the creation of entire exercise types in different languages, rather than simply translating them. The reason is that each language has specific literacy skill that need to be exercised; for example, spelling exercises in English, or exercises on accents in Italian.

R7 **To provide indications on how to use the app.** We integrated in-app tutorials for all app screens and exercises. The tutorials not only provide written guides, but also present mock exercises to explain key interactions. For example, for exercises using drag&drop interactions, the tutorial exercise teaches the user how to drag an element and drop it into a box.

R8 **To record user interactions with the app.** We included a remote logging facility which transmits anonymous usage data such as completed exercises, completion time and errors. This helps us to detect app problems and to understand how the users interact with *WordMelodies*, which exercises are used more frequently and which are more difficult to solve. This way we can improve our software and research new accessible education instruments.

In the second iteration we evaluated interface and interaction accessibility. Again, the app was tested by the two domain experts who reported clarity issues regarding the drag&drop interaction: it was not clear that, if a drop area already had an element in it, the initial element needs to be removed before dropping another one in it. We made this requirement explicit through a verbal message. While the React Native focus order issue was solved for Android devices after the first iteration, on iOS devices the issue was still present in some cases: some exercise elements were still announced before the audio-icon providing the initial hint because they were drawn slightly taller. To address these issues, we ensured that the elements have consistent dimensions on both Android and iOS.

Afterwards, we conducted an observational study with 3 adult participants with VIB to assess the overall app accessibility. The study did not focus on exercise appropriateness and literacy skills, which will be assessed in a future study with target users. The two low visioned participants reported that some GUI elements had poor color contrast and were hard to distinguish. We therefore chose a more contrasting color palette and redesigned the problematic elements. The third participant (who is blind), reported that some verbal messages in Italian, which were translated from the English version, were unclear. We therefore adopted a less direct but clearer and more natural sounding translation, based on provided feedback.

We also performed a preliminary analysis on one month of collected usage data, examining app use by platform (Android & iOS), form factor (smartphone & tablet), language (English & Italian), screen reader use, and exercises and tutorials usage. *WordMelodies* has been used by 194 unique users, of which 27 used a screen reader. Most accessed *WordMelodies* from smartphone (119), while 75 used a tablet. As expected [13], iOS devices were more common (128 users), however Android was used on more than 1/3 of devices (66). 128 users performed exercises in English, while 66 users did exercises both in English and in Italian, indicating that Italian users were also interested in the ability of the app to support foreign language learning. Tutorials were activated by 99 users, indicating that this functionality might be useful for the majority of users. In particular, drag&drop tutorial was activated by 21 users. 1070 exercises were performed, and drag&drop exercises were among the most popular ones in both English and Italian (2nd most popular), with a number of errors consistent with other exercises ($\sim$ 10%).

3 DISCUSSION AND LIMITATIONS

3.1 Literacy Education Assistive Technologies

The initial stage of *WordMelodies* design process highlighted a research gap and lack of apps for literacy education aimed at children with VIB. Assisted learning of other subjects, such as math, has been extensively studied, with a number of assistive technologies for students with VIB [16]. Instead, the literacy education resources are few and often only associated to braille proficiency, which is not widespread, in particular among people with low vision.

Mobile applications are a great opportunity for inclusive literacy education, through multi-modal access to same teaching material and exercises For this, the accessibility to digital education content needs to be guaranteed, not only through auditory and visual interfaces, but also supporting assistive tools such as visual enhancers and zoom, as well as refreshable braille displays.

3.2 Digital Literacy for Children with VIB

Mobile device interaction often includes gestures hard to perform for children with VIB, in particular with screen reader. Prior works suggest using simplified interactions to provide easy access to digital teaching material for grade school children with VIB [12]. Instead, we argue that children with VIB also need to acquire the ability to perform common and complex touchscreen interactions and gestures. Thus, we included exercises and tutorials to support the learning of drag&drop, one of the more complex yet common interactions. Preliminary remote usage data analysis confirms that tutorials and exercises on this topic were indeed accessed by *WordMelodies* users. We therefore believe that *WordMelodies*, and other edutainment apps can be effective tools also for digital literacy and for learning common digital interactions for children with VIB.

3.3 Edutainment App Localization

In the second iteration we localized the app, initially available only in English, also in Italian language. A key requirement identified at this stage (R6) was that the exercises should not be simply translated, but designed anew to address specific linguistic skills for each language. Indeed, preliminary usage data analysis shows that popular exercise types differ between English and Italian. However, participants with VIB noticed that also other app text and instructions needed to be reviewed for clarity. Thus, in addition to linguistic exercises which need to be specifically designed for each language, a direct translation, while linguistically correct, is not always appropriate or clear also for generic app text localization.

3.4 Cross-platform Availability

Prior works report that people with VIB more often use iOS over Android devices [19]. Preliminary remote usage data analysis confirms this finding. However, 1/3 of all users had Android devices, which is more than expected based on prior literature, which suggest that iOS users with VIB are about 80% of the total [13]. Furthermore, while most users had a smartphone, many accessed *WordMelodies* from a tablet device. This indicates that accessibility apps cannot be aimed at a single platform only, and confirms our choice in using cross-platform development to reach all possible users.

4 CONCLUSIONS AND FUTURE WORK

We presented *WordMelodies*, a mobile app that supports inclusive teaching of literacy skills for children with VIB and sighted children. *WordMelodies* is a cross-platform app, available for Android and iOS smartphones and tablets. It has been designed to support easy creation of new exercise and localization to different languages.

As future work, we will implement also Braille literacy exercises through the usage of a refreshable Braille display. We will conduct studies with children, focusing on app accessibility, usability and exercise appropriateness. We will also continue to collect app usage data and we will perform large scale analysis on the app usage data collected remotely to better understand user preferences and behavior, thus stimulating future research and app development.

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