Understanding m-learning experiences for blind students

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Abstract: When designing educational technologies for blind people, we need to consider technological and pedagogical strands. From the pedagogical point of view, m-learning has the potential to benefit blind students. Regarding the technological aspect, m-learning is an appropriate approach for blind students. Motivated by the adequacy of m-learning and the scarcity of works involving m-learning experiences for blind students, we present an exploratory study to uncover important information when blind users interact with mobile applications, focusing on the educational and technological perspectives. We investigated the interactions of nine blind users with mobile devices to unveil their technology-related singularities in the educational context. Based on the familiarity of blind users, some interaction design patterns have proven to be easy to use after conducting a usability and user experience test on a prototype. The results also highlighted the relevance of educational mobile applications to provide greater independence to blind users. This paper contributes towards improving the current awareness of the accessibility aspect of m-learning collaborative tools, and reveals the aspects of interactions and needs of blind students.

Keywords: collaborative learning; blind students; interaction design patterns; m-learning.

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1 Introduction

New technologies, such as screen readers, enable the participation of blind people in online learning. Accessibility involves many challenges and opportunities for e-learning, and they must be considered. Nowadays, new technologies are generating new educational demands that lead us to rethink and expand educational methods for students with special needs. In fact, in the current educational system, there are several students who need a unique teaching approach. In particular, the social, cultural, economic, and educational opportunities provided by information and communication technologies can greatly benefit blind people. The Royal National Institute for the Blind (1998, n.p.) states, "The internet is one of the most significant developments since the invention of Braille. For the first time, many blind and visually impaired people can have access to the same wealth of information as sighted people and on the same terms."

In particular, the educational use of digital mobile technology (m-learning) has great potential. In recent years, exploring the use of mobile technology to support learning is a major challenge for educators and instructional designers (Saleh and Bhat, 2015). Mobile devices are now considered cultural instruments that can transform socio-cultural practices and structures in all spheres of life. This transformation is considered central because it empowers people to engage in interactions that are free from the constraints of physical proximity and spatial immobility. According to Metz (2014), mobile learning provides learners with new possibilities, such as personalised learning, contextualised and unobstructed by temporal, locational, or environmental constraints. The use of mobile learning in education is growing at an exponential rate (Crompton et al., 2016). M-learning is one of the most promising frontiers of today's educational technologies (Ally, 2009; Kukulska-Hulme, 2005; Norris and Soloway, 2015) and can be defined as learning in multiple contexts through social and content interactions using personal electronic devices. The widespread distribution of mobile devices, the increasing accessibility of related infrastructures, and the heterogeneity of applications available on platforms such as Google Play and Apple Store have created a conducive environment for the use of mobile applications in teaching and learning.

Zurita and Nussbaum (2004) implemented a constructivist mobile learning environment, successfully applying handheld devices for teaching syllables and words to first-grade students. Wang et al. (2009) reported a formal implementation of a mobile learning system in a blended English classroom of 1,000 students, where m-learning activities were more engaging. A case study, conducted with health and human services professionals in Newfoundland and Labrador in Canada, showed that the benefits of mobile learning included improved access to information, potential for enhanced knowledge acquisition, staying up to date, and verifying information (Curran et al., 2019). A mobile technology-supported experimental learning system was developed, and a case study was conducted on a science course in an elementary school. The empirical results unveiled that this m-learning approach can significantly increase students' learning achievements, environmental attitudes and collective efficacy (Cheng et al., 2019).

Regarding accessibility, m-learning has tremendous potential to support a variety of disciplines in the field of special education for at least three main reasons. First, it allows and promotes the use of multisensory inputs capable of overcoming possible communication problems, potentially enhancing understanding (Sierra and Togores, 2012). Second, the personalised support provided by the mobile technology is especially important for students who need individual attention and instruction. Third, the collaborative dimension that mobile device can provide through an emerging, positive trend in disability studies (Fage et al., 2014). As mentioned earlier, mobile learning provides opportunities for inclusive education.

However, there is a demand for research to uncover effective learning technologies for blind students. Many researchers have indicated research gaps in e-learning tools for blind people. For instance, Buzzi et al. (2012) showed that learning tools and collaborative tools are rarely designed for good usability and user experience (UX) for blind users. Collaborative tools are difficult or not at all usable for blind users. In general, blind students are unaware of changes made by other users, the formatting toolbars and interactive elements, such as menus, are difficult or impossible to access, and the list of documents is not readily available. Seo and Richard (2018) highlighted that blind students are neglected and excluded from computer-supported collaborative learning due to the lack of efforts to modify the design (e.g., attaching braille labels and providing logical organisation systems), and indicated the importance of research works focusing on accessibility issues because having accessibility in mind can provide new learning opportunities to blind students to foster their computational thinking. Miesenberger (2012) found that aspects such as semantics, structural information, or adaption of presentations according to the needs of blind users are not sufficiently addressed in e-learning collaborative tools.

Another gap in published research is the lack of studies involving m-learning collaborative tools for the blind. There have been a few studies on the usability of m-learning collaborative systems and fewer studies on e-learning systems (not m-learning nor collaborative) for blind students; however, to the best of our knowledge, there has been no previous study on m-learning collaborative systems for totally blind people.

Besides, blind people will only benefit from the educational advantages of online learning if information, educational methods, and technologies are properly designed.

Inclusive education involves focusing on the individual needs of students, helping them overcome any barriers that may prevent them from reaching their potential (Walker and Logan, 2009). In this broad definition, any student may require assistance so that they can reach their potential. Thus, an important issue is to identify the barriers and challenges that blind students need to overcome. Contrary to popular belief, blind people tend to develop other perceptual skills that need to be explored, or even managed to help other students. In addition, some of the practices developed to accommodate students with special needs may also be beneficial to other students (Petrie and Edwards, 2006). Thus, all students can learn effectively regardless of their differences.

Thus, given the conducive scenario and the lack of published research on collaborative m-learning for blind students, the aim of this study is to present the results of an exploratory case study to serve as a basis for the development of an educational accessible application (app) in higher education.

The Accessible Learning Group application will be designed for Android devices as a tool to facilitate the collaboration and interaction of blind users. Besides providing a basis for the development of an educational app, the general contribution of this work is to provide an insight into blind users' interactions and predispositions towards m-learning, which can help to inform them on the design of inclusive mobile educational applications. Therefore, the research questions that lead this study are: "How do blind students interact with mobile apps?" and "When blind students are collaborating on an academic project, is a learning tool to coordinate activities relevant for them?"

2 Related works

Mobile devices and wireless technologies are continuously evolving. Various accessibility solutions for smartphones have been explored over the past decade (Grussenmeyer and Folmer, 2017). The proliferation of smartphones with advanced functionalities has created wider opportunities for learning. Because of the current usage of touchscreen mobiles by blind people, it is essential to take this opportunity to develop effective and practical methods for people with visual impairment to access this technology that conveys educational content.

The use of smartphones for educational purposes has recently gained interest among researchers and educators. Smartphones offer dynamic, connected, and collaborative methods of finding and exchanging information. Many research studies have revealed that m-learning is increasingly emerging as an effective learning method (Oyelere et al., 2018; Crompton et al., 2017; Kambale and Eude, 2017). The main advantages, such as mobility and flexibility, of mobile devices provide new opportunities for improving the learning environments in different forms such as social learning (Oyelere et al., 2018), flipped learning (Hwang et al., 2015), collaborative learning (Fu and Hwang, 2018) and exploratory learning (Liu et al., 2012). Thus, mobile technology has the prospects to originate cutting-edge innovative educational tools.

The m-learning approach using mobile technologies has the potential to enhance students' motivation, attention, interest, and engagement, and improve student performance. When designing educational technologies for blind people, we need to consider technological and pedagogical aspects. From the pedagogical point of view, collaborative m-learning has the potential to benefit blind students. From the technological perspective, collaborative m-learning is an appropriate approach to provide flexibility, personalisation, and collaboration to blind students along with other students.

Regarding flexibility, m-learning provides students with flexibility and freedom in learning. It is not confined to formal educational contexts. Mobility allows students to learn in multiple environments. Mobile devices allow students to access content and communicate with other students and instructors anywhere and anytime (Chee et al., 2018). Always switched on and highly portable, smartphones can be used for learning in any context, anywhere, and at any given time. To provide personalisation, m-learning allows the display of specific content to increase performance or provide alternative ways to display content and afford access. Personalisation provides an adaptive m-learning environment where individual learning styles and needs are supplied (Kambale and Eude, 2017). Therefore, learning is not hindered by temporal or environmental constraints, and learners can use mobile phones to access a variety of information without context limitations, depending on their availability and circumstances (Stanton and Ophoff, 2013).

From the pedagogical point of view, collaborative learning in mobile devices favours interaction and knowledge building (Chee et al., 2018). Bringing together personalised and collaborative aspects, m-learning yields group collaboration while supporting the individual needs of students, considering individual differences such as speed of communication and learning, and thus, allowing students to be more autonomous and master their skills. In addition, the participation of students in a more collaborative learning environment can take advantage of social communication features and opportunities in smartphones.

Many researchers have confirmed the positive effects of collaborative learning on the performance of students. Some works have mentioned the potential of computer-supported collaborative learning for blind students. Previous studies have shown that blind students have high listening competence, and collaborative learning is an appropriate educational method to capitalise on the dialogical capability of blind students (Najafi et al., 2012). As blind students have no vision capacity, they should be encouraged to engage in discussions. Conducting discussions is the main feature of collaborative learning, thus blind students can use more of their verbal ability, immersing themselves in a more conductive environment for learning.

Collaborative learning, and particularly its online form, presents features that generally improve student participation. Particularly, asynchronous text discussion has characteristics that may be beneficial to blind students. The personalised pace and anonymity of asynchronous text discussion has been shown to improve the social interaction of learners with special needs, where the students can equally contribute to and benefit from discussions. No learner can dominate the conversation by taking a disproportionate amount of time allocated for discussion (Tennyson and Jorczak, 2011). According to Buzzi et al. (2012), m-learning collaborative tools for blind students can seize opportunities by considering a student's time, pace, knowledge levels and objectives, active participation, and collaboration with other students, awareness of other students such as who is collaborating, what they are doing, when and where they are doing it, and providing educational content across different sensory channels. Besides, interactions between blind students and students without disabilities can increase the perception of less exploited internal sensory representations for both blind and sighted students.

Compared to published research on mobile learning, there have only been a few studies on mobile collaborative learning (Fu and Hwang, 2018). There have been even fewer studies on mobile learning for the blind (Robson, 2015). Furthermore, the attention to blind learners in collaborative mobile learning has been marginalised. Blind learners have been faced with inaccessible instructional technologies such as inappropriate graphic labels, ill-structured e-learning content for assistive technologies, and software/hardware interfaces designed without accessibility in mind. It is imperative to address the needs of a large number of blind learners who have traditionally had limited access to general education (Seo et al., 2017). Further research is required in this direction, given the importance of the theme and lack of research on collaborative m-learning for the blind. In this study, we investigated how blind people interact with Android smartphone interfaces, unveiling the challenges that these students need to overcome and also the opportunities that designers and researchers must be aware of in order to provide subsidies to develop mobile m-learning applications.

3 Methodology

This work followed a mixed research methodology in which we include and report on outcomes from both qualitative and quantitative (restricted to descriptive statistics) methods, given the multidisciplinary nature of the research. Two steps were taken to achieve the objectives of this research: an exploratory case study, and the development and testing of a prototype.

3.1 Exploratory case study

An exploratory case study is characterised as a qualitative method (Merriam, 1998; Goodrick, 2014), which, in our research, was studied to understand the educational situation of blind students in the context of using smartphones as a tool to support the performance of tasks in a group. The purpose of the exploratory case study was to examine how blind students interact with smartphones, the role and importance of these phones in their academic life, and the main challenges encountered in relation to group work and other educational situations in which collaborative learning occurs, both in terms of learning and social interaction concerning the use of technology.

The methods used for data collection were the structured and semi-structured interviews (Creswell, 2007) and participant observation (Barbier, 1977). Interviews with blind students were conducted to obtain information about their smartphone usage, such as when they use smartphones, number of hours of use per day, and is it used for academic purposes. We also obtained information about their learning: how they access educational content, their participation in group activities, limitations encountered with assistive technologies, and the major issues in accessing and interacting with apps when using a mobile device. An additional ‘why?’ was added to the questions when necessary.

Blind users interact with smartphones through listening and interactive actions such as typing, tapping, or swiping. To provide accessibility to the blind users, the visual interface elements on the screen are transformed into an auditory list of serial words or phrases describing the visual interactive design. Blind people use assistive technology that helps them to operate a computational interface. All the participants in this study use the TalkBack assistive technology to obtain auditory feedback and interact with the interface. TalkBack is an accessibility service available on Android devices, which allows blind and vision-impaired users to interact with interface elements. TalkBack is a screen reader that provides spoken feedback to blind users by describing their actions and interface elements while they navigate through the mobile screen.

Participant observation (LeCompte and Schensul, 1999) requires the researcher to be in the same scenario as the participants to actively record their day-to-day activities, learn about their interactions, actions, behaviours and cultural knowledge. For the application of the participant observation in this research, tests were carried out to record the interactions of students with some scenarios of technology use. The blind students performed a to-do list in a series of apps. Some apps were familiar to them. The user interactions were recorded in a video. The blind students interacted with Facebook, WhatsApp, and Instagram apps. On Facebook, the blind users were asked to access the postings, read a post, and check their notifications. On WhatsApp, they were asked to read a new message and send a message. On Instagram, they were asked to take a picture and post it.

3.2 Educational prototype development

The method used for the development of the prototype is composed of the following phases of the human-computer interfaces design: requirements analysis, and implementation of the interface and application testing of accessibility (Nielsen, 1993), usability (Nielsen, 1999) and UX (Norman, 1988, 2004; Hartson and Pyla, 2012). Accessibility testing is defined as a type of software testing performed to ensure that the system interface (desktop or app) being tested is usable for people with disabilities. For example, for the blind users, every functionality must also be operated using the computer keyboard because they are unable to use the mouse. An accessibility test checks if all the information is perceivable, all interface elements, such as menu, are operable, and all the information is understood by blind users. The purpose of a usability test is to check if the users are operating the system interface efficiently and effectively. A UX test provides information about users' emotions, satisfaction, and identification, among other aspects, during their interactions.

3.3 Reliability of the methods

Regarding the data collection, the data was collected by questionnaires. A preliminary test, involving nine blind people, was applied to assure the understanding of the questionnaires before its application. Concerning the selection of the participants, they were randomly selected, resulting in a heterogeneous and representative test group. The size of the sample is in accordance with Jakob Nielsen user tests recommendations (Nielsen and Landauer, 1993). With regard to ethical aspects, this research was approved in an Ethics Committee and all participants of the research signed a consent agreement.

4 Results

4.1 Educational perspective

From an educational perspective, participants answered the questionnaire in Appendix A, which provided information about the identification of the subjects, the use of smartphones, and the need for the educational use of smartphones. Nine individuals with total blindness participated in this study. Four participants are graduates and the rest are undergraduates. The age range was between 19 and 35. Five participants are males and the rest are females. All respondents use their smartphone for more than four hours a day. Everyone uses their smartphone for educational purposes, using apps such as Google Drive, reading books online, and searching information on Google. They utilised the TalkBack assistive technology for spoken feedback and interactions. The study was conducted on the campus of a university, and the same researcher watched every participant.

The fact that the participants use their mobile devices several hours a day and use it for educational purposes makes them agree with the idea that the mobile device should be used more for educational activities than leisure activities. In addition, everyone responded that they would like to see more integration of the mobile phone into extra-class tasks, and considered that it would be useful to use an application that can monitor the accomplishment of tasks during group activities because it would provide greater agility and independence. The participants of the study were generally excited about the idea of an educational app for group work. Their main issue was that they are highly dependent on others, and thus, demand autonomy. The second major issue was the lack of academic accessibility in apps, with a few exceptions such as the Google Drive app that offers reasonable accessibility. All of these factors point to the need to create an activity coordination app when blind and sighted students work together on an academic project.

4.2 Technological perspective

From the point of view of the use of technology, respondents answered the questions in Appendix B after performing some tasks in applications such as WhatsApp and Facebook. Regarding the interaction of blind users on smartphones, the interviewees do not know how to define their interaction, nor do they form a mental image of the screen, nor do they conceptually know how the design patterns, such as menus, tabs, or lists, work. We heard statements such as, ‘I never stopped to think about it’, ‘It is an intuitive process’, and ‘I am not able to describe’. For example, with regard to cards, an interaction pattern that is widely used today does not have any kind of visualisation, but blind people find it easy to use. They also considered interaction with tabs, lists, menus, and floating buttons to be easy to use. With respect to the forms of interaction and navigation, they restrict the different forms of interaction and navigation of the TalkBack owing to the fear of clicking something wrong or losing something.

The biggest problem with the use of technology is the lack of accessibility. The vast majority of apps such as Lojas Americanas, Duolingo, and Pinterest are not operable and the information in these apps is not perceived well. Even in ‘accessible’ applications, limitations still exist for those that pass the automatic accessibility tests, that is, they are eligible to use the application. For example, it has been revealed that figures within the messages are not perceived well in WhatsApp, causing constraint on interaction. Another example is that the emojis have textual descriptions that are not defined precisely.

4.3 Prototype development

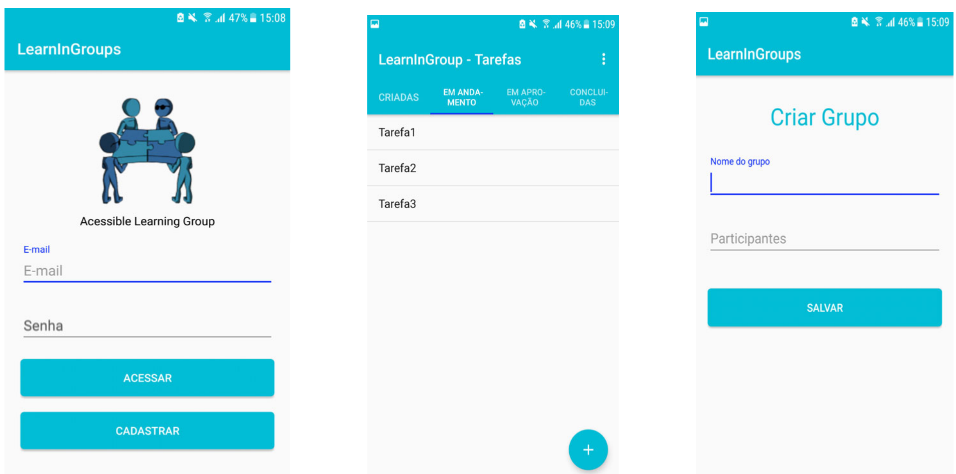
From the point of view of exploratory study, the requirements that emerged were accessibility, simplicity, communication, planning and monitoring of tasks, visualisation of the state of each task (in progress, executed or completed), formation and management of groups, and loading the products generated by students. The tool used to develop the prototype was the Android Studio. Concerning accessibility, the interface design demands universal access to enable collaborative and educational processes between blind and sighted undergraduates, and the application the Web Content Accessibility Guidelines (WCAG) is mandatory.

Regarding simplicity, the design patterns chosen were commonly used patterns and considered to be easy to use by the blind users. The interaction patterns chosen were tab, list, card, menu and floating button. Tabs organise and allow navigation between related content groups at the same hierarchy level. They organise content into categories to help users easily find different types of information. They are displayed next to each other as pairs, in categories of equal importance. Lists are continuous vertical indexes of text or images. They have the function of listing current content in such a way that it is easier to identify a specific item in a collection and its action. They display icons, text, and actions in a consistent format. They are classified in logical ways, such as alphabetic, numeric, chronological, or user preference, which make the content easy to scan. Cards contain content and actions on a single subject. A card is identifiable as a single, contained unit. It exists on its own, without depending on elements surrounding the context. The main menu is at the top of the screen, displaying a list of options on temporary surfaces. They are easy to open, close and interact. Content is tailored to the needs of the user. They are easy to navigate. The float button performs the main or most common action on a mobile screen. It performs constructive actions such as creating, sharing, or exploring. The floating button is located in the lower right corner of the screen of the mobile device.

Tabs are applied to display the main content of the app because they organise and allow navigation between related content groups and at the same hierarchy level by arranging the content into categories to help users easily find different types of information. Lists are used to present the cards that display the groups and tasks created consistently, helping in their identification. Cards are used as an intuitive way of showing groups and tasks created. The main functions are displayed in a top menu, facilitating the navigation of the application and maintaining consistency with other apps familiar to the users. The use of the floating button simplifies the interface because the main function of the screen lies in the floating button, making it easier to use the application.

Figure 1 shows some screens of the prototype elaborated in this research. We implemented an initial subset of functionalities: login, group creation, task creation and notification configuration. In the login screen, the user is asked to enter a name and a password. Before the task's creation, a group must be created. During the group creation, all group participants are specified. After the group creation, the tasks to be executed during the project are created. Initially, all tasks are under a status named 'created'. When a task is being performed, the status shows 'under development'. When a task is finished, it must be approved by all group participants. During this stage, the status shows 'under approval'. Finally, when the task is approved, the status changes to 'completed'. The notification configuration functionality allows the user to set if they want to receive notification and when.

Figure 1 Some prototype screens (see online version for colours)



An automatic test was performed using the scanner accessibility tool. The tool did not find any improvements to be made to improve application accessibility, as proven during the usability test with users. We also applied a usability test on nine blind users. The blind users performed four tasks: create user, create group, create tasks and configure notifications. All users were able to complete the tasks successfully. After the execution of the tasks, a usability and UX questionnaire was applied to verify the understanding, utility, satisfaction, and effort demand of the users with respect to the app, along with its perception about the information organisation, accessibility, quantity of information, disposition and nomenclature of the elements of the interface in the screens, assimilation of the information, ease of memorisation, degree of satisfaction regarding the time of accomplishment of the tasks, and ease of navigation to find the desired information, uniformity, and clarity of the information and identification of the user with the prototype.

The step-by-step usability test is described below. Blind users are asked to perform the following tasks on the app:

1 Create user

Access the application.

Press the register button.

Fill fields of the registration screen.

Press the save button.

2 Create group

Log into the app.

Access the groups tab.

Press the floating button or top menu in the add group option.

Fill fields on the create group screen.

Press the save button.

3 Create task

Log into the app.

Access the groups tab.

Select a created group.

Press the floating button or top menu in the add task option.

Fill field of the create task screen.

Press the save button.

4 Configure notifications

Log into the app.

Access the notifications tab.

Press floating button or the top menu in the configure notifications option.

Select screen times configure notifications.

Press the save button.

The behaviours of the blind users were recorded and observed while they performed the tasks. The interaction of the blind users with the device, the number of tasks they could complete, the tasks they could not complete, and the difficulties they faced were observed. The accessibility problems encountered in the unfinished tasks were noted. The usability issues encountered in the unfinished tasks were reported. The interaction of blind users with the cards and other patterns of interaction were observed. The usability and UX questionnaire described in Appendix C was applied.

Most users encountered no difficulties while performing tasks, presenting a good usability. 83.3% of users found the app easy to use and 16.7% found it very easy. 66.7% of the users answered that the effort demand was low and 33.3% answered very low. 66.7% of respondents expressed that information organisation was very good and 33.3% expressed good. 100% of users agreed that the information was accessible and that the amount of information was sufficient. 66.7% of users pointed out that the layout of the screen elements and the nomenclature of the links were very clear and 33.3% considered it clear. Regarding the capacity of assimilation and memorisation of information, 66.7% answered that it was very easy and 33.3% answered that it was easy. 66.7% of the users were very satisfied and 33.3% were satisfied with the time of accomplishment of the tasks. 83.3% were able to find information very easily and 16.7% were able to find it easily.

On the other hand, while performing a task or navigating through the app, 83.3% responded 'never felt lost', 16.7% responded 'almost never', and 0% responded 'often' or 'always'. No user experienced difficulty reading content, navigating, or identifying an interface element in the prototype. All blind users identified themselves with the prototype.

In addition to the information obtained by the questionnaire, observing the blind users while they performed the tasks unveiled some meaningful information. The results of the conducted exploratory investigation are shown as follows. While listening to the TalkBack auditory feedback, the text sequence properly reflected the natural reading sequence of the sighted users. The interactions of the blind users rely on the auditory information of the interactive actions and their posterior consequences. This entails that the logical order, clarity, and completeness of the auditory information are important qualities to consider for a good UX. The screen reader instructed the blind users in a simple way about what actions they had to take, providing clear instructions for required actions on the current screen. The interaction design was simple and straightforward, avoiding confusion when read by the screen reader. The logical sequence of actions and the simplicity of the interface provided a proper UX.

The interaction design patterns are built on well-established solutions and work under specific situations. The familiarity of blind users with the proposed design patterns directly influenced the UX during the test. The participants had previously experienced touch screens and interacted with the design patterns addressed in the tasks. The previous experiences of blind users have a determinant impact on the success rate of the tasks. The blind users were familiar with the order of the actions and also utilised previously acquired strategies to locate objects on the interface. For example, simplifying the interactive process by memorising the position of an interface element.

The blind users demonstrated a good positional awareness of objects on mobile interfaces. For example, they were able to find the floating button on the mobile screen. Consequently, they proved to have a good spatial ability. Spatial ability is a condition to have awareness of the interface, and a requirement to memorise the positions of the buttons on the screen. The participants were also aware of the effect of their interactions and the sequence of actions that should be performed. The logical order of the content and navigation was also adequate. The blind users easily went forward and backward in a sequential order to easily find the information.

5 Conclusions

There is a need to investigate the accessibility and usability of m-learning systems for blind people. Our study gathered information on the interactions of blind people in the context of m-learning under both educational and technological perspectives. By focusing on a more inclusive design, blind learners can experience an equal learning opportunity. Our study reinforces the importance to design interfaces for blind people and unveils the information for m-learning designers. In this research, we investigated the interactions of blind users on Android smartphones using the available accessibility features to uncover the level of difficulty their interaction with some design patterns is. A study was also conducted to reveal the particularities encountered by blind students when using mobile applications. Although the case study involved only nine blind users, we were able to obtain relevant results.

The main contributions of this study are the results highlighting the importance of an educational app for coordinating group tasks striving for the independence of blind students, great importance of designing the m-learning systems considering the blind users' previous experiences, lack of accessibility, lack of ability to describe their mental model of the interface, and positional strategies developed to facilitate their interactions. The results of the study indicated positive predispositions of blind students for m-learning because of their huge involvement with smartphones combined with their craving for independence. The main problem revealed during the case study regarding learning in groups was the dependence on other people's help. An app that supports group tasks will provide the blind people with opportunities to act independently.

Concerning previous UXs with mobile technologies, the nine blind users that participated in the study applied their previous experiences while using the interaction patterns such as tabs, lists, cards, menus and floating buttons. The familiarity with the mobile interface has proved to be central for a consistent interface design. The findings of this study illustrated that a consistent use of interface design contributes to a positive UX. The results provided evidence of accessibility and usability issues encountered by the blind users when interacting with mobile applications. Besides developing the accessibility guidelines for smartphones, offering a rich environment to address the needs of blind users is either not enough to fulfil their needs or is simply ignored by the designers.

A mental model of the interface is a person's intuitive understanding of its functions based on previous encounters. Understanding the mental models is important to achieve positive engaging UXs. This research uncovered an existing inability of blind users to describe their mental model concerning mobile interfaces, despite their positive results regarding the performance and engagement. To overcome these issues, further research is required. Spatial ability is defined as the skill to manipulate or transform the image of spatial patterns into other arrangements. The mental models of a physical spatial pattern may have a great influence on the interaction of a user. The results of the study indicate that although blind people cannot perceive the visual content in the same way as sighted people do, they are able to memorise positional information on the screen, which is crucial for performing a task.

The exploratory case study performed in this research will serve as the basis for future work that will involve the development of the Accessible Learning Group app. The Accessible Learning Group application will be developed for Android devices to facilitate collaboration and interaction among blind students, and also between blind and sighted students. The results of the study reinforce the idea that good accessibility must be assured, not only by performing automatic accessibility tests but also by performing more detailed tests. For consistency and familiarity, the use of design patterns cards which include tabs, lists, cards, menus, and floating buttons is a suitable option.

The results also indicate that a learning tool to coordinate the activities of blind students when collaborating on an academic project is relevant for their autonomy during collaborations. Besides contributing towards digital inclusion for blind people, the use of a smartphone and an educational app can also allow their inclusion in the educational environment. We believe that the results of this study will contribute to the human-computer interaction area on accessibility and UX for mobile learning, bringing insights into blind users' interactions and inclinations. This research contributes to the present awareness of the accessibility aspect of m-learning collaborative tools, draws attention to the importance of blind students becoming self-reliant, confident, and independent, and highlights the relevance of facilitating their equal participation in educational group activities. The results of this study contribute to the learning technology area, revealing that blind people easily interact with some mobile design patterns that can be used to implement m-learning applications and showing that they have positive perceptions and readiness to use an app for managing group tasks.

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Appendix A

Questionnaire of users' background and use of smartphones

Personal information

1 What is your full name?

2 What is your date of birth?

3 What is your gender?

4 What is your degree of blindness?

Educational information

5 What is your level of education? In which year did you receive your degree?

6 If you have graduated, what is your major? When did you start your course?

Professional experience

7 What is your profession?

8 How long have you been in this profession?

( ) Less than one year
( ) Between one and two years
( ) Between two and four years
( ) More than four years

Computational experience

9 How long have you been using computers?

( ) Less than one year
( ) Between one and two years
( ) Between two and four years
( ) More than 4 years

10 Where do you use a computer? (You can select more than one option).

( ) I utilise my computer at home
( ) I utilise a computer at work to perform my job tasks
( ) I utilise a computer at school for educational purposes
( ) I utilise a computer in other scenarios

11 On average, how many hours per week do you use computer?

( ) Less than two hours
( ) Between two and five hours
( ) Between five and ten hours
( ) More than ten hours

12 What assistive tool(s) do you usually use on your computer?

Using smartphones

13 How long have you been using smartphones?

14 How many hours per day do you use your smartphone?

15 What assistive tool do you usually use on your cellphone?

16 Which apps do you use?

17 Do you use your smartphone for academic purposes? Which educational platforms do you use (Quizlet, flashcards, Pearson and Duolingo, dictionary, Wikipanion, Evernote, Dropbox, Google Drive, keynote, MOOCs, distance learning courses or books)? How?

18 Would you like more integration of the mobile phones for extra-class activities?

19 Do you believe that using an application to monitor the accomplishment of tasks during group activities would be helpful? Why do you believe that?

Appendix B

Users' interactions questionnaire

1 How do you interact with an application the first time or the first few times you use it?

2 How do you interact with an application you are already familiar with?

3 How do you imagine or visually view the application screen? What is your mental image of a user interface?

4 What forms of interactions, such as tapping, and dragging your finger horizontally and vertically, do you know?

5 What is your mental image of a card interaction pattern?

6 Do you consider the use of a card interaction pattern easy?

7 What interaction patterns, such as menus, tabs, and buttons, do you know?

8 How do you navigate through each page of an application or a website using a mobile device?

9 How do you navigate through the pages of a mobile app or a website?

10 What are the main issues encountered during your interactions, access, or searches on mobile apps or websites?

Appendix C

Usability and UX questionnaire

Table A1 shows the usability and UX questionnaire.

Table A1 Usability and UX questionnaire

	Question	*Answer*
1	What is the purpose of the app?	
2	Overall, how easy is the app to use?	( ) Very difficult () Difficult ( ) More or less ( ) Easy ( ) Very easy
3	How much effort was required?	( ) Very high ( ) High () More or less ( ) Low ( ) Very low
4	In your opinion, how is the organisation of information?	( ) Very good ( ) Good ( ) Reasonable ( ) Bad ( ) Very poor
5	Was the information accessible?	( ) Strongly agree ( ) Agree ( ) More or less ( ) Disagree ( ) Strongly disagree
6	Was the amount of information sufficient?	( ) Extremely ( ) Very ( ) More or less ( ) Not quite ( ) Not at all
7	How is the layout of the elements on the screens?	( ) Very clear ( ) Clear ( ) More or less () Confused ( ) Very confused
8	How is nomenclature of links?	( ) Very clear ( ) Clear ( ) More or less ( ) Confused ( ) Very confused
9	How was your assimilation of the information?	( ) Very difficult ( ) Difficult ( ) More or less ( ) Easy ( ) Very easy
10	Is it easy to remember where things are?	( ) Very difficult ( ) Difficult ( ) More or less ( ) Easy ( ) Very easy
11	What was your degree of satisfaction at the time of accomplishment of the tasks?	( ) Very satisfied ( ) Satisfied ( ) More or less () Unsatisfied ( ) Dissatisfied
12	In general, what do you think about the test performed?	( ) Very interesting ( ) Interesting ( ) More or less ( ) Somewhat monotonous ( ) Monotonous
13	Do you think the app was designed considering the first-time users?	( ) Strongly agree ( ) Agree ( ) More or less ( ) Disagree ( ) Strongly disagree
14	What do you think about the shortcuts in the interface?	( ) Extremely sufficient ( ) Sufficient ( ) More or less ( ) Insufficient ( ) Extremely insufficient
15	Were the navigation errors easy to fix?	( ) Strongly agree ( ) Agree ( ) More or less ( ) Disagree ( ) Strongly disagree
16	Were you able to find the information you wanted?	( ) Very easily ( ) Easily ( ) More or less ( ) Hardly ( ) Very difficult
17	At some point during navigation, did the application lose its identity? Did you have the feeling of being in another application or lost?	( ) Always ( ) Often ( ) Sometimes ( ) Almost never ( ) Never
18	At some point, did you find it difficult to read the content of the application?	( ) Always ( ) Often ( ) Sometimes ( ) Almost never ( ) Never
19	At some point, did you have difficulty identifying any element of the application?	( ) Always ( ) Often ( ) Sometimes ( ) Almost never ( ) Never
20	Did you identify yourself with the application?	( ) Always ( ) Often ( ) Sometimes ( ) Almost never ( ) Never
21	Have you encountered difficulties navigating through the application?	( ) Always ( ) Often ( ) Sometimes ( ) Almost never ( ) Never