Remote Graphic-Based Teaching for Pupils with Visual Impairments: Understanding Current Practices and Co-designing an Accessible Tool with Special Education Teachers

KAIXING ZHAO, School of Software - Northwestern Polytechnical University, China and Yangtze River Delta Research Institute- Northwestern Polytechnical University, China
JULIE MULET, IRIT - University of Toulouse, France
CLARA SORITA, IRIT - University of Toulouse, France
BERNARD ORIOLA, IRIT - CNRS, France
MARCOS SERRANO*, IRIT - University of Toulouse, France
CHRISTOPHE JOUFFRAIS*, IPAL - CNRS, Singapore

The lockdown period related to the COVID-19 pandemic has had a strong impact on the educational system in general, but more particularly on the special education system. Indeed, in the case of people with visual impairments, the regular tools relying heavily on images and videos were no longer usable. This specific situation highlighted an urgent need to develop tools that are accessible and that can provide solutions for remote teaching with people with VI. However, there is little work on the difficulties that this population encounters when they learn remotely as well as on the current practices of special education teachers. Such a lack of understanding limits the development of remote teaching systems that are adapted. In this paper, we conducted an online survey regarding the practices of 59 professionals giving lessons to pupils with VI, followed by a series of focus groups with special education workers facing teaching issues during the lockdown period. We followed an iterative design process where we designed successive low-fidelity prototypes to drive successive focus groups. We contribute with an analysis of the issues faced by special education teachers in this situation, and a concept to drive the future development of a tool for remote graphic-based teaching with pupils with VI.

580

CCS Concepts: • **Human-centered computing** → *Accessibility design and evaluation methods*; **Participatory design**.

Additional Key Words and Phrases: Remote teaching, Pupils with VI, Co-design, Graphic-based

ACM Reference Format:
Kaixing Zhao, Julie Mulet, Clara Sorita, Bernard Oriola, Marcos Serrano, and Christophe Jouffrais. 2022. Remote Graphic-Based Teaching for Pupils with Visual Impairments: Understanding Current Practices and Co-designing an Accessible Tool with Special Education Teachers. *Proc. ACM Hum.-Comput. Interact.* 6, ISS, Article 580 (December 2022), 29 pages. https://doi.org/10.1145/3567733

*Both authors contributed equally to this research.

Authors' addresses: Kaixing Zhao, School of Software - Northwestern Polytechnical University, China and Yangtze River Delta Research Institute- Northwestern Polytechnical University, China, kaixing.zhao@nwpu.edu.cn; Julie Mulet, IRIT - University of Toulouse, France, julie.mulet@irit.fr; Clara Sorita, IRIT - University of Toulouse, France, csorita@ensc.fr; Bernard Oriola, IRIT - CNRS, France, bernard.oriola@irit.fr; Marcos Serrano, IRIT - University of Toulouse, France, marcos.serrano@irit.fr; Christophe Jouffrais, IPAL - CNRS, Singapore, christophe.jouffrais@irit.fr.

2573-0142/2022/12-ART580 $15.00
https://doi.org/10.1145/3567733

1 INTRODUCTION

Because of mobility issues, economic reasons, or even the scarcity of special education centers [24], pupils with visual impairments (VI) cannot always attend face-to-face lessons. The recent COVID-19 pandemic emphasized this issue and put many pupils with VI in a situation of scholar exclusion [33]. Besides the lack of physical presence which can negatively impact the learning experience of pupils with VI, not all types of learning activities are suitable for being conducted online. Many crucial topics are very difficult or impossible to study with traditional online video-conference tools [33], especially those are based on graphics (e.g., Science-Technology-Engineer-Mathematics (STEM), History, Geography). However, today we have limited knowledge into what are the current practices of special education teachers when giving remote lessons, or how they ensure the quality of graphics-based teaching during remote lessons with pupils with VI.

While both synchronous [37] and asynchronous [28–30] remote learning have received much attention for the general public, few previous works have explored it for pupils with VI. Therefore, it is not clear if special education teachers have already leveraged specific teaching tools and methods for remote. Besides, while previous work in HCI has explored different alternatives to make graphics accessible for people with VI, such as using interactive tactile graphics [6, 10], or exploring virtual graphics with vibrotactile feedback [3, 43], none of these works considered the situation where the teacher and the pupil are remote. Hence there is still a need to come up with novel tools to ensure accessible online teaching.

In this paper, we report a survey followed by a series of focus groups with special education workers (i.e. specialized teachers, O&M instructors, Braille transcribers), to assess what are the current practices and the design requirements for a remote accessible teaching tool based on graphics. During the focus groups, we relied on a co-design method (as in [23]) that involved two types of special education workers - including teachers and instructors - and various low-fidelity prototypes to drive the discussions and the design iterations. Our work intends to address the following questions: (1) What are the current practices of special education teachers when giving remote lessons? (2) How can we co-design remote teaching tools with special education workers? (3) What are the design requirements and application scenarios of a remote graphic-based teaching tool?

To answer these questions, we first conducted a preliminary survey to better understand the practices and difficulties experienced by special education workers during the COVID-19 pandemic and the necessity to organize remote teaching with pupils with VI. Based on the results of the survey, we designed a low-fidelity prototype of a remote teaching device relying on a regular tablet (i.e. to present digital graphics). We used this prototype to drive the Focus Group 1 (FG1) with special education teachers. The outcomes of the first focus group confirmed the shared interest for a remote graphic-based teaching tool and pointed out that the digital graphics should be enriched with tactile information. We then designed a second lo-fi prototype with a tactile overlay over the touchscreen that we used to drive three other focus groups. The goal of the Focus Group 2 (FG2) was to identify the main interaction and functionality requirements and to define the application scenarios. The goal of the homogeneous Focus Group 3 (FG3) and Focus Group 4 (FG4) was to validate the device and identify usability issues in two specific application scenarios involving O&M instructors (FG3) and special education teachers (FG4) respectively.

In summary, our contributions are:

1) The description of the current practices of special education teachers, and how they adapted to a forced remote teaching situation, based on an online survey;

2) A set of recommendations to design a remote graphic-based teaching tool for pupils with visual impairments based on a series of heterogeneous and homogeneous focus groups;

3) A general discussion to summarize our findings and envision the development of the tool.

2 RELATED WORK

In this section, we provide a review of existing works on 1) graphics exploration for people with VI; 2) remote and online learning accessibility; and 3) remote graphic-based teaching for people with VI.

2.1 Graphics exploration for people with VI

As in regular education, graphics play an important role in education for people with VI [24]. For example, people with VI often explore tactile maps during Orientation & Mobility (O&M) classes [10]. However, graphical information exploration is an inherently difficult task for pupils with VI [4, 42]. Generally, there are two main types of solutions for providing people with VI with access to digital graphical information: graphics with alternative descriptions [36] or interactive digital graphics [6]. For the first type of solution, graphics are labeled with descriptive text, which can be converted to speech using TTS interfaces when necessary. However, this method usually provides only general information about the graphic and is very limited for understanding the configuration of the graphic and the location of the different constitutive elements. Regarding interactive digital graphics, various interactive tools have been proposed in recent years. According to [10], they can be divided into two categories: (1) digital graphics and (2) hybrid graphics. Digital graphics are based on digital devices only, such as smartphones or tablets, and graphical information is totally digital. Users can then rely on vibrotactile feedback, which can be combined with TTS, to explore the displayed graphic [3, 43]. Hybrid graphics depend on an additional tactile overlay over the digital graphic [6]. For example, Melfi et al. [22] proposed the TPad system, which is an audio-tactile solution for graphics learning in school context. However, while these approaches (either digital or hybrid) have been tested in the context of special education, they have not been adapted to the context of remote teaching.

2.2 Remote and online learning accessibility

Online learning or e-learning is the delivery of learning through digital resources, such as computers, tablets or mobile phones that are connected to the Internet [16]. More generally, online learning is one type of remote learning which the latter occurs when the learner and instructor, or source of information, are separated by time and/or distance. Russ et al. [33] recently reviewed and analyzed fourteen papers published in the last eleven years on e-learning accessibility, which illustrates that students with VI face many issues when accessing online course content [5, 13, 14, 19, 26, 39]. However, limited efforts had been conducted in this direction.

In general, remote learning can be classified into two categories [25]: asynchronous and synchronous. For asynchronous remote learning, one of the most famous platforms is Massive Open Online Courses (MOOCs), which has attracted millions of learners every year [40]. Previous work on asynchronous learning accessibility has focused on managing accessible images when generating online educational content [34], on improving the examination by generating accessible questions [20] or to gain awareness when collaboratively editing a document [17]. Moodle and Sakaki have been shown to be the most accessible e-learning platforms [34]. As for synchronous remote learning, more and more students participate in live online lessons around the world [37], especially during the COVID-19 pandemic. One accessibility problem that was specifically addressed in this context was how to provide students with disabilities with a simplified access and control to connected cameras [26].

However, despite these research works on synchronous and asynchronous remote learning accessibility, there is still limited effort in remote learning or teaching for people with VI when it comes to graphical information.

2.3 Remote graphic-based teaching for people with VI

As mentioned previously, there is very limited research about remote graphics teaching for people with VI [21, 27, 38]. Oshiro et al. [27] recently presented a preliminary investigation on the specific problem of making mathematical graphs accessible during remote learning. They proposed a series of sonification for math graphs, evaluated with three participants. Weill-Duflos et al. [38] recently demonstrated a dedicated force-feedback device which could be suitable for remote learning for pupils with VI. Manshad et al. [21] presented a tangible collaborative graphic distance learning environment called Trackable Interactive Multi-modal Manipulatives (TIMMs). TIMMs supports remote and active position, proximity, stacking and orientation tracking on tabletop surfaces. When learning graphics using TIMMs, each pupil with VI can construct the graph individually. The instructor can remotely monitor pupils' learning process and help to correct if necessary. The instructor can also send instructions to the pupils with VI that will be presented in the form of auditory or music feedback. Although these two research works [21, 38] are valuable, they rely on specific tools that are not available (force-feedback device and TIMMs prototype) in regular settings. In addition, the solutions have not been evaluated so far and probably raise accessibility issues.

Beyond these preliminary works, there is no previous research addressing the general question of making remote graphic-based teaching accessible to pupils with VI. Then it is important to conduct a study involving the different instructional stakeholders, considering the various needs that can emerge from different teaching practices (for instance specialized teachers vs. Orientation & Mobility instructors). In this paper we address this challenge by adopting a participatory and iterative design approach combining a survey with many focus groups driven by prototypes, as described in the following sections.

3 OVERVIEW OF THE APPROACH

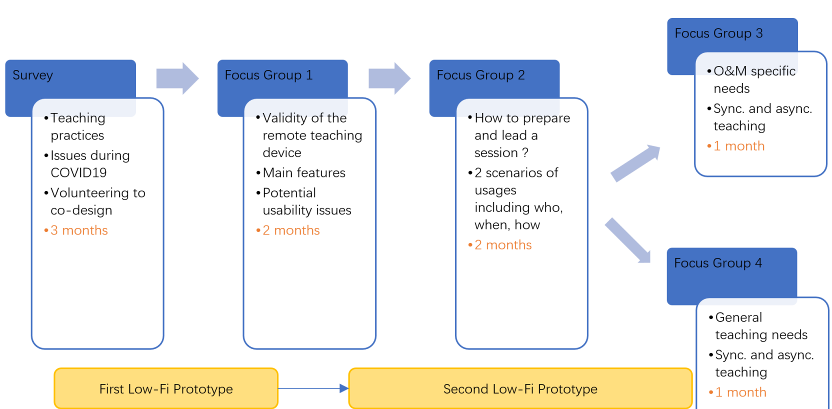

Fig. 1. Illustration of the different steps of our twelve months study.

The concept of a graphic based remote teaching tool emerged during the COVID-19 lockdown when professionals of visual impairments told us about their difficulty in supervising remote students. We therefore developed a survey to better understand the regular practices and the situation during the COVID-19 lockdown. The results of the survey confirmed that no suitable tool exists and that such a tool is needed.

In a second participatory design step, we worked with professionals who volunteered in the survey to work on the design of the tool. The two first focus groups involved two professions that were more concerned with the tool (O&M instructors and special education teachers) and that volunteered in the online survey. During the first focus group, we were able to validate the utility of the device and define the main functions. During the second focus group, we worked on how to use the device in a remote teaching context. We identified that the device can be used in different settings with different instructional aims. Indeed, special education teachers are more often attending a classroom with a small group of students (4-8), whereas the O&M instructors are more often doing a face-to-face teaching.

Hence, we designed two usage scenarios that are specific to the two populations (O&M instructors and special education teachers), and we organized two separate homogeneous focus groups with O&M instructors on one hand, and special education teachers on the other hand, which were either coming from the initial groups or new participants. These two focus groups allowed us to address in depth the specificities of each teaching context. We asked questions related to the preparation and management of sessions with the tool, which also allowed us to identify potential usability issues.

In this paper, we worked with a low-fidelity prototype only. Different from research focusing on the evaluation of interactive systems, the main contributions of the current work rely on empirical data gathered with special education professionals. As indicated in [41], empirical research is one of the main research contributions in HCI as it provides new knowledge through findings based on observation and qualitative or quantitative data gathering.

In addition, the evaluation of a high-fidelity version of the prototype would require recruiting pairs of participants (teacher and pupil with VI) and conduct a long-enough study in an ecological setting, which is beyond the scope of this work. Instead, our contribution lies on the co-design of the prototype and on collecting the empirical needs and comments from professionals.

Figure 1 illustrates the whole process of this twelve-month study with a flowchart. We chose a participatory and iterative method based on online focus groups inspired by [23]. The entire co-design process was cross-iterative, which means that the low-fidelity prototype drives the focus groups, and is improved after the outcomes of the previous focus group. All the steps in this study were carried out online in order to comply with COVID-19 safe distancing rules.

4 PRELIMINARY SURVEY

Online teaching has gradually become preeminent, especially during the COVID-19 pandemic. In this period, almost all the special education activities had to be conducted remotely. However, unlike regular education which can rely on several public digital tools such as videoconference and e-teaching systems, education for pupils with VI faced even more challenges. To better understand the impact of this context and the resulting needs, we conducted an online survey that lasted about two months (from the preparation to analysis). The main objective of this survey was to collect issues experienced by special education teachers and how they changed their practices to adapt to the situation. More specifically, we aimed to identify the digital tools that they already leveraged or developed, their remote teaching experience as well as their needs.

4.1 Method

The survey was implemented on a local version of Yakforms (GNU GPL v2), and took approximately 10 minutes to complete. We verified the accessibility in advance with one person with VI. The survey consisted of 27 questions, including 25 closed-ended questions and 2 open-ended questions. The form was divided into different sections regarding demographic information, current practices, use of digital tools in teaching activities and impact of the pandemic on teaching practices.

Our goal was to have a targeted, anonymous, informative participation with relevant feedback for our study, but for the community too. We therefore prepared our survey with care to limit the influence of different biases. First of all, we added inclusion criteria to our call (professionals in the field of visual impairment actually caring for children or adults). Obviously, the responses were anonymous in order to respect ethical rules but also to allow a freer expression. We also mentioned that the results of the survey would be available freely to the community (we will broadcast a technical report after the current paper being accepted).

We pre-tested the survey with three professionals in order to avoid duplicate, poorly formulated, imprecise or irrelevant questions. Finally, we favored questions with multiple choices (4-7 items and box “other), and we added free comment areas to allow for clarification when needed. The survey (translated in English) is attached as appendix.

4.2 Results

In total, 59 special education workers participated in the survey. Among them, 20 are special education teachers and 7 are O&M instructors. The other respondents were transcribers, document makers who are not involved in face-to-face teaching. Hence, in the following design steps we selected participants that are either teachers or instructors. We report the main results in the following sections.

4.2.1 Use of digital tools. All participants use computers and smartphones on a daily basis for their work (Figure 2 left). Tablets are also used but much less and always in association with smartphones and computers. According to the participants, the pupils with VI that they care for use computers, smartphones and several specific tools (Figure 2 right). More precisely, 32% of pupils with VI chooses computers as their preferred digital tool while 27% of them chooses smartphones. In addition, 28% of pupils with VI use special assistive tools, such as adapted software, voice synthesis or Braille displays.

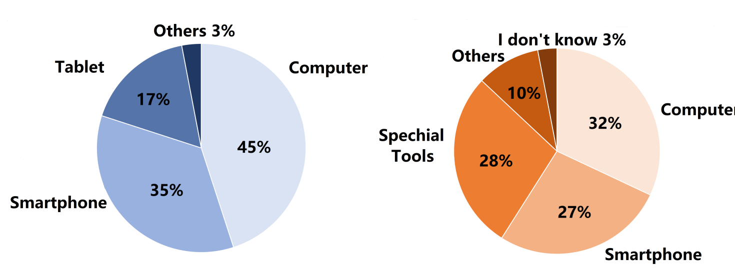

Fig. 2. Results on digital tools used by special education workers (left) and their pupils with VI (right). N= 59.

The use of digital services is very much focused on phone calls, but also on sending emails and documents. Video conferencing tools and social networks are less used. Figure 3 shows the results for special education teachers (N=20), and O&M instructors (N=7) respectively (i.e. the two professions conducting teaching activities in our sample). Most of the special education teachers use computers daily during their work. In contrast, the use of smartphones or tablets is less frequent, and their use is often in combination with computers. However, for O&M instructors, the use of smartphones is more frequent than computers. This is probably related to the nature of their work: computers are more cumbersome and less convenient for lessons on mobility. Moreover, smartphone features such as mobile microphone and camera, can better answer the needs of O&M instructors. Interestingly, the participants consider themselves as having an average (20/59), good (29/59) or very good level (5/59) in using new technologies.

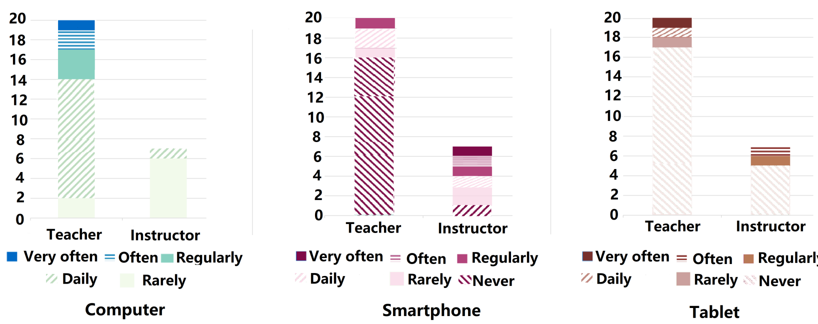

Fig. 3. Usage frequency of computers (left), smartphones (center), and tablets (right).

4.2.2 Adaptation in teaching during the lockdown. Overall, professionals mentioned that most of their teaching activities have been stopped or limited during the lockdown (23/27). However, the contact with their pupils was regular and fairly easy, with the exception of a few cases. The main activities were related to sending documents and graphics (21/27), making phone calls (27/27), sending emails (19/27), doing videoconferences (10/27), and communicating on social medias (11/27). Notable changes that we identified were few: teachers sent fewer digital documents during lockdown but contacted their students more via email and phone. Conversely, O&M instructors sent more documents (i.e. learning materials used during special education, such as large print document and raised-line graphics). Social networking and video conferencing tools remained underutilized.

In general, the strategy of special education worker was to maintain a close contact with people in care and their families. The technologies used in this context were phone, email or other regular digital tools. None of the participants mentioned a tool (specific or not) that he could use to compensate for their limited teaching activity.

4.2.3 Needs and ideas for improving remote teaching. It appeared that remote teaching has posed difficulties for most of the professionals (15/27). These difficulties were expressed as doubts or questions, particularly by teachers and O&M instructors: "*it is really not suitable to work remotely with the visually impaired*"; "*it is difficult in locomotion instruction; but maybe also some specific work about mental representations… on a map… But which tool could be used?*"; "*remote teaching in locomotion instruction is impossible*". However, other ones seemed more optimistic: "*maybe we can adapt locomotion instruction lessons remotely*".

When asked about their ideas and needs, especially concerning digital tools, the suggestions focused on the use of platforms and applications that, in addition to maintaining the contact, would allow the sharing of documents and screens (20/27). Some suggestions refer to pedagogical and/or adaptive strategies based on remote games or remote descriptions (16/27), use of audio documents (19/27), etc. When talking about using graphics remotely, they mentioned that there would be a lot of issues regarding sharing an online document and monitoring the pupils' hand movements (i.e. monitoring hand movements is very important because it allows to verify that the documents are correctly explored) (22/27). Some professionals insisted on the need to have tools that are simple to use (15/27), and one of them indicated: "*to work remotely, we need a tool that meets our needs*".

Another important point emerged from the comments was: the people in care must have recent and functioning computers and smartphones, which is not always the case (8/27).

To sum up, the survey showed that special education teachers have experienced difficulties during the lockdown period, but very few notable changes in their practice were identified. It appears that remote monitoring raised concerns for some professionals - one of the respondents indicated that "*it is really difficult to work remotely with the blind*". Another one mentioned that "*we could try to work on mental representations, with maps... but how to ensure accessibility with a digital remote tool during remote use?*" When asked about their ideas and needs, especially concerning digital tools, their suggestions mainly focused on the use of applications that allow the sharing of documents and screens. Some suggestions refer to adaptive strategies including remote games, use of audio description functions and audio documents. Many professionals insisted on the need to have tools that are simple to use, and one teacher mentioned that "*the best way to work remotely would be to find a tool that meet our needs*". Following this survey and additional discussions with two special education teachers, we decided to co-design an accessible graphic-based remote teaching tool with special education workers.

5 FIRST LOW-FIDELITY PROTOTYPE OF THE REMOTE GRAPHIC-BASED TEACHING TOOL

Based on our survey, preliminary discussions with teachers and O&M instructors and relying on previous works on face-to-face graphic-based teaching [6, 23], we designed a low-fidelity prototype of a remote graphic-based teaching tool. As stated in the survey responses, the tool must be simple and easily accessible. We have therefore chosen to use marketed PC or tablets and not to add any physical objects on the screen (i.e. focusing on Digital Graphics rather than Hybrid Graphics [10]). Hence, feedback provided during exploration was based on digital multisensory graphics leveraging vibration and sonification [3, 6, 43]. In this low-fidelity prototype, we have included the main functions needed to manage a remote lesson: i) Remote control of the graphic content by the teacher; ii) Annotation functions for both teacher and the pupil; iii) Functions to navigate among different contents. Based on the additional discussions with the specialized teachers, we have added the function to track the position of the fingers on the graphic which seems useful for the teacher to better manage the pupil's behavior and attentional focus. The goal of this low-fidelity prototype was to drive the first focus group and to gather ideas. We used Axure (version 10.0.0.3826 from Axure Inc.) to design the prototype because it allows online sharing with dynamic features (i.e. clicking on a button to get an audio feedback or an animation). With Axure, we were able to easily build interactive prototypes that are clickable. This tool is convenient in a participatory design process to test solutions and gather feedback, as well as iterate until the group reaches an appropriate solution (we added our presentation documents in the supplementary materials). It should be noted that the low fidelity prototypes used to drive the first focus group can be presented either on a PC or on a tablet, we leverage tablet in our paper only for facilitating presentation.

5.1 Remote control of the graphic content by the teacher

This function was inspired by regular face-to-face teaching where teachers can freely change the documents used to teach a lesson. Obviously, enabling changing the documents is also a need in remote teaching, especially when dealing with graphics. With this function, teachers can remotely control the interactive contents of the graphic. Figure 4 shows that the teacher can hide one side of the graphic (e.g. the Asian continent in this figure) when he wants the pupil to focus on the other side of the graphic. In addition, this function provides the teacher with the ability to filter the data. For example, if the teacher wants to simplify the content in a world demographic map, he can decide to display only the names of the countries rather than both the names and demographic data. To do this, teachers can select/unselect the elements of the graphics as well as attached data (i.e., data filtering) on their interface.

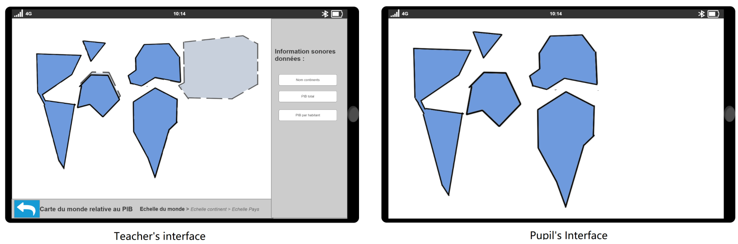

Fig. 4. Left side: The teacher interface with a menu to play with the graphic content. In this example, one continent is hidden. Right side: The pupil's interface provides vibratory and sound feedback according to the finger location on the drawing. The drawing depends on the teacher actions (in this example, one continent is hidden).

5.2 Annotation functions for both the teacher and the pupil

This function was inspired by regular face-to-face teaching too, where teachers can pinpoint a location on the graphic and provide details regarding this location. In addition, since everything is digital in our remote teaching prototype, it is easy to make this annotation permanent if users want to. In the prototype, we provided both auditory and vibratory annotations (Figure 5). The teachers can see the existing annotations on their interface but can also add, delete, and modify annotations. The pupils can feel (tactile vibration) and hear (sonification) existing annotations. They can also add annotations with a simple gesture, such as two-finger click or long touch (in this low-fidelity prototype, the aim was to focus on the annotation function and not on the gesture being used to annotate).

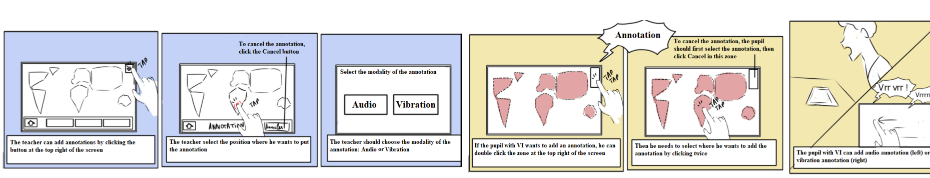

Fig. 5. Usage scenario illustrating how both the teacher (top, in blue) and the pupil with VI (bottom, in yellow) can add interactive annotations (vibration or sonification).

5.3 Function to navigate among different contents

This function came from previous research [11] showing that panning and zooming are important functions when relying on a tablet display with a limited size. In our scenario, the teacher prepared the session with different graphics in advance. The navigation function should enable both teachers and pupils to navigate between different graphics or zoom levels (e.g., from the World map to the European map). When changing of graphic, the pupil receives sound feedback (e.g., voice prompt "change to European map").

Table 1. Demographic information of the first focus group participants

Participant	Age	Profession	Description	Year of special education
P1	42	Special education teacher	Female	11
P2	53	Special education teacher	Male, Blind	28
P3	51	Special education teacher	Female	20
P4	36	Special education teacher	Female, VI	8
P5	39	Special education teacher	Female	12
P6	48	Special education teacher	Female	22

5.4 Remote tracking

As mentioned previously, with real-time hand movement tracking, teachers can have a better awareness of the pupil's behavior and attentional focus. This function was mentioned as needed during follow-up discussions with special education teachers. Figure 6 illustrates how we envisioned remote tracking: the blue box represents the teacher's interface, and the yellow box represents the pupil's one. The two interfaces display the same content (in this case a world map), but the pupil's hand movements are displayed on the teacher's interface. Therefore, the teacher can remotely track the finger movements of the pupil in real-time, to ensure the pupil understands the instructions and is correctly exploring the graphic.

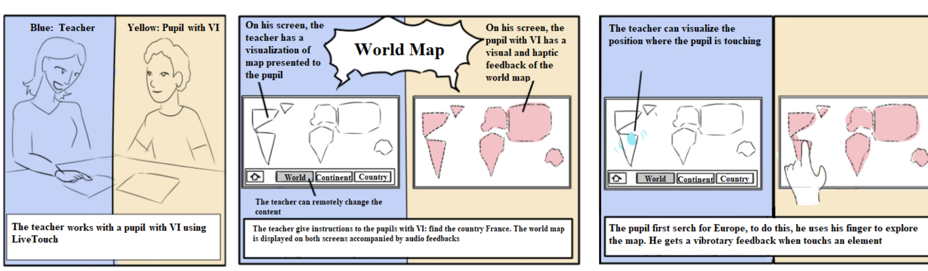

Fig. 6. Usage scenario illustrating how the teacher can see on his interface (blue) the pupil's hand movements and interactions on the interactive graphic (yellow).

6 FIRST FOCUS GROUP: THE CONCEPT OF A REMOTE GRAPHIC-BASED TEACHING TOOL

The main objective of this focus group was to validate the interest for the device and ask about utility and usability issues (gather comments and suggestions about the functions and the envisioned issues that can occur during a remote teaching session). This focus group was held online and lasted about two hours. We took care to describe the interfaces and interactions so that the participants with visual impairments can participate in the discussions.

6.1 Participants

We recruited six participants from local special education institutions (5 females, 1 male). All of them are special education teachers. The average age of the participants is 44.8 years (SD: 6.8). Table 1 gives their detailed information.

6.2 Focus group preparation

Due to the lockdown, we conducted the focus group online. We chose Zoom as the online videoconference platform because of its accessibility (two of the invited participants are VI). In addition, we used an online brainstorming platform (Conceptboard) to enable participants to interactively share ideas with others. We showed the mockups of the prototype to help participants better understand the four functions that we proposed.

6.3 Scenario

To help participants better understand the designed device, we introduced a scenario that was based on the COVID-19 propagation. The goal was to help pupils with VI to learn the global pandemic situation using a world map during an online lesson with our prototype. Relying on the four available functions, the teacher can lead a session with pupils with VI in real-time. They can hide/display different parts of the map, zoom in a part of the map, filter the data related to the pandemic spreading and track the pupil's hand movements during tactile exploration of the map. In addition, both of them can add annotations when needed. Of course, they can talk to each other during the session.

6.4 Procedure

During the two-hour focus group, we followed a pre-defined procedure divided into the following parts:
1) **Introduction**. Before presenting the prototype, we first introduced the objectives of the focus group. We highlighted that the concept of this tool came from needs collected with a survey and preliminary discussions with colleagues. We also explained that during the focus group, all points of view would be welcomed, and participants were free to comment.
2) **Prototype presentation**. The second step of the focus group was to present the four different functions that we designed. We presented the mockups to help the participants better understand the functions.
3) **Questions**. To drive the discussions, we presented four questions related to the usability and accessibility of the prototype:

a) What do you think about this remote graphics-based teaching prototype (pros and cons of the prototype and its envisioned functions)?

b) Do you have comments about the general use of this tool?

c) Do you think the proposed tool would be easy to use?

d) Can you imagine interesting remote teaching scenarios based on this tool?

We recorded and saved the discussion in accordance with local data protection regulations. After the focus group, we transcribed the verbatims and identified recurrent comments. The identification procedure was conducted by two coders and based on an open coding method (see [18]). In addition, when facing uncertainty or contradictory comments, a third opinion was requested to reach a consensus. After all the codes (i.e., short comments) were produced, they were discussed among all authors. The aim of the discussion was to synthesize them into higher-level themes.

6.5 Outcomes of the focus group

Regarding the interest of the tool, participants expressed positive feedback. They mentioned that it can allow pupils to build a mental representation of the graphics. However, they mentioned that it should be used in combination with a raised-line graphic (tactile overlay), as one of its downfalls is the lack of tactile cues. Overall, they felt the prototype would be useful for remote teaching, as well as for co-located teaching.

Regarding the annotation function, participants confirmed the importance of allowing teachers to make and share annotations. This function should be available for both the teacher and the remote pupil, as it can be used for noting down things and improving memorization. The annotations should be available as text or audio. Finally, it is important that these annotations can be saved for later reading.

Regarding the navigation function, some of the participants indicated that it could be useful for large graphics or to explore multiple layers of information. However, they were worried that it could be difficult to tackle by remote pupils. They insisted on the importance of audio feedback when using this function.

The hand movement tracking function was judged as mandatory to make sure that the pupils correctly explore the graphics and understand the instructions.

Overall, the first focus group unveiled six important points:

a) For most of participants, the tool is interesting for remote teaching but also for co-located teaching: "*I am not a student, but I find it is really very interesting and personally as a user, I would like to have access to such a device*" (P3).

b) It should be combined with raised-line overlays: "*tactile exploration without raised-line graphics needs a learning phase*" (P2); "*it would be difficult to use without raised lines by a student that does not have a good mental representation*" (P1); "*without raised lines, this is a tool that cannot be used in first intention*" (P3). Although they agreed that using digital graphics could simplify the logistics (no need to prepare, print and send the raised-line graphics), they still thought that exploring digital content without tactile cues [43] may lead to cognitive issues for pupils with VI and thus impairs learning: "*I agree with ** (i.e. name of P3), I think it would still need a relief support, perhaps right beside, it would allow you to refer tactile markers during exploration on the tablet*" (P6).

c) The annotation function is necessary and should be enabled for both teachers and pupils with VI: "*it can enable us to put a lot of information on a given point or area*" (P4).

d) The navigation function should not be integrated in the tool at this stage. Although this function can support more complex teaching tasks, it is not mandatory and may lead to accessibility issues for pupils with VI (as indicated in [11]): "*if there are scale changes, the student must have the information about the current scale. You know, scale changing is difficult*" (P2). Moreover, participants emphasized the importance of leveraging existing system gestures for conducting navigation: "*why reinvent gestures? There are already gestures in Android, why don't you use them?*" (P5).

e) The hand movement tracking function is mandatory.

f) In addition to the teaching tool, special education teachers raised the question about how to prepare the interactive graphics.

To sum up, the first focus group confirmed the utility for a graphic based teaching tool with basic important features related to a simple and adapted use, as well as a high-level control of the session by the teacher. However, participants raised the important issue of providing tactile feedback for the students.

7 SECOND LOW-FIDELITY PROTOTYPE: A REMOTE GRAPHIC-BASED TEACHING TOOL WITH A TACTILE OVERLAY AND AUTHORING SOFTWARE

Based on the comments from the first focus group, we enhanced the concept of our graphic-based teaching tool with a tactile overlay (i.e. raised-line graphic, Figure 7) placed over a touchscreen similar to what has been presented in previous works [6]. Then we developed a conceptual device based on two software: an authoring software used to prepare the interactive graphics (audio and vibratory feedback on the drawing), and a reader installed on a touch sensitive screen (laptop or tablet). We prepared a presentation and videos to show how the whole device can be used.

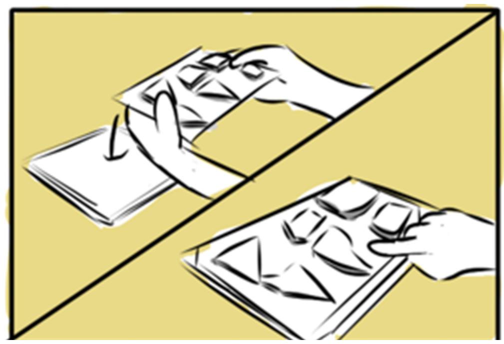

Fig. 7. The second prototype was based on adding a tactile overlay over the touch surface.

Table 2. Demographic information of the second focus group participants

Participant	Age	Profession	Description	Year of special education
P1	36	Special education teacher	Female	7
P2	58	O&M instructor	Male, VI adults	32
P3	44	O&M instructor	Female	18
P4	42	Special education teacher	Female, VI adults	17
P5	51	Special education teacher	Female	26
P6	31	Special education teacher	Female	5

8 SECOND FOCUS GROUP: USAGES AND ENVISIONED ISSUES

We organized the second focus group with O&M instructors and special education teachers. The aim of this discussion was to focus on the potential usages of the device (who, where, and how) in a real setting (e.g. remote teaching during the pandemic), as well as potential usability issues.

8.1 Participants

The focus group was conducted with 4 special education teachers and 2 O&M instructors that did not take part in the previous steps. The average age of the participants was 43.67 (SD: 9.81). Table 2 summaries the demographic information of the participants.

Although among four special education teachers, we included two special education teachers who work with VI adults only due to difficulties in recruitment, the results of our focus group would not be greatly influenced. This is because: 1) there is limited difference between VI pupils and adults in terms of usage of our remote graphic-based teaching tool. The main difference will be the accompanied teaching documents corresponding to the educational level of people with VI; 2) during the focus group, other two special education teachers who had many experiences in working with pupils with VI can help teachers who only have experiences with VI adults to transfer their needs as well as suggestions to the design considerations of a tool for pupils with VI.

8.2 Focus group preparation

We used Zoom as the communication tool. To present the device and its functions, we used a PowerPoint presentation and videos. In addition, we used Padlet as the online brainstorming tool for collecting the comments from participants. Padlet allows for online voting too, which we used to quickly rank the collected comments.

8.3 Procedure

Like the previous focus group, we first introduced the objectives and gave participants a brief introduction of our ongoing study. Then we showed the presentation and videos that we prepared. Slides and videos showed the aim and the usage of the prototype, including: 1) the preparation of an instructional sequence with the authoring tool. This step included the preparation of the raised-line graphic on a microcapsule paper; and 2) the usage of the remote teaching tool with the three main functions that were acknowledged in the first focus group (remote control of the graphic, shared annotations, remote hand movements tracking,). As suggested, the navigation function was not included in this device.

For the discussions, we split the six participants into two groups. Each group was assigned to one experimenter from our research group to drive the discussion and to answer possible questions. After a 40 minutes discussion around several questions (see below), everyone was gathered in the same channel to discuss their answers and ideas. Finally, we organized an online vote to rank the best ideas. In terms of data analysis, we adopted the same procedure as in the first focus group.

8.4 Questions

We organized the group discussions using seven questions covering different aspects of the usage of the prototype for teaching activities:

a) Who would use this tool? A teacher (you) with a single pupil with VI or with many pupils with VI? May it also be used among pupils with VI? How old are the pupils likely to use it?

b) Where would the pupils be? In the classroom or at home? And the teacher (you), where would you be (classroom or elsewhere)?

c) When would you use this tool? Only during the lockdown period or any time when there is a need for remote teaching (for example when teachers or pupils have mobility issues).

d) Which device would the teacher (you) use (PC, tablet, smartphone, or anything else)? Which device would the pupils use?

e) Which scenarios would the teacher (you) use the prototype for? Would the content and interactions be prepared in advance or during the class?

f) In your opinion, what would be the main advantage of using this tool for remote graphic-based teaching? Why?

g) In your opinion, what would be the main difficulties in using this tool for remote graphic-based teaching? Why?

8.5 Outcomes of the focus group

This focus group lasted two hours and was completely recorded. We transcribed the verbatim of the participants and the Padlet notes. We report our observations and analysis of the verbatim below.

1) **Who can this tool be useful for?** The participants confirmed that this tool can be useful for pupils with VI. However, they also stressed the need for prerequisite skills or knowledge. They mentioned mandatory skills related to the use of digital tools as well as knowledge on raised-line graphic exploration, especially for younger learners: "*for young children, we can imagine some games based on objects association*" (P6); "*this could be useful but only for a child with a previous knowledge about spatial vocabulary and who doesn't need hand guidance during tactile exploration*" (P2). To address this concern, participants discussed that there is a need to develop solutions to compensate the lack of specific skills: one interesting solution that they mentioned was to involve parents in the learning activity. Since the tool targets remote teaching, parents of the pupils may help the pupils during their first experience with the tool: "*it can counterbalance the difficulties of a child who cannot explore with the necessary spatial vocabulary when their parents could come to support and*

explain" (P3); "*I have students who have a good learning level, when they need to understand a route and we can have their parents who can help them*" (P2). Another proposed solution was to design learning contents that are obviously adapted to the educational level but to the remote teaching situation too (i.e. adding specific instructions). Both teachers and O&M instructors mentioned that the tool could be used for both individual and group teaching. However, they do not think that the tool can be used in a collaborative task with pupils with VI only. They agreed that the tool would be helpful for pupils with VI of all ages: "*of course it would be useful for teachers but also parent with young children, especially when having fun applications*" (P3); "*without doubts not for psychologist or orthoptists*" (P1).

2) **What type of teaching (when) can this tool be useful for?** One shared point of view was that the tool can be useful for teaching the instructional activities (STEM) but also for teaching additional skills (Compensatory, Independent Living, Orientation and Mobility). Regarding the location, participants mentioned that although this tool is designed for remote usage, it can be used in regular face-to-face lessons too: "*I would imagine this device to support a virtual visit of a museum, we could discover the works by touch*" (P5); "*I can also think of a use case in a sports context… it might help to understand the configuration of a ski run*" (P2).

3) **What are the most appropriate teaching scenarios with this tool?** As mentioned previously, the tool can be used for all instructional activities, but the discussion focused on the activities of the two represented professions. For instance, the teachers mentioned that it could be used for homework in order to reinforce previous face-to-face lessons: "*for example, I leave my students several maps and let them use these interactive buttons*" (P1). In this perspective, the annotation function is particularly interesting as it can serve as an additional channel for discussion and questions between the teacher and the pupil. The O&M instructors further discussed remote O&M lessons with the tool. For instance, they can use the tool to get the pupils prepared for a specific journey with the localization of landmarks along the walk: "*at home, the students can exercise to replace all the points on the journey learned from their instructors*" (P2). All the participants agreed that the choice of the device (tablet or computer) should be made according to the user, task and context. For instance, most of them (5 in 6 participants) agreed that for pupils with VI, using a 10 inches tablet would be a good choice.

4) **Advantages of the tool.** Beyond the variety of the activities that are supported by the tool, the participants raised that the tool could foster participation and inclusion. They mentioned that the tool would be valuable when remote teaching becomes mandatory (e.g. during the lockdown periods). Interestingly, they also mentioned that the tool would foster the commitment of the families. Indeed, they explained that the parents of pupils with VI are not involved enough in the relation with the special education center, mainly because of the lack of appropriate tools. Participants also mentioned that the use of the tool can be also extended to non-lockdown tasks: "*travel takes time and we think that even outside of lockdown, we could add remote sessions for requesting students to do exercises remotely*" (P4). Finally, the tactile overlay was also recognized as an advantage of the tool: "*I have a second-year student and when I work with him on a math exercise over the phone, I have to tell him, 'imagine an orthonormal frame with points…', because I can't give him the relief and I think that your tool would be very useful*" (P1).

5) **Potential issues.** The participants discussed many potential issues regarding the use of the tool. First, they wondered how to provide the pupils with raised-line graphics if they are not in a face-to-face setting. The possibility of adding interactive contents to the graphic without modifying the raised-line overlay raised questions too. More broadly, the importance of face-to-face sessions between teachers and pupils with special needs was also addressed. The participants also discussed instructional considerations: some of them pointed out that the tool can facilitate independence, but others thought it could only be the case for pupils having preliminary skills and knowledge.

They almost agreed that the first use of the tool should occur during face-to-face lessons. Finally, although some participants thought the tool could save time in their teaching, others questioned the amount of time required for preparation.

To sum up, the second focus group helped to identify different tasks and contexts where the tool can be used. Two scenarios related to either O&M teaching or primary school teaching were further discussed as application scenarios, which we decided to further explore with two specific homogeneous focus groups. In addition, important comments were made about: i) providing the home-based pupils with raised-line overlays, and ii) mandatory face-to-face sessions before remote sessions.

9 THIRD AND FOURTH FOCUS GROUP: USAGE SCENARIOS

In preparation of these two homogeneous focus groups, we have specified the two scenarios (O&M lesson with the map of the school building, and a history lesson with a geographic map). In order to raise pros and cons of the tool, we also designed three different remote tasks (a driven graphic exploration, a synchronous lesson, and an asynchronous lesson). In addition, we prepared questions for the participants to think about how they would lead the remote teaching activity (which interactions to use and how to lead the session).

9.1 Third focus group: O&M scenario

1) **Scenario:** We asked instructors to assist a pupil with VI to learn the map of the school building before the beginning of the schooling year (see Figure 8 left). Usually, this task is done by exploring a raised-line map during a face-to-face session. The scenarios include a synchronous session with the O&M instructor being online, and an asynchronous session with the O&M instructor being offline.
2) **Participants:** In this focus group, we recruited two O&M instructors (2 females aged 35 and 48) from a local special education center.
3) **Procedure:** We followed a similar procedure as before, which consisted of three steps: (1) present the aims of the focus group; (2) present the prototype using slides; (3) present the application scenario using slides. The focus group was ended by a free discussion around the prepared questions. The focus group lasted 80 minutes. For data analysis, we followed the same procedure as in the previous focus groups.
4) **Outcomes:**

a) **Scenario design/planning:** the participants agreed that they prefer a progressive exploration of the map: "*to overcome the problem posed by the fact of planning everything before a session, we could play on different layers to change the interactions*" (P1). To do this, they want to leverage on multiple interactive layers to gradually increase the complexity of the graphic and attached interactions. Hence, they can activate the layers gradually during the exploration of the map. Then, they proposed to design tasks based on learning different routes to navigate the building. They also wanted to design exercises on finding specific locations in the building (e.g., restroom) or route identification between two landmarks (e.g., from the dining hall to a classroom): "*we can do reinforcement, if he has to go to the psychomotor room on Monday, we ask him to make the trip and when he gets there, we have a cheering sound or applause*" (P1). They emphasized the importance of asking the pupils to describe the routes being learned during the exercises (verbal communication). In addition, instructors mentioned that keeping track of the hand movements would be useful to them: "*yes it is important to be able to follow the student's fingers. I saw that when we did test in the past*" (P2). They can replay the session in order to understand the pupil's errors and explain learning difficulties. Finally, the instructors mentioned that the asynchronous task is not relevant for them because they always conduct their lessons during face-to-face sessions.

b) **Which interactions?** O&M instructors are used to leverage tactile maps but not interactive maps. They considered the interactions on the maps as a mean to reinforce spatial learning with multimodality. For instance, they mentioned that audio feedback may be used to reinforce spatial learning (e.g. associate different sounds to different rooms in the building), and that the vibratory feedback could be used to indicate dangerous places (e.g., stairs): "*we could use different sounds depending on the type of room*" (P2); "*vibrations are good for alerts*" (P1). They mentioned that the design of the sound and vibratory feedback could be inspired by existing electronic canes: "*it's like with the electronic cane*" (P2); "*for danger zones such as stairs, vibrations could be used*" (P1).

c) **How to lead the session?** O&M instructors preferred having a direct access to functions (e.g., activate or deactivate an interaction) with buttons on the interface rather than using menus: "*if the children is asked to find the rehabilitation rooms, each time he finds one and double-clicks, an annotation can be added*" (P2). They also indicated that it is essential to be able to restrain the use of annotations by the pupils. They proposed to design three modes: i) the pupil cannot add annotations; ii) the pupil can locate an annotation (finger location), but only the instructor can manage the annotation; iii) the pupil can locate and create the annotation: "*if the children can add and modify the annotations, there is a risk that instead of exploring the plan, they play at putting annotations*" (P2); "*it would be better to take several levels, we can create the annotations depending on the level of the student who could be totally autonomous or guided by the teacher*" (P1). They also mentioned that it is very important for the pupils to be aware about any changes made on the drawing (provide accessible feedback).

Fig. 8. Screenshots of the Zoom meetings for the third focus group with O&M instructors (left), and for the fourth focus group with the special education teachers (right).

9.2 Fourth focus group: Instructional scenario

1) **Scenario:** we asked special education teachers to teach a pupil with VI about the Grand Voyage (i.e. the discovery of America) remotely, using an interactive geographic map (see Figure 8 right).
2) **Participants:** we recruited three special education teachers (3 females) from a local special education institution. Their ages are 28, 33 and 45 respectively.
3) **Procedure:** we used the same procedure except that the scenario was to explore a geographical map during a history class. This focus group lasted 70 minutes. In terms of data analysis, we leveraged the same procedure as the first focus group.
4) **Outcomes:**

a) **Scenario design/planning:** Similar to O&M instructors, special education teachers also preferred a progressive exploration (i.e. gradually adding contents to explore, rather than showing it all at once): "*we could start from a blank map and as the discovery progresses, we could enrich the map with voice information*" (P2). Building upon the proposed scenario, they designed a teaching session dedicated to the exploration of continents and oceans. In their idea, the audio feedback would provide the names of the continents but also spatial relationships between them: "*it would be nice to have sound feedback to locate the continents in relation to each other*" (P1). In terms of exercises, they were open to both synchronous and asynchronous teaching sessions: "*it's interesting that there are parts for autonomous use by students*" (P3). For synchronous exercises, teachers suggested to add external resources, for example links to videos and websites or other local documents. They also considered to include quizzes, which are commonly used exercises. With the device, they can easily imagine asynchronous exercises (homework) to strengthen the learning out of the teaching periods. Homework exercises could be based on quizzes and map annotations: "*the students would keep the same materials during the process but they could evolve and enrich them*" (P1).

b) **Which interactions?** Audio feedback to assist exploration and describe the content of the map was considered as very important: "*audio should be very important, I did this kind of exercise with a map in relief and I spent my time saying where America was, Europe....*" (P3). Multimodality was, once again, mentioned as an efficient method to reinforce learning in pupils with VI. Vibratory feedback has been little mentioned.

c) **How to lead the session?** In contrast to O&M instructors, special education teachers prefer having a menu to lead the session and use the different functions. They also mentioned that annotations made by the pupils themselves would be very useful. However, they said that it would only be appropriate with older pupils that are skilled in technology and tactile exploration. For the same reasons as the instructors, they emphasized the interest of online hand movement tracking, as well as saving the traces for later viewing: "*it would be nice to have a recording of the student's exploration to better understand a posterior what went well or badly*" (P2); "*having the traces would already make it possible to verify that the student actually did the requested exercise and then to understand how he carried out the task*" (P1). They also mentioned that the remote teaching tool could be useful for group teaching with multiple isolated pupils. However, they have some concerns about using the tool with unmotivated pupils: "*it would be very convenient to be able to follow several children remotely at the same time. I have a colleague who was following up with two children during the pandemic, one of the two was at home with Covid, it would have helped him to follow the two children at the same time from a distance. There would be three locations, the school, the student's home and teacher's home*" (P3).

Overall, the five participants involved in the two focus groups were convinced by the remote graphic-based teaching tool and they acknowledged the different functions that were proposed. However, small discrepancies appeared between the two groups that were related to the interface, as well as the usage of feedback and asynchronous homework. Indeed, O&M instructors preferred simple buttons to menus, and focused a bit more on vibratory feedback than teachers. In addition, they found little value in asynchronous exercises while the teachers were enthusiastic about it. These discrepancies correspond to different needs that are easy to address in the tool. In fact, this is more an argument in favor of the tool that can be adapted to different pedagogical needs rather than a usability issue.

10 DISCUSSION

In this section, we first provide an answer to the research questions presented in the introduction and then further discuss the envisioned application scenarios and challenges for adopting a remote graphic-based teaching tool for pupils with VI.

10.1 What are the current practices of special education teachers when giving remote lessons?

Overall, as it appeared in the results of the survey, special education teachers have experienced important difficulties in conducting remote teaching with their pupils with VI. Most teachers focused on keeping contact with pupils with VI, rather than compensating for missing teaching sessions. Although there were differences between different teachers (e.g. some of them focused on sending more documents while others gave more calls), there was no significant changes in terms of using digital tools for remote teaching. This is not surprising since they mention that they do not know of any specific tools for this. For example, regarding the use of graphics, professionals mentioned issues with sharing documents and monitoring student hand movements remotely. Hence, the survey led us to focus on a remote graphic-based teaching tool, which has never been designed before.

10.2 Is a remote graphic-based teaching tool for pupils with VI needed and what are their needs?

We found that existing apps have already been used during remote lessons by special education teachers and pupils with VI, but their main utility was to ensure remote communication. The observation is clear-cut that there are no tools that can assist teachers in remote teaching with graphics, and that there is a need for such a tool. But, we also observed that there are many challenges related to the design and usage of a remote graphic-based teaching tool for pupils with VI. First, it should fit to the needs of the specialized teachers and students with VI, but also address a lot of challenges related to the usability of such a device.

More precisely, the tool should rely on the use of tactile overlays for providing tactile cues, which poses constraints on the logistics and the ergonomics (installation of the overlays by the pupil). However, previous research such as [3] suggested that digital only graphics can be explored and understood with the help of audio and vibratory feedback. We can foresee pros and cons for each of the two uses. We think that the choice should be made according to the contents but also according to the content being displayed but also according to the age and the independence of the students. For instance [3] showed that it is possible to explore and understand complex interactive digital graphics with data spread in different areas in the drawings. It is probably different if it is important to explore the outline of the drawing in order to identify the shape of it (identification of an object for instance). These questions should be addressed in future work.

At the same time, an adapted tool for remote teaching with pupils with VI requires the main functions that are used in regular tools (sharing, control, etc.), but it also requires a very specific function related to remote hand movement monitoring. This feature ensures special education teachers with the ability to drive the tactile exploration behavior during a synchronous session, but also provides them with the ability to explore the overall exploration behavior and identify potential issues (such as an unexplored area) [4, 42]. For remote teaching tools involving people with VI, providing different levels of remote monitoring and control mechanisms is also necessary. More importantly, such tools should consider not only single remote user scenario (i.e. one remote pupil with VI), but also multiple pupils with VI at the same time. Future similar tools thus need to be based on the design outcomes of single user tools and explores the possibility of multi-user remote interaction techniques as well as their technical implementations.

Our results also show that there are different expectations related to this tool between the professionals. Hence the tool should be versatile enough to address these different expectations. However, we concluded that this is not an issue because the different functions that we designed were flexible enough to fit the different needs. For example, the remote control of the drawing enables the teacher to hide and filter different parts of the graphic and associated data according to their own scenarios, task or even pupils.

Finally, the tool should be usable in both synchronous and asynchronous lessons, and with single pupils or pupils in groups. Compared to the synchronous mode, the asynchronous one provides the students with more flexibility and independence to recap on previous lessons. It is a valuable function for teachers to deal with homework too. Overall, as summarized in [2], combining these two modes may improve both teaching and learning.

10.3 What are the envisioned application scenarios?

It is obvious that graphical information becomes more and more pervasive in our daily life based on computers, smartphones and tablets. Ensuring that people with VI are not excluded is a top priority challenge. Hence specific tools must be designed to provide access to graphics, but tools must also be designed to provide assistance in teaching with graphics. Regular video-conferencing tools cannot provide suan an assistance. Our study showed that a graphic-based teaching tool can be used in instructional activities based on maps, schemas and drawings (STEM) but also in teaching additional skills (Compensatory, Independent Living, Orientation and Mobility). In fact, we may also think about remote gaming applications, which were quickly mentioned during one of the focus groups. In addition, such a tool may support both face-to-face and group usages, which is another advantage, but an additional challenge in terms of design too.

10.4 Novelty of the proposed remote graphic-based teaching tool

It has been suggested that visualization is important for learning [35]. But for a student with visual impairments, it may be a particular challenge because he cannot see the illustration. Raised-line graphics [31] and interactive raised-line graphics [7] have been functional solutions to address this issue. But then one important question emerges: how to combine this solution with remote teaching? Two studies on the accessibility of e-learning materials showed that e-learning has the potential to facilitate the inclusion of students with visual impairments in classrooms [12], but this paper also mentions that "*the participants who were blind also indicated that their technology needs were not especially well met in the following situations: when taking distance education courses, . . . , and when their instructors used e-learning materials.*" Our study was built-up on these observations and aimed to design a device that can address the issues of remote learning based on graphics.

As mentioned in the Related Work section, accessible remote learning tools are still rare. Among a few research papers, Manshad and colleagues proposed a prototype of a tangible collaborative distance learning environment via a set of Trackable Interactive Multi-modal Manipulatives [21], that is designed to enable distance collaboration. This promising system, based on the manipulation of tangibles, would allow to work on mathematical graphs. Another recent work focused on making math graphs more accessible in remote education by providing sonification with non-speech sound [27].

Although all these devices are promising, they have important limitations since the tactile exploration of the graph is limited to one or a few points of contact only, which is not equivalent to a bimanual exploration of a graphic [9]. In our case, the device is based on the presence of a raised-line drawing which has the advantage of relying on practices used during face-to-face classes with specialized teachers. Hence, our device can augment the usual practices with remote teaching functions, including additional annotations and saving functions, which can be useful to teachers and students. Interestingly, this tool is not based on non-available research devices but on marketed PC and tablets, and regular tactile overlays.

Regarding the generalization of the results of this study, it seems that our system can be useful and usable for different contents and different students. Indeed, it was designed to provide basic functions that allow a teacher to work remotely on a graphic with a student, independently of the content, instructional aim, age and expertise of the student. Obviously, it would be necessary to verify this proposal by testing the system with different contents and different grade levels.

10.5 Next design iteration?

The survey showed that the professionals rely a lot on smartphones but less on computers, which can motivate the next design iteration of the remote graphic-based tool. Indeed, we could imagine an Android or iOS version of the tool specifically designed for the teachers, based on a small and restricted display but keeping the monitoring functions. This application would be a relevant complementary tool, and once the contents have been prepared on a personal computer, teachers could manage online sessions with the students and monitor their exploration progress thanks to the session logs recorded by the students.

11 LIMITATIONS AND FUTURE WORK

The limited number of participants in the focus groups may lead to an over-interpretation of some opinions and limit the external validity of the results. We want to stress that the scarcity [1] and commitment – especially during the COVID period – of specialists in the field of visual impairment made it difficult to recruit more people or to keep the same participants in each session. This is a well-known problem in accessibility research as underlined in [8]: "*beyond the recruitment of PVI in general, finding participants with a specific expertise is very difficult*". Hence, being able to recruit seventeen participants for our study was already notable and eventually not an issue. Indeed, previous research suggested that an appropriate number of participants in online focus group should not be too large (e.g., six people) [32]. Having more participants could make the online focus group difficult to run and would limit the qualitative feedback that we could gather from each participant.

However, more importantly, we were based on the initial design of the prototype that seemed obvious and needed to the community, which was confirmed by the two professions most concerned by the remote teaching tool (O&M instructors and special education teachers). In our experimental design, we first organized two focus groups (including these two populations), which allowed us to confirm that the remote teaching tool would be useful and usable under certain conditions, regardless of the profession, the teaching context, and the instructional aim. No major disagreements emerged during the first two heterogeneous focus groups. The last two focus groups were homogeneous (only one profession involved). They were specific to the practices of each profession and allowed us to focus more precisely on their teaching context and hence specific needs. Notably, new participants to the focus groups, who were not familiar with the project, were enthusiastic with the solution. Although this experimental design does not fully guarantee the external validity of the results, it takes part on it. Finally, the informal discussions about the intended device that we had with other professionals afterwards seem to confirm the utility and usability of the tool. Anyhow, a future experimental study involving teachers and students in an ecological setting is needed to validate the current results and to bring up usability issues that are specific to the users (age, level of education, tactile and graphic expertise) and context (setting, content, aim of teaching, etc.).

Another limitation of this study is a potential acquiescence bias in the first focus group [15]. Indeed, the Hawthorn effect shows that, during an experiment, participants tend to agree with the views of the experimenter. One of our questions was: "*Do you think the proposed tool would be easy to use?*" This question might lead participants to agree that the tool would be easy to use. However, despite the general positive comments about the tool, participants also highlighted several limitations regarding the lack of tactile cues, the difficulty of using the navigation function, and the lack of audio feedback.

Obviously, there is also limitation comes from technical aspects regarding the development of hardware and software. It seems to us that the challenges related to the hardware are manageable. Indeed, preliminary tests show that one can use touch sensitive monitors and tablets from the market for this type of use [43]. The main problem would be to design a system allowing to place and maintain the tactile overlay over the screen.

We do not see any major difficulty related to the development of software that will be based on standard servers and network communications. According to our ongoing brainstorming, the main challenge would be on the design of the interfaces for both the teacher and the pupil. The teacher interface should be rich and versatile enough to be usable in all the contexts mentioned in the study. Providing access to the different functions in the form of menus or buttons is not too complicated to design. However, managing several students simultaneously would be a real challenge. The design of the student's interface is also a real challenge because it must allow visually impaired users to be autonomous. As mentioned by the professionals, we can foresee usability issues related to pupils age, independence, tactile and computer skills, etc. This becomes particularly complicated if they are young and have associated disorders. All these issues will not be easy to address but solutions can be discussed. First of all, the tool should be used in local face-to-face settings before being used remotely. Second, family and friends may be involved to help the pupils with VI to manage usability issues.

The lack of involvement of pupils with VI to better understand their needs is also one limitation of the current study. However, involving students with VI was not possible during the lockdown, and must be based on the development of a functional system that is more advanced than our low-fidelity prototype. In the future work, it will be necessary to conduct an experimental study with one or more students with different visual abilities to verify the utility and usability of the system, as well as the users (teacher and student) experience.

The last limitation of this study is that we did not conduct further implementation and user evaluation. However, as the technologies used in the designed accessible remote graphic-based tool are commercially available and well known, there is no reason that the tool will be impossible to implement due to hardware limitations. In terms of usability issues, since we did not conduct user studies, we cannot give a definite answer. However, our whole prototype was based on a series of co-design workshops with special education teachers and O&M instructors, their experiences in special education with pupils with VI can enhance the rationality of the design.

12 CONCLUSION AND FUTURE WORK

We designed a remote graphic-based teaching tool that answers the important challenge of improving remote education for children with visual impairments. It can be used in different contexts and scenarios, according to the needs of different stakeholders. But there are still questions regarding the development of the tool and the usage of the tools in these different contexts. In a future work, we will implement the tool and deploy it in a special education center. The aim will be to address technical issues but also to check that the tool is compatible with the organization of the special education center. We will also address accessibility issues on the pupil side. In addition, we already thought about more specific interactions according to the topics that are addressed (e.g. history, geography, math, etc.). Our aim is to conduct a longitudinal evaluation [8]. In addition, inspired by Zhao et al. [42], who studied the exploration behavior of people with VI exploring raised-line graphics, we would like to provide the teachers with tools to track the exploration hand movements and better understand the pupils' errors. Such a function will rely on a challenging research work but should empower special education teachers with precious tools.

ACKNOWLEDGEMENTS

This research was supported by "The Fundamental Research Funds for the Central Universities (G2022WD01023)" of China. We thank all the special education teachers who participated in the project, as well as the Institut des Jeunes Aveugles, Toulouse, FR and the Cherchons pour Voir laboratory, Toulouse, FR.

A SURVEY QUESTIONS

Lockdown shows us how we were used to working face to face. It also highlights a set of problems that are difficult to solve when we want to do remote teaching with children or adults with visual impairments.

The aim of our study is to know and understand the tools and methods that are used by professionals for people with visual impairments. We will also try to understand how much the lockdown complicates the situation. Finally, we will rely on this analysis to propose new accessible face-to-face or remote tools, which could help professionals to teach students with visual impairments.

The following questionnaire will address three set of questions. First of all, we are going to ask about your usual working methods (before the lockdown). Then, we will ask about how you deal with remote teaching during the lockdown. Finally, we will ask about innovative ideas that you may have to deal with remote teaching.

The tool we use (Framaform: https://framaforms.org/) is a free software. The data collected is not used for any commercial purposes and is hosted in Europe. We will only use the data collected for research purposes: presentation to an academic conference or journal on a non-profit basis.

Within the framework of the General Data Protection Regulation (GDPR) (EU 2016/679) applicable on May 25, 2018 (article 99.2), personal data and associated processing should be explicit and with the consent of the participant. Personal data is the information (digital or not) allowing a person to be identified directly or indirectly. Therefore, if you wish to participate in this study, please provide us with your consent in the box below this text. Please note that in accordance with Articles 15, 16 and 17, you have the right to access, modify and withdraw your consent and your personal data at any time and without any justification.

You can exercise your rights by contacting the person in charge of this study Kaixing Zhao (kaixing.zhao@irit.fr, includes author information, to be completed after acceptance) or the directeor of the laboratory represented by Christophe Jouffrais (christophe.jouffrais@irit.fr, includes author information, to be completed after acceptance).

A.1 First block of questions: general information

Before getting to the core questions, we would like to know a little more about you and the VI people you accompany.

What type of institution do you work at?
- 7 types author's country institutions listed
- Other

1. What is your occupation?
- Specialized educator
- Specialized teacher
- Locomotion instructor
- Psychomotor therapist
- Occupational therapist
- Psychologist
- Transcriber
- Orthoptist
- Ophthalmologist
- Social worker
- Director

- Secretary
- Other (complete)

2. How long have you been working at this institution?

- Less than 1 year
- Between 1 year and 5 years
- Between 5 and 10 years
- Between 10 and 15 years
- More than 15 years

3. What is the average age of the PVI under your charge?

- Drop-down list from 0 to 100 years old

4. Visual status of PVI under your charge?

- Early visual impairment (before age 4)
- Late visual impairment (after age 4)
- Early blindness (before age 4)
- Late blindness (after age 4)
- Don't know

5. Visual abilities of PVI under your charge?

- Can use vision to assist mobility
- Can distinguish colors
- Can distinguish shapes
- Can distinguish brightness
- I do not know

6. Assistance technologies used by PVI under your charge?

- Guide dog
- White cane
- Digital applications on smartphones
- Specific tools (remote controls, others) (specify)
- No specific assistance
- I do not know
- Other (specify)

7. Do they have associated disorders?

- Hearing impairments
- Cognitive impairments
- Communication impairments
- Spatial-temporal impairments
- No associated impairments
- I do not know

A.2 Second block of questions: daily methods and tools to teach students with VI

Now that we know a little more about you, we would like to know more about the tools and methods you use to support people with VI that you accompany, and then we would like to identify problems you may face.

8. You teach?

- Locomotion
- Spatial landmarks
- Time markers
- Sciences (Mathematics, Physics, etc.)
- History-geography

- Writing
- Reading
- Leisure
- Autonomy daily living
- Other

9. How much time do you spend together in each session? (if the duration of the sessions is unequal, propose an average time)
- Less than 30 mins
- Between 30 mins and 1 hour
- Between 1h00 and 1h30
- Between 1h30 and 2h00
- More than 2h00

10. During these activities, are the students in a group?
- Single
- Groups between 2 and 4 people
- Groups between 5 and 8 people
- Groups between 9 and 12 people
- Groups with more than 12 people

11. If in groups, how would you evaluate group working method in general?
- I would prefer to receive them individually
- Not necessary but not problematic
- Really interesting
- Specify:

12. Are you in charge of students with VI in inclusive settings?
- Yes
- No
- I do not know

13. How do you work remotely with the students (prepare an inclusive class lesson for example)?

14. What is your travel frequency?
- Very little: once or twice a month
- Few: once a week
- Often: several times a week
- Very often: several times a day
- Other

15. Do the pupils with VI in inclusive settings work with a sighted attendant (e.g. a sighted student or an assistant)?
- Yes (specify)
- No
- I do not know

16. If yes, how would you evaluate the benefit of the attendant ?
- Not interesting
- Less interesting
- As useful as work between people with VI
- Interesting
- Very interesting

17. Do you use digital tools in your practices?
- Computer
- Tablet

- Smartphone
- None
- Other (specify)

18. How often are these digital tools used?
- Never
- Sometimes (once a week or less)
- Regularly (several times a week)
- Often (once a day)
- Very often (several times a day)

19. Why do you use these digital tools?
- Interactivity
- Sound feedback
- Tactile feedback
- Adaptability
- Ability to customize them
- Other

20. How would you judge the ability of mastering new technologies of students with VI?
- Very bad
- Bad
- General
- Good
- Very good

21. Do families or close friends encourage that you can count for the use of digital technology?
- Yes
- No
- I do not know

22. If families are involved, how would you rate their commitment?
- Provide occasional help
- Steady
- Strongly involved (proposal of tools, regular exchanges, etc.)
- I don't know

A.3 Third block of questions: support for residents during lockdown and use of collaborative tools

The current lockdown situation is disrupting our work habits and our daily lives. We would like to know more about how you have adapted to this situation and how you continue to work and support people with VI, particularly through the use of collaborative tools.

23. Do you work remotely with the students with VI ?
- Yes
- No

24. If not, what is (are) the reason(s)?
- Tools are not suitable
- I do not have sufficient network connection
- My students do not have sufficient network connection
- I cannot provide my teaching remotely
- Other (specify)

25. If you continue, what type of teaching do you provide?
- Locomotion

- Math
- Reading
- Leisure
- Geography
- Spatial landmarks
- Time markers
- Other

26. If you continue, how do you do?

- With one people
- Group between 2 and 4 people
- Group between 5 and 8 people
- Group between 9 and 12 people
- More than 12 people

27. How did you adapt to this situation? (free answer)

A.4 Fourth block of questions: do you want to help us develop new remote teaching tools?

As you have understood, the aim of this questionnaire is to identify your "collaborative" practices and how you face the current lockdown situation, in particular when you teach remotely.

Once the processing of this survey is completed, we would like to share our ideas with professionals in order to validate (or not) their relevance and to propose new remote teaching tools.

If you would like to work on that topic with us and/or be kept informed of the results of this questionnaire, leave us a contact address. If you do not wish to be contacted, you can just validate your answers without giving your address.

In any case, we thank you for the time you took to answer it!

Contact address: example@example.com

I wish:

- be informed of the results (Y/N)
- to participate in the development of new tools (Y/N)

REFERENCES

[1] AILDV. 2022. La locomotion - AILDV. https://www.aildv.fr/la-locomotion/

[2] Flora Amiti. 2020. Synchronous and asynchronous E-learning. *European Journal of Open Education and E-Learning Studies* 5, 2 (2020).

[3] Sandra Bardot, Marcos Serrano, and Christophe Jouffrais. 2016. From Tactile to Virtual: Using a Smartwatch to Improve Spatial Map Exploration for Visually Impaired Users. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Florence, Italy) *(MobileHCI '16)*. Association for Computing Machinery, New York, NY, USA, 100–111. https://doi.org/10.1145/2935334.2935342

[4] Sandra Bardot, Marcos Serrano, Bernard Oriola, and Christophe Jouffrais. 2017. Identifying How Visually Impaired People Explore Raised-Line Diagrams to Improve the Design of Touch Interfaces. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 550–555. https://doi.org/10.1145/3025453.3025582

[5] Concha Batanero, Luis de Marcos, Jaana Holvikivi, José Ramón Hilera, and Salvador Otón. 2019. Effects of New Supportive Technologies for Blind and Deaf Engineering Students in Online Learning. *IEEE Transactions on Education* 62, 4 (2019), 270–277. https://doi.org/10.1109/TE.2019.2899545

[6] Anke Brock and Christophe Jouffrais. 2015. Interactive Audio-Tactile Maps for Visually Impaired People. *SIGACCESS Access. Comput.* 113 (nov 2015), 3–12. https://doi.org/10.1145/2850440.2850441

[7] Anke Brock, Samuel Lebaz, Bernard Oriola, Delphine Picard, Christophe Jouffrais, and Philippe Truillet. 2012. Kin'touch: Understanding How Visually Impaired People Explore Tactile Maps. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI EA '12)*. Association for Computing Machinery, New York, NY, USA, 2471–2476. https://doi.org/10.1145/2212776.2223821

[8] Emeline Brulé, Brianna J. Tomlinson, Oussama Metatla, Christophe Jouffrais, and Marcos Serrano. 2020. Review of Quantitative Empirical Evaluations of Technology for People with Visual Impairments. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376749

[9] Julie Ducasse. 2017. *Tabletop tangible maps and diagrams for visually impaired users.* Ph. D. Dissertation. Université Paul Sabatier-Toulouse III.

[10] Julie Ducasse, Anke M Brock, and Christophe Jouffrais. 2018. Accessible interactive maps for visually impaired users. In *Mobility of visually impaired people*. Springer, 537–584.

[11] Julie Ducasse, Marc Macé, Bernard Oriola, and Christophe Jouffrais. 2018. BotMap: Non-Visual Panning and Zooming with an Actuated Tabletop Tangible Interface. *ACM Trans. Comput.-Hum. Interact.* 25, 4, Article 24 (sep 2018), 42 pages. https://doi.org/10.1145/3204460

[12] Catherine S Fichten, Jennison V Asuncion, Maria Barile, Vittoria Ferraro, and Joan Wolforth. 2009. Accessibility of e-learning and computer and information technologies for students with visual impairments in postsecondary education. *Journal of visual impairment & blindness* 103, 9 (2009), 543–557.

[13] Cole Gleason, Stephanie Valencia, Lynn Kirabo, Jason Wu, Anhong Guo, Elizabeth Jeanne Carter, Jeffrey Bigham, Cynthia Bennett, and Amy Pavel. 2020. Disability and the COVID-19 Pandemic: Using Twitter to Understand Accessibility during Rapid Societal Transition. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility* (Virtual Event, Greece) *(ASSETS '20)*. Association for Computing Machinery, New York, NY, USA, Article 5, 14 pages. https://doi.org/10.1145/3373625.3417023

[14] Svetlana Kurbakova, Zlata Volkova, and Alexander Kurbakov. 2020. Virtual Learning and Educational Environment: New Opportunities and Challenges under the COVID-19 Pandemic. In *2020 The 4th International Conference on Education and Multimedia Technology* (Kyoto, Japan) *(ICEMT 2020)*. Association for Computing Machinery, New York, NY, USA, 167–171. https://doi.org/10.1145/3416797.3416838

[15] Ozan Kuru and Josh Pasek. 2016. Improving social media measurement in surveys: Avoiding acquiescence bias in Facebook research. *Computers in Human Behavior* 57 (2016), 82–92.

[16] Caroline Lawless. 2018. What is e-learning. https://www.learnupon.com/blog/what-is-elearning/

[17] Cheuk Yin Phipson Lee, Zhuohao Zhang, Jaylin Herskovitz, JooYoung Seo, and Anhong Guo. 2021. CollabAlly: Accessible Collaboration Awareness in Document Editing. In *The 23rd International ACM SIGACCESS Conference on Computers and Accessibility* (Virtual Event, USA) *(ASSETS '21)*. Association for Computing Machinery, New York, NY, USA, Article 55, 4 pages. https://doi.org/10.1145/3441852.3476562

[18] Guanhong Liu, Xianghua Ding, Chun Yu, Lan Gao, Xingyu Chi, and Yuanchun Shi. 2019. "I Bought This for Me to Look More Ordinary": A Study of Blind People Doing Online Shopping. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3290605.3300602

[19] Emily Long, Sruti Vijaykumar, Serena Gyi, and Foad Hamidi. 2021. Rapid transitions: experiences with accessibility and special education during the COVID-19 crisis. *Frontiers in Computer Science* 2 (2021), 617006.

[20] Nathapong Luephattanasuk, Atiwong Suchato, and Proadpran Punyabukkana. 2011. Accessible QTI Presentation for Web-Based e-Learning. In *Proceedings of the International Cross-Disciplinary Conference on Web Accessibility* (Hyderabad, Andhra Pradesh, India) *(W4A '11)*. Association for Computing Machinery, New York, NY, USA, Article 26, 4 pages. https://doi.org/10.1145/1969289.1969323

[21] Muhanad S. Manshad, Enrico Pontelli, and Shakir J. Manshad. 2013. Exploring Tangible Collaborative Distance Learning Environments for the Blind and Visually Impaired. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (Paris, France) *(CHI EA '13)*. Association for Computing Machinery, New York, NY, USA, 55–60. https://doi.org/10.1145/2468356.2468367

[22] Giuseppe Melfi, Karin Müller, Thorsten Schwarz, Gerhard Jaworek, and Rainer Stiefelhagen. 2020. Understanding What You Feel: A Mobile Audio-Tactile System for Graphics Used at Schools with Students with Visual Impairment. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3313831.3376508

[23] Oussama Metatla, Sandra Bardot, Clare Cullen, Marcos Serrano, and Christophe Jouffrais. 2020. Robots for Inclusive Play: Co-Designing an Educational Game With Visually Impaired and Sighted Children. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376270

[24] Oussama Metatla, Anja Thieme, Emeline Brulé, Cynthia Bennett, Marcos Serrano, and Christophe Jouffrais. 2018. Toward Classroom Experiences Inclusive of Students with Disabilities. *Interactions* 26, 1 (dec 2018), 40–45. https://doi.org/10.1145/3289485

[25] Scott F Midkiff and Luiz A DaSilva. 2000. Leveraging the web for synchronous versus asynchronous distance learning. In *International Conference on Engineering Education*, Vol. 2000. Citeseer, 14–18.

[26] Zethembe Mseleku. 2020. A literature review of E-learning and E-teaching in the era of Covid-19 pandemic. *SAGE* 57, 52 (2020), 588–597.

[27] Keita Ohshiro, Amy Hurst, and Luke DuBois. 2021. Making Math Graphs More Accessible in Remote Learning: Using Sonification to Introduce Discontinuity in Calculus. In *The 23rd International ACM SIGACCESS Conference on Computers and Accessibility* (Virtual Event, USA) *(ASSETS '21)*. Association for Computing Machinery, New York, NY, USA, Article 77, 4 pages. https://doi.org/10.1145/3441852.3476533

[28] Phuong Pham and Jingtao Wang. 2015. AttentiveLearner: improving mobile MOOC learning via implicit heart rate tracking. In *International conference on artificial intelligence in education*. Springer, 367–376.

[29] Phuong Pham and Jingtao Wang. 2017. AttentiveLearner 2: a multimodal approach for improving MOOC learning on mobile devices. In *International Conference on Artificial Intelligence in Education*. Springer, 561–564.

[30] Phuong Pham and Jingtao Wang. 2018. Adaptive Review for Mobile MOOC Learning via Multimodal Physiological Signal Sensing - A Longitudinal Study. In *Proceedings of the 20th ACM International Conference on Multimodal Interaction* (Boulder, CO, USA) *(ICMI '18)*. Association for Computing Machinery, New York, NY, USA, 63–72. https://doi.org/10.1145/3242969.3243002

[31] Thomas Poon and Ronit Ovadia. 2008. Using tactile learning aids for students with visual impairments in a first-semester organic chemistry course. *Journal of Chemical Education* 85, 2 (2008), 240.

[32] Douglas J Rupert, Jon A Poehlman, Jennifer J Hayes, Sarah E Ray, and Rebecca R Moultrie. 2017. Virtual versus in-person focus groups: Comparison of costs, recruitment, and participant logistics. *Journal of Medical Internet Research* 19, 3 (2017), e6980.

[33] Shanna Russ and Foad Hamidi. 2021. Online Learning Accessibility during the COVID-19 Pandemic. In *Proceedings of the 18th International Web for All Conference* (Ljubljana, Slovenia) *(W4A '21)*. Association for Computing Machinery, New York, NY, USA, Article 8, 7 pages. https://doi.org/10.1145/3430263.3452445

[34] Sandra Sanchez-Gordon, Juan Estevez, and Sergio Luján-Mora. 2016. Editor for Accessible Images in E-Learning Platforms. In *Proceedings of the 13th International Web for All Conference* (Montreal, Canada) *(W4A '16)*. Association for Computing Machinery, New York, NY, USA, Article 14, 2 pages. https://doi.org/10.1145/2899475.2899513

[35] Melinda Y Small and Mary E Morton. 1983. Research in College Science Teaching: Spatial Visualization Training Improves Performance in Organic Chemistry. *Journal of College Science Teaching* 13, 1 (1983), 41–43.

[36] Abigale Stangl, Meredith Ringel Morris, and Danna Gurari. 2020. "Person, Shoes, Tree. Is the Person Naked?" What People with Vision Impairments Want in Image Descriptions. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376404

[37] Wei Sun, Yunzhi Li, Feng Tian, Xiangmin Fan, and Hongan Wang. 2019. How Presenters Perceive and React to Audience Flow Prediction In-Situ: An Explorative Study of Live Online Lectures. *Proc. ACM Hum.-Comput. Interact.* 3, CSCW, Article 162 (nov 2019), 19 pages. https://doi.org/10.1145/3359264

[38] Antoine Weill-Duflos, Nicholas Ong, Felix Desourdy, Benjamin Delbos, Steve Ding, and Colin Gallacher. 2021. Haply 2diy: An Accessible Haptic Platform Suitable for Remote Learning. In *Proceedings of the 2021 International Conference on Multimodal Interaction* (Montréal, QC, Canada) *(ICMI '21)*. Association for Computing Machinery, New York, NY, USA, 839–840. https://doi.org/10.1145/3462244.3481304

[39] Zikai Alex Wen, Erica Silverstein, Yuhang Zhao, Anjelika Lynne Amog, Katherine Garnett, and Shiri Azenkot. 2020. Teacher Views of Math E-Learning Tools for Students with Specific Learning Disabilities. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility* (Virtual Event, Greece) *(ASSETS '20)*. Association for Computing Machinery, New York, NY, USA, Article 44, 13 pages. https://doi.org/10.1145/3373625.3417029

[40] Wikipedia. 2021. MOOC. https://en.wikipedia.org/wiki/Massive_open_online_course

[41] Jacob O. Wobbrock and Julie A. Kientz. 2016. Research Contributions in Human-Computer Interaction. *Interactions* 23, 3 (apr 2016), 38–44. https://doi.org/10.1145/2907069

[42] Kaixing Zhao, Sandra Bardot, Marcos Serrano, Mathieu Simonnet, Bernard Oriola, and Christophe Jouffrais. 2021. Tactile Fixations: A Behavioral Marker on How People with Visual Impairments Explore Raised-Line Graphics. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 27, 12 pages. https://doi.org/10.1145/3411764.3445578

[43] Kaixing Zhao, Marcos Serrano, Bernard Oriola, and Christophe Jouffrais. 2020. VibHand: On-Hand Vibrotactile Interface Enhancing Non-Visual Exploration of Digital Graphics. *Proc. ACM Hum.-Comput. Interact.* 4, ISS, Article 207 (nov 2020), 19 pages. https://doi.org/10.1145/3427335