Voice User Interfaces in Schools: Co-designing for Inclusion With Visually-Impaired and Sighted Pupils

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ABSTRACT

Voice user interfaces (VUIs) are increasingly popular, particularly in homes. However, little research has investigated their potential in other settings, such as schools. We investigated how VUIs could support inclusive education, particularly for pupils with visual impairments (VIs). We organised focused discussions with educators at a school, with support staff from local authorities and, through bodystorming, with a class of 27 pupils. We then ran a series of co-design workshops with participants with mixed-visual abilities to design an educational VUI application. This provided insights into challenges faced by pupils with VIs in mainstream schools, and opened a space for educators, sighted and visually impaired pupils to reflect on and design for their shared learning experiences through VUIs. We present scenarios, a design space and an example application that show novel ways of using VUIs for inclusive education. We also reflect on co-designing with mixed-visual-ability groups in this space.

CCS CONCEPTS

• **Human-centered computing** → *Participatory design*; *Accessibility design and evaluation methods*; • **Applied computing** → *Collaborative learning*.

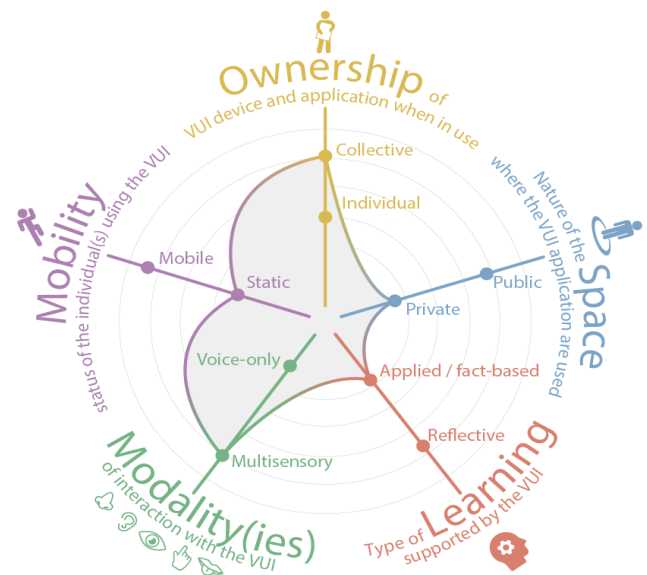Figure 1: A design space for VUIs in inclusive education.

KEYWORDS

Voice User interfaces, Visual Impairment, Education, Inclusion, Co-design.

1 INTRODUCTION

Voice is the primary interaction modality in the resurgent wave of personal assistants devices, such as Amazon Echo and Google Home. These devices are mainly designed for

home settings and provide a voice-user interface (VUI) to allow users to accomplish day-to-day tasks including accessing online content, such as weather information or music playlists, managing shopping, and controlling home appliances. However, while VUIs are increasingly popular in home settings, their potential as a means of interaction in other contexts is less explored. In particular, despite voice being a natural interaction modality for people living with visual impairments (VIs), VUIs support for pupils with and without VIs in mainstream education is yet to be fully investigated.

Children living with VIs are increasingly educated in mainstream rather than special schools [41]. However, despite being included with their sighted peers – a setting we herein refer to as mixed-visual ability classrooms – recent research identified persistent issues with participation [52, 55], reduced opportunities for collaborative learning and social engagement [4, 16] and potential for isolation [30]. These challenges have been attributed in part to the technical support that children with VIs receive in mainstream schools. In particular, assistive learning technologies are often designed to be used by pupils with VIs alone and not by their sighted peers, and can therefore exacerbate the above issues [30].

Voice interaction can offer a common interaction modality for visually impaired and sighted pupils and could enhance inclusive education, but this potential remains untapped. Researchers are only beginning to understand how VUIs are being used by the general population [22, 37], with very little work done on the co-design of voice interactions [12], and much less with people with disabilities [39]. There is therefore a need to explore the potential that voice interaction offers for inclusive education in mainstream school settings. This also provides a strong case to engage both visually impaired and sighted pupils and their educators in co-designing VUIs for inclusive education technologies. This can help in addressing common needs and uncovering potentials that may otherwise be overlooked when working with each group separately.

In this paper, we address exploratory questions around inclusive education of pupils with VIs alongside their sighted peers. In particular, we explore the extent to which off-the-shelf VUIs devices, which are not necessarily designed with accessibility in mind [39], could be used to design support for inclusive education in mainstream school settings, and what forms such support might take. We thus aim to extend current work in this area by focusing on co-designing VUIs in a new context of interaction (mainstream schools), and with a mix of stakeholders (pupils with and without VIs and their educators). We address three key questions: (1) what challenges of inclusive education can VUIs address? (2) What ideas do pupils with mixed visual abilities and their educators have about their shared learning experiences and how VUIs could enhance them? (3) How can we co-design VUIs

with visually impaired and sighted pupils and their educators? To answer these questions, we first held focus group discussions with educators at a mainstream school and with special educational needs (SENs) professionals employed by local authorities in order to understand more about the challenges faced by pupils with VI in mainstream school settings. We also used bodystorming as a method to engage visually impaired and sighted pupils in further discussions and to identify scenarios where technologies, like VUIs, might help. We then engaged a smaller group of participants with mixed visual abilities, including pupils and educators, in a series of co-designing workshops to validate and design a potential VUI application to support one of the identified scenarios: peer revision. We contribute 1) a characterisation of challenges facing pupils with VIs in mainstream schools and how these relate to "voice" as an interaction modality; 2) identification of novel scenarios and a design space of how VUIs could be used to support inclusive education; and (3) reflections on inclusive co-design as well as future work on VUIs for groups with mixed visual abilities. These findings are significant as they provide a basis for designing support for inclusive education through VUIs and extend the design space of VUI application areas beyond home settings.

2 BACKGROUND

We focus on use of voice as an interaction modality, which distinguishes our work from the study of text-based conversational agents and other aspects of voice-enabled technology, such as speech recognition and artificial intelligence. We thus present related work in the areas of voice user interfaces, accessibility, inclusive education and co-design, as the primary domains in which we aim to extend prior work.

Voice User Interfaces

The ability to have authentic communication between people and machines is a long standing objective of both research and industry. Technologies that facilitate this communication have been referred to as virtual or intelligent personal assistants [10, 39], conversation agents [3, 27] or voice user interfaces [37]. All have in common that they help people complete tasks relevant to their everyday activities. Focusing specifically on voice as an interaction modality, research on VUIs has been regaining ground in HCI, and across a variety of domains, from supporting interactions in smart homes [33] to providing companionship to elderly people [40, 51]. However, researchers are only beginning to understand how VUIs are being used by the general population. For example, Porcheron et al. [37] recently showed the subtleties of embedding VUIs in routine everyday interactions and highlighted collaborative activities around the use of voice in terms of invocation and handling responses from a voice-enabled device. Purington et al. [40] noted that voice assistants are not

only used for accessing information or entertainment, but also as a companion for the users. As contexts and applications areas of VUIs broaden, a recent panel on the design of voice assistants recommended that the HCI community should continue to strive to understand and enhance this technology across a wider range of domains [20], which we aim to do in the present work.

Voice User Interfaces and Accessibility

Voice interactions occupies a significant place within research on how systems could be developed to improve the lives of people with disabilities. This typically takes the form of speech-based screen-reader display for people with visual impairments [48] or as an alternative to keyboard text-entry through voice dictation for people with motor impairments [53], as well as for speech therapy [36]. Assessing the acceptability of a smart home equipped with a VUI by elderly people, Portet et al [38] showed that voice technology has a great potential to ease everyday life for the elderly. More recently, Pradhan et al. [39] interviewed participants with VIs who owned a home-based VUI and found that they experienced difficulties with discovering new functionality, and expressed a desire for richer VUI applications. In contrast with much of this previous work, we seek to explore design ideas and possibilities for VUIs that move beyond accessibility to explore inclusive interaction between people with and without disabilities. We are specifically interested in what design ideas pupils with and without VIs co-construct in relation to how such technology can support inclusive interactions in the context of schools.

VUIs in Schools

While there is research done on potential uses and development of conversational pedagogical AI, including chatbots and Intelligent Tutoring Systems, in education (e.g. [21, 49]), research investigating the potential of VUI devices in schools is much more scarce. There is also anecdotal evidence[1] of use of commercial VUI devices like the Amazon Echo in classrooms, but a robust research base on the actual use of VUI in schools or to support inclusive education is lacking. Moreover, the anecdotal evidence suggests that uses are primarily around classroom organisation or personalised tutoring, not necessarily aimed to address challenges of inclusion or purposefully designed alongside pupils and educators.

Inclusive Education Technologies

Inclusive education refers to the practice of providing a learning environment that allows pupils to experience and embrace diversity, and to schools creating an environment and

employing teaching approaches that enable learners to participate fully in a mainstream setting regardless of their needs [46]. Often cited as a goal by policy makers and educators, inclusion is a challenge to put into practice. One way that schools work towards more inclusive classrooms is through the use of teaching assistants (TAs). The recent move toward inclusive provision has been accompanied by a huge increase in the number of teaching assistants (TAs) working in mainstream schools [11, 44]. However, evidence from recent reviews suggests that TAs rarely receive the necessary support and training they need, and that this can have negative effects on academic progress for pupils with additional support needs [11, 17]. Recent research on mixed-ability classrooms also suggests that inclusive education technologies can alleviate some of the challenges associated with inclusive provision in mainstream schools [16, 30, 32, 50]. The present work extends this body of work in terms of method and participants, combining focus group discussions with bodystorming and inclusive co-design to characterise challenges and conceptualise technological opportunities for the provision of inclusive education.

Inclusive Co-Design

There is growing interest in exploring ways to co-design with and for people living with VIs across a number of domains [6, 24, 29, 31, 42]. For example, to develop support for sensory motor rehabilitation of children with VIs [23], to co-design toys [26], and multisensory educational technologies [7, 30]. Research has also demonstrated that co-designing technology with children with certain SENs is valued for creating meaningful technology as well as for enriching and empowering participants experiences [15]. Many researchers are now actively seeking to involve children with SEN in the design of new educational and assistive technologies (e.g. [25, 30, 54]). However, relatively little research has examined co-designing with both children who are blind or have a VI and their sighted peers. Yet, this is particularly important when aiming to support inclusive education so that the context is more authentically understood [5, 30, 50]. There are also very few examples of research work with children that considers the design of VUIs specifically [12]. We therefore build on and extend this prior work by exploring how we can co-design VUIs with VI and sighted pupils in the context of inclusive mainstream education.

3 FOCUS GROUP DISCUSSIONS

We started investigating the potential of VUIs in inclusive mainstream education with discussions with experts in the education of children with visual impairments. The aim at this stage in the research was to learn about inclusive mainstream schools in general and the challenges facing pupils with VIs and their educators in these environments. We held

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[1]E.g. Media and news reports.

two focus group discussions with experts from two partners; educators and staff at a mainstream school, and staff from the local authorities' sensory support services who are qualified teachers of visual impairments (QTVIs).

Five QTVIs took part in the first focus group discussion session. QTVIs work closely with families and with schools. Each QTVI typically works up to 20 families and follows their children from the onset of visual impairment diagnosis through until they reach the age of 25. QTVIs also work closely with schools to monitor provisions, train school staff and deliver specialised one-to-one teaching to pupils with VIs. At the school, the second focus group discussion included the school's special educational needs coordinator (SENCo), two teaching assistants (TAs) and one science teacher. The school was a state funded secondary school for children aged 11-18, and it has two pupils with VIs, who also later became involved in this research; One pupil was a 15 years old male with very mild light vision, fluent in Braille, an expert user of screen-readers, and uses a white cane as a mobility aid. The other pupil was a 12 years old girl, with an initial diagnosis of degenerative blindness. She still had functional sight at the time of this research, but her sight was expected to gradually degenerate by the time she finished her secondary education. At the time, she was being instructed on reading and writing in Braille and on how to use screen-readers to access computers. Two TAs at the school support both pupils.

We met with QTVIs at their offices, and with school staff at the school premises at a convenient time. Each session lasted for two hours. We started by presenting the overall objectives of the research and described how we, as non-experts in this domain, needed to learn about mainstream school settings its challenges. We asked probing questions along these lines, but then participants drove the discussions as they were describing their work to us and identifying challenges that needed addressing. As topics were raised, we probed for more information and encouraged discussion around the potential of VUIs and other technologies. We audio recorded and transcribed the focus group discussion verbatim. one researcher produced initial codes and labels of data segments. We conducted peer validation throughout the coding process [2], where two researchers met regularly to review and clarify coding and grouping decisions. General themes were then determined through iterative discussions.

Challenges in Mainstream Schools

Discussions focused on the technological support available to pupils with VIs in mainstream schools and on issues related to provisions for and the experience of inclusion. Here, we focus on the most salient challenges as they relate to the current role that voice and voice-enabled technology play in learning experiences.

Pace of learning. Teachers are typically encouraged to keep up the pace of lessons, particularly in secondary education, and this was highlighted as a challenge to pupils with VIs. This challenge is compounded by differences in the ways learning materials are accessed by visually impaired and sighted pupils during lessons. Relying primarily on voice compared to other means of engaging with learning material takes time. A pupil with VI will at times have to listen to screen-reader output through an ear piece or to verbal descriptions provided by a teaching assistant for additional descriptions, e.g. when graphics are involved. Complex concepts require longer descriptions, which means that pupils with VIs face more of a disadvantage in keeping up with the pace of lessons. It was suggested that an introduction of voice interaction and description for everyone at specific points of a lesson may mitigate this disadvantage. However, participants highlighted that voice may not be appropriate for all descriptions. An interesting debate was the extent to which voice description can capture the richness of other typically visual learning materials. For example, a description of war propaganda materials in a history lesson may not capture the richness of visual depiction, which is itself the object of learning. It is therefore important to identify where voice description would be most appropriate as a common modality of learning when addressing the challenge of pace.

Stimulating interest in content. Related to the concern about the extent to which voice description regulates learning pace was the issue of academic stimulation. Participants discussed the impoverishment of sensory stimulation, and consequently academic stimulation, that pupils with VI experience when accessing learning materials through Braille or a screen-reader. Participants referred to the monotone *"robotic voice"*, that *"lacks energy and passion"* when content is read through a screen-reader and to *"boring dots"* when reading through a Braille display. Some teaching assistants mentioned that they sometimes record content and descriptions in their own voice and attempt to incorporate various forms of prosody to make content more interesting and stimulating for the pupil. However, all participants highlighted the laborious nature of this activity, particularly since they often need to review their recordings, and that, given the pace of lesson and frequent last minute changes, it is not always possible to prepare such material in advance. It was suggested that a novel VUI could address this by incorporating prosody and automatically identifying and incorporating content from online resources when planning lessons.

Technological isolation. While providing necessary access to educational content, the use of technologies such as screen-readers, screen magnifiers and Braille displays was highlighted as potentially problematic on a two levels. On a practical level, bulky technology takes too much space, which

means that pupils with VI may end up having to sit by themselves on a table to host all their equipment. Participants highlighted that this also includes handwritten notes, which are sometimes required by all pupils when, for example, revising for exams, and for which pupils with VI would use a big sheet that takes up space. Additionally, the use of voice display through a screen-reader, means that pupils with VI are accessing content through a different medium, often through an ear piece, which compounded with the space issue, could lead to them being isolated in *"a sort of technology bubble"*. On a social level, participants highlighted that, as they grow older, pupils with VI tend to reject assistive technologies and instead use of their own phones or tablets. They explained that relying on their own devices is not ideal but that this is how some pupils with VI may feel more comfortable, for example to stand up and take photos of the board with a phone. How pupils manage how they are perceived by their peers is significant in this case; if a technology solutions is too bulky, which will likely increase the potential of embarrassment, and not wanting to be seen as different, they will reject it. Mentioning technologies such as Amazon Echo, participants pointed out that these could be a means for uniform access to content and note taking, which could reduce the potential of technological isolation and of "standing out" from peers.

Recording and revising from notes. Another challenge associated with recording information in Braille notes or voice recordings, is the organisation and retrieval of such notes, after recording, particularly for the purposes of completing homework or revising for exams. Participants noted that some pupils with VI require specific training on how to take notes and organise them for later retrieval, strategies often supported by their teaching assistants. Interestingly, the participants noted that the issue of developing skills for recording, organising and retrieving notes is relevant to both visually impaired and sighted pupils, and they therefore linked this to the potential for peer revision and collaborative learning. Participants suggested that a VUI could assist with automatic retrieval of content from online resources, allow pupils to organise and navigate their notes quickly through voice commands.

Independent mobility inside and outside of classrooms. Participants discussed issues relating to independent mobility within school premises, e.g. in school corridors or when visiting unfamiliar buildings. Mobility was described as *"a huge issue"* particularly when pupils with VIs transfer to a new school where often they are trained on specific routes. Participants explained that pupils with VIs tend to stick to familiar routes, which can lead to reduced opportunities for social encounters. This could also lead to less independence, especially at social times, e.g. between lessons and at recess. Participants suggested that a VUI could be used to support more effective mobility within school premises by acting as a guide, providing step-by-step instructions on how to navigate unfamiliar areas; or used as information points at fixed locations in the school where both sighted and VI pupils could inquire about e.g. where a particular class is taking place or about the current schedule for a particular room.

4 IN-SCHOOL BODYSTORMING

Having gained professional insights identifying five potential challenging areas facing pupils with VIs in mainstream schools, we next aimed to engage visually impaired and sighted pupils to gain their personal insights and perspectives on their learning experiences. Rather than holding a regular focus group discussion, we opted for organising a bodystorming session with a whole class at the aforementioned school. Bodystorming [8] is a method that allows for the generation of ideas in context and permits immediate feedback for generated ideas and insights, thus it can provide a more accurate understanding of contextual factors [35]. Bodystorming has also been previously shown to be an effective method to engage sighted and visually impaired children in inclusive ideation and co-design, allowing for sharing of perspectives and exposing the diversity of abilities [30]. Here we use bodystorming as an ideation method in the original location of teaching and learning. We planned the bodystorming session in partnership with the drama and science teachers at the aforementioned school. We met twice, discussed the aims and objectives of the session and organised a set of activities to realise them. The drama teacher also embedded their own teaching objectives in the session, in particular, role play and improvisation.

One teacher and a whole class of 27 pupils (13 female, 12-15 years old) including the pupils with VIs mentioned in Section 3 took part in the actual bodystorming session. The teacher taught drama and had 8+ years of teaching experience. The pupils were recruited by their school teachers, and the session was carried out during a normal school day. Ethical clearance was obtained both from the researchers' institution and the school who coordinated distributions of information sheets and consent forms.

Procedure

We gathered in the school's drama studio where the teacher introduced the researchers and described the lesson plan and objectives for the day. This included moving into the science lab where the bodystorming session was to take place, and carrying out three activities: simulating a lesson, sharing and reflecting on non-visual learning aids, and simulating non-visual mobility around school premises. Data collected included transcripts of initial lesson simulation, researchers' notes taken during the resources and mobility simulation,
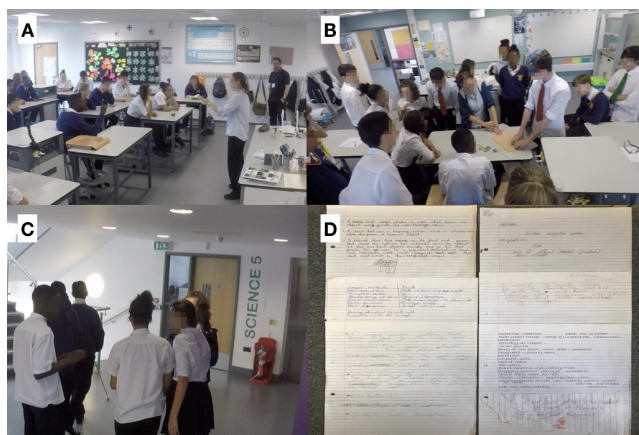
Figure 2: Parts of the bodystorming session; a) simulating a chemistry lesson; b) sharing and reflecting on learning aids; c) simulating non-visual navigation; d) ideas sheets.

and the notes produced by pupils during the small group discussions. Data analysis followed the same process as outlined in Section 3.

Lesson simulation. The drama teacher played the role of a chemistry teacher based on a lesson plan provided by the science teacher. They went through the first 10 minutes of the lesson while encouraging the pupils to consider how they would engage with the lesson's content and classroom space if they had no access to one or more sensory modalities (Figure 2 A). The teacher did this by emphasising her own experience of having an impaired sense of smell. The pupils were asked to interrupt the lesson to highlight a challenge or to discuss an insight. When no pupil interrupted, the teacher picked a pupil randomly and ask them to think about a potential challenge related to that particular moment in the lesson simulation. This part lasted 20 minutes.

Sharing and reflecting on learning aids. The pupils shared, described and reflected on the models and props they use as part of the chemistry lesson. In particular, the pupils gathered around to explore a number of accessibility aids designed by teaching assistants at the school, for accessing some of the materials of the chemistry lesson alongside printouts of graphical aids. Aids included physical and graphical models of molecular structures and diagrams drawn on paper and on plastic embossing film (Figure 2 B). Sighted pupils took turn to explore the artefacts guided by the visually impaired pupils who described how they should be used to make sense of them in the context of the lesson. This was therefore an opportunity for sighted peers to experience an alternative way of making sense of the lesson and of constructing meaning that was possible without vision. This lasted for 15 minutes.

Simulating mobility. We included this part because mobility came up as one of the challenging areas that voice technology could contribute to overcoming during the focus groups discussions. In this activity, a sighted pupil put on a blindfold and partnered with the VI pupil who served as a human guide, offering their elbow for their sighted partner to grasp. A researcher followed from a close distance to observe as well as make sure sighted pupils stayed safe since they had no prior training navigating independently under blindfold. Due to time constraint, only few sighted pupils were guided by the VI pupil, others followed from behind and engaged in conversation, they also switched blindfolds at times (Figure 2 C). The VI pupil walked through a corridor, a staircase, a hall and a recess area, alerting sighted partners to sounds, textures, and spatial cues they use to navigate. This was a further opportunity for sighted peers to experience an alternative way of making sense of space without vision. This part lasted for 20 minutes.

Small Group Discussions. The class then reconvened, pupils were divided into groups, with three to four pupils per group, and asked to think about the experiences they had through the bodystorming activities. They were then asked to imagine, discuss and write down ideas for future technological interventions that could facilitate more inclusive interactions (Figure 2 D). This part lasted for 15 minutes.

Outcomes

Challenges. The pupils identified three broad categories of potential challenges from the bodystorming session: lesson-related graphics, peripheral visuals in the classroom, and "silent hazards" inside and outside the science lab. By *Lesson-related graphics*, pupils referred to depictions used as part of the lesson, such as graphs, diagrams, pictures and animations. By *peripheral visual aids*, they referred to two types of visuals displays around the classroom walls; subject-related content and decorations. For example, there were a number of instances of the periodic table of elements displayed around the class, and which pupils could use as a reference during the lesson, and a number of decorations on the walls, such as DNA models, models of elements, and motivational signs that made the class "more pleasant" but which were only visually accessible. Inside the science lab, *silent hazards* referred to being unaware of the status of lab equipment, e.g. that the gas tap was switched on. In relation to mobility, silent hazards referred to fixed and dynamic signs around the school, which included flyers advertising various ongoing activities, and warning signs, e.g. that the floor is wet. The latter was discussed in terms of both a potential physical hazard – that a pupil could walk into the actual sign – and an "awareness hazard", i.e. being unaware of the hazard that the sign is warning against.

Ideas. The ideas generated from the session can be broadly grouped into two categories: support for individual and group learning activities (e.g. note taking and revising for exams at the school library); and personification and personalisation of interaction. Voice interaction appeared frequently across these two broad categories. These included using voice assistance for note taking, for description and narration of lessons, and for augmenting voice assistance with a form of personality. For example, a voice that encourages students when it detects that a group activity becomes quite, or a voice that "tells off" pupils when it detects that they veered off topic during group work. There were also a number of ideas about embedding voice in wearable personal artefacts, such as wristbands, trousers and shoes. Some pupils suggested combining voice output from a wearable with vibration for notifications in public areas, like the library, and with non-verbal sounds to add aural decorations to the classroom. For example different chemical elements could be played using a different musical instrument or voice to give wall displays the pleasant soundscape of a choir. Pupils also thought that the very activity that we asked them to do at the end of the session; i.e. to work in groups and generate design ideas, could itself be supported by a VUI. For example, they can record an interactive voice presentation similar to a using slides to share their findings with the rest of the class.

5 SCENARIOS OF VUIS IN SCHOOLS

The focus group and bodystorming sessions provided us with many insights about the challenges of inclusive education and suggestions about how voice technology might help address them. We present three scenarios inspired by our engagement with educators and pupils, showing how VUIs may be used in schools to promote inclusive education.

Scenario 1: Peer revision and instruction: Alex, a visually impaired pupil, and his sighted friend Tom are both preparing for a chemistry exam. They agree to meet at the school's Voice Booth to revise together first thing on Monday. At the Voice Booth, Alex and Tom sit at the table with a VUI device in the middle, they invoke a download of material on atomic models from the school's online resources, they go through the material together, asking for a read out of topic headings and summaries. This helps them jointly decide on which topics they felt they revised well for and which they needed to improve on. They ask the VUI to quiz them on the ones they felt confident about. The VUI application generates random questions from the summaries. Alex and Tom answer the questions in turn. In this scenario, there is a dedicated area in the school where pupils can engage with VUIs for the purposes of independent collaborative learning. Voice interaction supports peer revision, making revision materials accessible through playful interaction.

Scenario 2: Classroom activities and pedagogical strategy: Having asked the pupils to organise into small groups, Mrs Green, the science teacher, brings out a set of VUI devices for each group. Their task is to create an audio presentation about carbon cycle, which they have been learning about in the previous two lessons. Each group sits around the table with the device in the middle, and launches the VUI application associated with the subject. First they retrieve information relevant to the topic from the available resources that Mrs Green made available through the application, and then they construct a presentation scenario recorded in the form of a role play interview with the VUI device. At the end of the break out session, each group performs the role playing interview to the rest of the class. As a final activity, Ms Green launches her assistant VUI application for the usual final open discussion, where the pupils can ask any questions they like about today's subject, and the teacher's VUI application answers them. This scenario depicts an inclusive collaborative learning activity; the material for constructing group presentation is aural and therefore allows all pupils to engage in the construction of the presentation on an equal footing. There is also an exploration of different pedagogies and student-teacher relationships, where the teacher observes and gauges understanding and comprehension based on the nature of inquiry that pupils engage in.

Scenario 3: Navigating school premises: Joyce is a visually impaired pupil with a particular passion for debate. She was on her way home when she overheard a group of pupils talking about the special debate event that is about to start; an impromptu event she wasn't aware of. She did not catch where the event was taking place, but she was near one of the school's Voice Information Points (VIPs), so she walked up and asked the VUI device to list today's after-school events. She locates the event in question, realising it is taking place on the other side of the school where she is less familiar with the layout and routes. She asks the VUI at the VIP to generate and transfer step-by-step directions to the VIP App she has installed on her phone. She walks away, launching her VIP guidance, and makes her way to the event. As she does, the VIP App whispers *"don't worry Joyce, still plenty of time for you to make it"*. In this scenario, the pupil is able to access a set of resources about ongoing social events at the school, as well as being able to switch between static voice interaction at the information point and interaction with the mobile version. The VUI application provides navigation assistance as well as additional personalised cues about estimated arrival time.

Initial Design Space and Design Challenges

The scenarios describe three ways that VUIs could be used in schools to help make them more inclusive for VI and

sighted pupils: making small group and whole class activities more engaging; supporting collaborative learning and peer revision; and engendering discovery through independent mobility. They also describe potential support for novel pedagogy and playful and personalised interaction. We can therefore start to envision an initial design space for inclusive education through VUIs that considers whether interactions occur amongst groups or individually, in a public or a private space within the school, and statically or on the move. The design space can also cover different types of learning activities that VUIs would support, e.g. reflective inquiry. The scenarios also point out the need for research to investigate effective voice interactions within these settings. For example, recent research uncovered a mismatch between users expectation and experience with VUIs in terms of system capability and goals [22], and highlighted the importance of accounting for perceived personality of voice agents [9]. These issues are also likely to arise in the context of inclusive education. There is also a need to investigate the extent to which VUIs could be used in acceptable ways inside a classroom, how they may be integrated with and augment ongoing pedagogical practices and used securely in a school.

6 INCLUSIVE CO-DESIGN WORKSHOPS

We next aimed to address our third research question (How can we co-design VUIs with visually impaired and sighted pupils and educators?). To do this, we ran three co-design workshops at the aforementioned school that were two to three weeks apart. We aimed to engage participants in validating a scenario by designing a VUI application that exemplifies it. The workshops took place during a normal school day and so it was not feasible to include everyone who was involved in the previous sessions. Instead, we recruited six participants who we felt reflected the diverse set of perspectives we had encountered so far: a sighted and a visually impaired pupil, the SENCo, two TAs and one teacher. Due to further unexpected work commitments, the teacher and one of the TAs were only present at the initial workshop, and the other TA was only present for the first and second workshops. The pupils and SENCo were present in all workshops. The two pupils were friends, both 15 years old at the time, both male, and both were involved in the bodystorming session. Ethical clearances was obtained from the researchers' institution and the school, which coordinated the distribution of information sheets and consent forms.

Materials

We used an Amazon Echo device in the workshops [2]. We combined low-fidelity prototyping using Lego construction
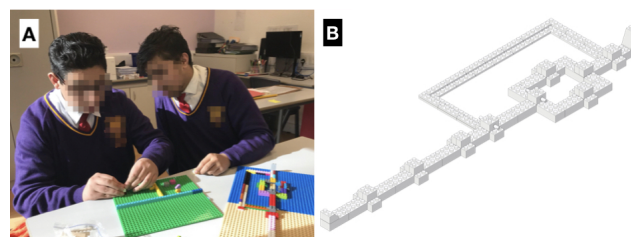
Figure 3: Inclusive co-design activities: A) lo-fi prototyping using Lego construction; B) example of a structure of a VUI.

and Wizard-of-Oz evaluation in initial workshops, with high-fidelity prototyping and real-time coding in later workshops to develop an Alexa Skill application. The design materials thus gradually changed throughout the workshops, which allowed participants to revisit and revise ideas, and to experience imagined voice interaction at a higher level of fidelity. This dual prototyping approach is often recommended when designing with children (e.g. [47]) and is similar to a recent approach by Fitton et al [12], and which was found to be effective for co-designing VUIs with teenagers.

Procedures and Outcomes

Workshop 1: Familiarisation and scenarios. We spent one hour familiarising the participants with voice technology and the Amazon Echo device. We gave an informal aural presentation about voice technology, and demonstrated the capabilities of the Echo device through a number of default and pre-programmed examples, e.g. demonstrating prosody, voice effects, speaker identification, invocations, and voice-based games. We then reflected on possible scenarios of use and encouraged participants to imagine alternatives or modified scenarios from the three scenarios above, with the aim that they choose to focus on one they found compelling.

Outcomes: All participants were familiar with the technology but had not used it before with the exception of the pupil with VI who used Apple Siri extensively. The demonstrations were therefore helpful in providing all participants with hands-on experience with voice technology and the Echo device in particular. At the time of this research, the two pupils were preparing for GCSE examinations and the peer revision scenario appealed to them as they wished to explore ways of revising together at school. Together with their educators, the pupils settled on designing a VUI application to help them revise for their history exam, choosing to design a quiz game as a revision aid. This provided the design brief and focus for the next workshops.

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[2]The main motivation for choosing an Amazon Echo was the price. At the time of this research, the Echo was 25% cheaper than other off-the-shelf devices. Cheaper technology is important in the context of working with

schools, who are more likely to take up novel technologies when these constitute less of a burden on their budgets.

Workshop 2: Lego low-fi prototyping. We spent two hours designing a structure for the revision quiz game and discussing strategies for populating the game with relevant content. In addition to a quiz game, participants indicated that they would prefer an interactive experience that also allows them to construct their own personalised revision materials and to share this with their peers. We used Lego construction to engage participants in conceiving such as a structure, i.e. to combining generating personalised revision materials with an embedded quiz. To do this, we first started by defining how we could use different Lego blocks to represent different components of a VUI application; for example, the start and end of the interaction and significant events such as invocations, as well as basic programming constructs, such as conditionals and loops. We combined Lego blocks with a Wizard-of-Oz display to simulate the behaviour of the VUI. Whenever participants felt that a reasonable portion of the application structure was constructed and wished to test it, a participant traced the blocks with their finger, and a researchers uttered possible corresponding voice output.

Outcomes: There was a strong emphasis on supporting pupils in creating their own revision materials prior to being quizzed by the application. Figure 3 (B) shows an example of a VUI application structure that includes an initial set of states for generating revision materials, followed by an optional loop for a quiz game, and ending with an option for uploading these materials to a repository to be shared with peers[3]. Participants therefore imagined that the VUI application would first allow them to browse an online resource from which they can select a number of "bite-sized summaries" relevant to their choice of topic. They emphasised that they should be able to indicate when they felt ready to be quizzed, at which point the VUI application should generate a set of random questions based on the personalised summaries. By placing emphasis on both generating and sharing personalised revision materials, participants have effectively extended Scenario 1 above in an important way; to allow for both peer revision *and* peer instruction by jointly creating, organising and sharing revision notes.

Workshop 3: Alexa Skill hi-fi prototyping. Participants produced an initial conceptual design of an example VUI application in the previous workshop. Before the third workshop, the research team developed the conceptual design into an Alexa Skill application and brought this to the school. The aim of this third workshop was therefore to present the participants with a materialised version of their design and to

reflect on how we can improve it. We spent two hours engaging participants in hi-fi prototyping of the Alexa Skill application, which we achieved through live coding, modifying the Alexa Skill in response to the feedback. Particular emphasis was placed on the details of the voice interaction aspects of the quiz game - that were otherwise superficially examined through Wizard-of-Oz. Additionally, we also brought to the workshop an additional set of devices and wearables, mainly wristbands, buttons, and tablets, because participants indicated a wish to explore the potential of playing the quiz game on the go as per Scenario 3. In terms of workshop outcomes, participants discussed three themes:

How to engage with Alexa: Participants explored and discussed issues related to invocations, in-game voice commands, as well as navigating the structure of the game Skill application. An invocation of an Alexa Skill is currently typically achieved by uttering the following voice command: *"Alexa, launch [name of Skill]"*. We encountered an immediate accessibility issues with the built-in feedback of the Echo device, which uses light to tell the users whether Alexa has "heard" the trigger word. A sighted user could see the light and understand whether to repeat what was just asked of Alexa or proceed with the rest of the request. To accommodate this need, Amazon includes a system of a "sound on receive" and "sound on complete" options. But this has to be explicitly set up rather than run by default. Following the launch of the desired Skill application, issuing a voice command to, e.g., request a revision question could be achieved using a command of the form: *"Alexa, ask [name of Skill] to ask the next question"*. Participants found this compounded invocation to be cumbersome and awkward during game play, often forgetting the *"Alexa, ask"* part, which led to inappropriate responses from the device. One way around this is to set up Alexa with a continuous listening mode, so that the particular Skill continues to run in the background, and so the aforementioned voice command could be reduced to the form: *"[name of Skill], ask the next question"*. However, we discovered that a continuous listening mode would still be inappropriate for a collaborative learning activity, since pupils are likely to engage in side conversations, which in turn may result in unwanted voice triggers.

Physical and multisensory augmentation: As a work around the above issues, participants suggested augmenting the VUI application with physical controllers. For example, a shared button could be pressed to invoke Alexa or the skill in question, thus breaking commands into a tangible action and a shortened voice commands. They suggested that such physical controllers could also be used to quickly navigate the Skill or the retrieved resources. At this point, the pupils suggested using game console controllers, since most pupils would be both familiar with, and likely proficient at using them. The

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[3]See supplementary materials for details about the Lego language we co-created and the resulting application structure shown in Figure 3 (B).
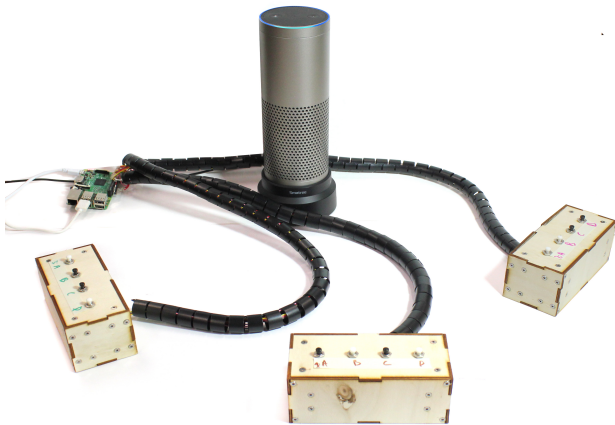
Figure 4: The Voxtopus quiz application: co-designed as an Echo device augmented with physical controllers.

discussion about the introduction of game controllers led us to imagine the quiz part of the VUI application as a set of multiple choice questions (MCQs), with the controllers acting as an input method for supplying answers. But this also led to considerations for using other sensory modalities to augment the VUI application further. For example, participants described how in a joint activity, they may sometimes wish to conceal answers from each other, but at the same time receive feedback or notification about their own answers in non-speech form. They suggested to use vibration on button presses to give early personalised feedback about incorrect MCQ answers. They also imagined an olfactory reward system where correct answers trigger pleasant odours, and deviations from revision, e.g. into tangent discussions, could be detected by the device, which in turn could nudge the pupils by displaying an unpleasant odour that could only be removed by returning to the topic of revision.

Personal and shared space: The final design ideas discussed in the workshop were related to negotiating personal and shared space while interacting with the VUI. The discussions were first triggered by our suggestion to use a wearable device, like a wristband to hail Alexa, hence avoiding the cumbersome form of voice commands described above. However, participants found a wearable to be problematic for two reasons; first, other players might attempt to interact with your own wristband, which was not welcomed and considered a breached of personal space, particularly by the pupil with VI who described being startled by unwanted contact. Second, unlike a personal wearable wristband, a shared controller, e.g. a button in the middle of a revision table, would afford more engaging and playful interactions with peers.

Voxtopus: A VUI Peer Revision Quiz

The co-design workshop provided a rich set of design ideas and reflections on the use of voice interaction to support peer revision. We developed a VUI application using Amazon Alexa that captures these design ideas, named Voxtopus (Figure 4). Voxtopus allows pupils to engage in peer revision and augments the Echo device with a set of physical controllers that support audio-tactile display and can be used for answering and navigating questions [4]. Importantly, Voxtopus supports potential for collaborative learning activities, where pupils participate in the design of personalised revision materials (summaries and quiz) and share them with others. The technology therefore enables and supports inclusive pedagogy and activities. We are currently in the process of finalising and deploying Voxtopus for a longitudinal evaluation at a school, where it will be accessible to all pupils from the resources room in a space dubbed the "Voice Booth".

7 AN UPDATED DESIGN SPACE

Our exploratory engagement with pupils, educators and staff helped us articulate an initial design space for supporting inclusive education through VUIs (Figures 1). Initially, this described four dimensions: **Ownership** identifies who is the immediate user of the VUI and differentiates between individual and collective use, e.g. Scenario 3 vs. Scenario 2 where collective ownership allows for inclusive engagement of both sighted and VI pupils. **Space**, identifies where a VUI would be used and distinguishes between public spaces, (e.g. school corridors, playground), and private space (e.g. using the VUI in a specially designated area - Scenario 1). **Learning** identifies the kinds of content and pedagogy that VUIs could support e.g. fact-based MCQs vs. open reflective inquiry (Scenario 2). **Mobility** identifies whether the VUIs user is static or on the move (Scenario 3). Following on from the co-design workshops, it was clear that an additional dimension is needed to account for the potential augmentation of VUIs with additional sensory **Modalities**. This first appeared in the bodystorming session, where pupils suggested combining voice with non-speech sounds and vibration, and then anchored in more concrete ideas of augmentation during the co-design activities, where participants explored functional ways of extending VUIs with physical controllers, and private and playful interaction through vibration and smell displays. With these five dimensions we can, for instance, reflect on the design of the Voxtopus: it is **collectively owned**, designed to be used in a **privately** designated space, in a **static** set up to engage pupils in collaborative **fact-based learning** activity that allows for the sharing of revision materials through **multisensory** interaction[5].

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[4]See supplementary material for a technical specification of Voxtopus.
[5]Figure 1 depicts how Voxtopus fits within the proposed design space.

8 DISCUSSION

The resurgence of voice-based personal assistant devices has not yet extended to contexts outside home settings. In this paper, we explored how VUIs might provide a common modality of interaction for sighted and visually impaired pupils in mainstream schools. Findings from exploratory investigations with educators and pupils through focus discussions, bodystorming and co-design showed that VUIs offer significant potential for inclusive and accessible interactions in this setting. Our investigations demonstrate that an important step towards achieving this potential, is to break "voice" – as an interaction modality – out of the confines of screen-readers and human assistant voice descriptions. Construed as such, voice can be exploited in implementing the shift from an often-singular focus on functional forms of accessibility towards a wider consideration of the various factors that can affect inclusive interactions and social connections among all pupils, regardless of ability, which has not been demonstrated before.

Our design-based approach allowed us to discover novel usage of VUIs in schools. Interestingly, initial forms of engagement with educators (focus discussions) and pupils (bodystorming) yielded different forms of insights. Educators highlighted high level concerns related, for example, to learning pace and academic stimulation, whereas pupils picked out more practical challenges, such as handling lab equipment and making the aesthetics of the classroom experience accessible. We captured these ideas in three scenarios that illustrate key problems that need to be addressed to foster more inclusive interactions in schools through VUIs. The scenarios are useful to others developing VUI technology for visually impaired and sighted people because they give insights into how VUIs may be used effectively in this context.

A VUIs Design Space For Inclusive Education

We proposed a design space that captures the variety of perspectives we encountered and characterises potential inclusive education experiences to design for. For example, designers should consider the *location* of the VUI and how it relates to the kind of learning activities that take place within that space. We found VUIs could be integrated in whole-class activities to engage pupils in reflective inquiry, as well as to engage smaller groups in independent fact-based peer revision and instruction. The implications of the immediate *ownership* of the VUI device or application should also be considered, which is particularly critical when considering the increasing use of personal devices by pupils with VIs in schools as a replacement for more specialist equipment [30]. Switching between individual and collective usage should also necessitate considerations for the private and public character of the *use space*. Interestingly, "space" can

also be described in terms of how voice display is delivered, e.g. headphones or speakers, which is important to consider given the potential distracting character of voice display, particularly in a classroom settings and the impact of using private vs. public audio channels on individual and collective work dynamics [28]. Our findings highlight the need to also investigate these issues when using VUIs in schools.

The design space also highlights how the capabilities associated with commercial VUIs might allow for flexible *learning practices and pedagogies*. At the same time, we also found a number of accessibility issues related to limited functionalities of VUI devices when used for group learning, such as failure to account for on going conversation. This led to considering augmentation of VUIs with physical controllers and multiple *modalities* for private and playful interaction, which also points to fruitful avenues of future work. Finally, the design space can also be used to inspire novel solutions to problems by identifying new applications of VUIs; e.g., benefiting previous research on non-visual *mobility* [13, 19].

Extending the Design Space

We note that the proposed design space was the result of investigating challenges of inclusive education and possible solutions employing VUIs. Future work should therefore aim to amend and revise the design space by explicitly considering challenges specific to interacting with VUIs. As a community, we are only beginning to understand how people interact with and through voice-based personal assistants [22, 37] and how to co-design them [12]. The co-design workshops we conducted presents a clear example of how considerations of concrete interactions with VUIs can lead to extensions in the design space. Extending the design space effectively, then, requires deployment and long term evaluation of VUIs in schools; e.g. to examine impact on learning and teaching practices, such as through the scenarios we propose. This is an avenue we are currently pursuing by deploying and evaluating the Voxtopus quiz game in a "voice booth" at our partner schools, and which we anticipate would lead to further refinements of the proposed design space.

Implication for Inclusive Education Pedagogy

Whether imagined, e.g. reflective inquiry (Scenario 2), or designed (Voxtopus), our investigations highlighted examples of how VUIs could support inclusive education pedagogy. For example, with Voxtopus, pupils and educators did not design just another way of making MCQs accessible via voice, but the ideas that emerged sought to describe a tool that enables inclusive relationships and equitable roles in revision. It is also interesting to consider the effects of being able to use a VUI device to ask questions on the ways and types of questions pupils ask and how this changes the nature of inquiry that the pupils engage in. At the same time, while

VUIs seem to offer opportunities for inclusion, it is important to consider how teachers can retain control of their classroom. Our investigations point to interesting challenges that should be explored in relation to the acceptability of learning technology in general [1] and assistive technology in particular [18]. What is raised are questions to further investigate through using and observing the technology in-situ – not in a way that assumes it will transform educational experiences or measures learning outcomes but in a way that tries to understand what happens when a VUI is introduced to support inclusion. For example, how do VUIs impact and change physical spaces, be that classroom environments or public school spaces. How might they work in busy, noisy environments? What happens if only a select group of pupils has access to a VUI device? Could inclusive activities with a group of pupils also create other inequitable practices?

There are also ethical issues of use to consider, including genuine security and privacy concerns, e.g., what is being recorded (intentionally and unintentionally); who can access recordings and controls this data. This might take the shape of co-developing responsible use policies or guidance alongside all involved (teachers, SEN personnel, parents, pupils). In relation to inclusion, future avenues to explore include examining how this kind of technology reduces barriers to accessing school curriculum, physical environments and learning activities? How might VUIs enable more equitable opportunities for participating in learning and relating to peers and school staff through peer working and new teacher-student relationships? While not addressing these questions explicitly, our research and proposed design space opens up potential avenues for these important questions to be explored through HCI research.

Inclusive Co-design

The design-based approach we presented in this paper advocates shifting emphasis from accessibility to inclusion in the design of technology, and in bringing pupils and educators of mixed visual ability as active designers in this process. Our aim was to engage pupils in identifying potential challenges to inclusive education, to reflect on shared learning experiences as well as to imagine and design scenarios of how VUIs could help. This is the first study of its kind to explore co-designing VUIs with visually impaired and sighted pupils and their educators.

We chose to combine a number of design methods to achieve this, starting with bodystorming as an ideation method, through to Lego construction and Wizard-of-Oz evaluation for conceptual design, and live coding an Alexa Skill applications in real-time as a form of high-fidelity prototyping. Bodystorming had a strong elements of embodiment of ideas, which was engaging for the pupils. It also had elements of

empathic modelling or disability simulation, which is a popular method for helping non-disabled people to understand what it might be like to have a disability. Research on disability shows that in some cases disability simulation can lead to more negative views of disability through representing it as a diminished experience [14, 34]. However, research has also shown that simulations can actually improve attitudes about disability when used as a positive learning activity [45]. In our case, the key for achieving this was to centre the VI pupil as experts at sharing their own experiences. In this case, the activities provided the sighted pupils with ample opportunities to experience how to make sense of the world effectively without relying on vision.

It is generally difficult for participants to contribute ideas when they are less familiar with a particular technology, as was the case in our sessions. Showing actual working examples can help, but this risks influencing participants and can block creativity and engagement. This is why we opted to combine Lego construction with Wizard-of-Oz simulation before introducing a higher-fidelity prototype. Lego construction was also effective in bringing the visually impaired participant's perspectives strongly as leading and negotiating the formulation of alternative design ideas. Evidence for this included instances where we observed "debugging" behaviours, were the pupils identified areas of the construction that did not flow well, as well as instances of negotiating alternative design ideas, for instance how scores should be kept and represented in the application. But despite its tangibility, Lego construction remains a visual method, and thus deprived the pupil with VI from, for example, quickly gaining an overview of the alternative structures being developed and discussed. We believe that this disadvantage was mitigated in the third workshop, where all participants experienced the developed conceptual designs through an equally linear modality of presentation. The bodystorming and Lego construction activities were thus effective in preparing the participants, by sharing experiences and appreciating perspective.

In terms of approach, we ensured that co-design activities embedded learning objectives; for example the drama teacher embedded learning about role playing and improvisation in bodystorming, and Lego construction had a scaffolding element that allowed for communicating key concepts about the inner functioning of VUIs and their underlying structures through basic programming constructs (e.g. conditionals and loops). The presence of the drama teacher as both a participant and a leader of the bodystorming session was also critical in achieving high levels of engagement with the pupils. This approach builds on prior work on inclusive co-design in educational setting, which recommends sharing roles and ceding control to participants who have close and well developed relationships with child participants [30]. We

thus build upon earlier work exploring collaborative learning with children of mixed-visual abilities [30, 43, 50], and extend it by using a set of engagement methods involving mixed stakeholder groups. We note that co-designing with groups of mixed-visual ability is an under-explored area and very few design tools have been explored in this space. Possible alternatives include using accessible design materials, such as audio-based post-it notes, but prior research has shown that these can form barriers to engagement and create asymmetries between sighted and visually impaired participants [29]. Accounts of our process and outcomes therefore provide descriptions that could serve as starting points for eliciting insights and guidance for research and design in this area.

Broader Implications

The above findings contribute to the under-explored space of co-designing voice user interfaces in general, and co-designing with young people in particular [12], as well as to designing for group interactions around VUIs [37]. For example combining low-fidelity prototyping with Wizard-of-Oz evaluation was both engaging and helpful in thinking beyond the capabilities of off-the-shelf VUIs. The trade-offs highlighted in our design space should also be useful in tackling the subtleties of interaction with and around VUIs, for instance the need to augment voice interaction with other sensory I/O, which can therefore serve as a push for further explorations of multimodal interaction through VUIs. More broadly, the above findings could also provide useful insights for pedagogy. However, because the focus of our explorations was explicitly on designing for inclusive interactions, applying and extending these general implications beyond this context should be done with caution.

9 CONCLUSION

We explored challenges to the inclusion of visually impaired pupils in mainstream schools and how voice user interface can help overcome some of these challenges. We engaged visually impaired and sighted pupils and their educators in a series of exploratory investigations including focus groups, bodystorming and inclusive co-design workshops to reflect on their shared learning experiences and to imagine how VUIs could be used effectively in schools. Outcomes include a design space for thinking about inclusive education through VUIs, a set of scenarios that illustrate possible uses of VUIs in inclusive education, and an example prototype application validating one of the identified scenarios and helping extend the design space to the realm of multisensory and tangible interaction. These findings are significant as they provide a basis for designing support for inclusive education through VUIs and contribute to extending the design space of VUI application beyond home settings, thus providing a foundation for future design and research in this area.

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