Co-designing Inclusive Multisensory Story Mapping with Children with Mixed Visual Abilities

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ABSTRACT

Story mapping is used in schools to promote children's understanding of stories and narrative structure. As a collaborative activity, it can support creativity and facilitate group interaction. However, most techniques used in primary schools rely on visual materials, which creates a barrier to learning for children with visual impairments (VI). To address this, we set out to design a collaborative story mapping tool with a group of children with mixed visual abilities and their teaching assistants. Using co-design approaches over ten workshops, we designed and prototyped different ideas for engaging children in storytelling and design. We present our co-design process and findings, and the resulting story mapping system. We outline how using multisensory elements can facilitate creativity and collaboration to help children with mixed visual abilities create and share stories together, and support learning and social inclusion of VI children in mainstream classrooms.

CCS CONCEPTS

• **Human-centered computing → Participatory design**;
• **Applied computing → Collaborative learning**;

KEYWORDS

Inclusion, Education, Co-Design, Children, Mixed Abilities, Multisensory, Storytelling, Tangibles

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Figure 1: Co-design activities with children with mixed-visual abilities with a *box of multisensory stuff*.

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1 INTRODUCTION

Many primary schools in the UK use story mapping to promote and support children's understanding of the components of stories (plot, structure, character, setting), and to help them with remembering and structuring the events of stories they are learning about in class. Story mapping can also be beneficial in enabling children to create and plan out original story ideas. It can be applied as a whole class activity, group activity, or as an individual task. Story mapping has been shown to improve reading comprehension and have positive transfer effects to creative writing skills [42, 49]. Research has also shown positive benefits of using story mapping to support story recall and comprehension for children with special educational needs and disabilities (SEND), such as Specific Learning Disabilities [8, 40, 74], autism [11] and ADHD [18, 21], as well as for struggling readers [37, 38].

In a broader context, story mapping can support storytelling and creative writing, with research showing that such learning activities can promote imagination and creativity, build confidence, and improve memory and sequencing skills [16, 31]. Storytelling also has the potential to be a social and collaborative activity, which can engage children of different abilities and increase motivation to learn [35]. However, the use of story mapping in primary schools relies heavily on visual materials as a graphic organisation method to plan or map out story elements. Such a strong visual focus on framing both group and individual understanding of stories can compound problems of social and academic exclusion for children with visual impairments, who are increasingly educated in mainstream rather than special schools [67]. Inclusive learning for children with VIs in mixed group settings is a largely under-researched area, and we are using storytelling and co-design as a starting points to explore this problem. Specifically, this research asks two questions: to what extent can multisensory storytelling help to facilitate inclusive, engaging and collaborative learning experiences for children with mixed visual abilities? And additionally, how can this aim be supported through co-design approaches?

Building on previous research on co-design with users with SEND and the growing body of research on engaging children with VI in design, we set out to design a multisensory story mapping and development system with a group of children (aged 8-10 years old) with mixed visual abilities at a primary school in the UK. The group also involved mixed stakeholders, including teaching assistants (TAs), SENCos (Special Educational Needs Coordinators) and researchers, as well as children, in the design. Over ten workshops we discussed ideas surrounding storytelling and technology design, and explored several prototypes (ranging from lo-fi to hi-fi) for engaging and supporting the children in collaborative story creation. The co-design workshops culminated in the development of two creative outputs, the multisensory story system (contributed to by all participants in the study), and two original stories created by the children with support from the educators.

Here we report on the process and outcomes of our co-design workshops and the design of the resulting system. Our contribution lies in extending prior work on the crucial role of co-design in generating more inclusive and accessible technology, and showing how tangibility and storytelling can combine to drive processes of creativity and collaboration for a group of children with mixed visual abilities. In doing so, we demonstrate that using multisensory materials provide a novel way to foster group discussion, interaction and participation, which can have positive applications for other curricular areas, and for other user groups.

2 BACKGROUND

Inclusive Education and Co-design

Inclusive education refers to the practice of providing a learning environment and employing teaching approaches that enable learners to participate fully in a mainstream setting regardless of their needs [72]. It is important that this environment allows students to experience and embrace diversity. Inclusion of children with SEND in mainstream education has become established practice in the UK [1] and across many other parts of the world [71]. Much research has investigated what makes a classroom inclusive, ranging from the pedagogical practices of individual teachers [23, 27, 60], to more joined up approaches among teachers and learning support staff [59], to the importance of peer-learning and collaboration [17, 52, 57].

Another key focus is how technology can support inclusive learning [27, 28, 56]. Recent research has demonstrated that co-designing technology with children with SEND leads to more meaningful technology, as well as helping to provide enriching and empowering participant experiences [7, 29, 33]. Many researchers are now actively seeking to involve children with SEND in the design of new educational and assistive technologies (e.g. [48, 54, 83]).

There is also growing interest in exploring ways to co-design with and for people living with VIs across a number of domains [9, 47, 53, 55, 69]. Some examples include co-designing toys [51], multisensory educational technologies [12, 54], developing support for sensory motor rehabilitation of children with VIs [46], and developing tools to support co-design activities with VI participants [45].

However, research on co-design with users with mixed visual abilities is more limited, despite being particularly important in understanding how best to support inclusive learning for children with VIs [7, 54, 78]. In this paper, we build on and extend this prior work by exploring how we can co-design multisensory story mapping with VI and sighted pupils in the context of inclusive mainstream education.

Similar to Magnusson et al., we are working towards co-design in which the participants are "active and creative contributors" [47] to the design of inclusive technologies. Further to that, we see co-design as a way to foster inclusive learning experiences for children who may frequently experience isolation or separation from peers in lessons for a number of reasons, including needing TA support and assistive technology equipment [5, 54]. In this way, VI learners, together with their sighted peers, can become more active and creative contributors to inclusive learning technologies and their own learning experiences.

Interactive Storytelling and Tangibles

Storytelling technologies in education have a broad range of positive outcomes for children, from improving literacy outcomes, such as word and sentence fluency and reading comprehension [10, 15, 58], to supporting social processes and development [31]. Other research reveals the potential for interactive storytelling, particularly with tangibles, to support creativity and imagination [16, 19, 20] and facilitate collaboration and group work [22, 24, 35, 75].

Tangibles enable children to create and share stories using physical objects embedded with digital capabilities, contributing to greater opportunities for collaborative learning around storytelling, particularly for users with SEND. Recent tangible story systems have explored a diverse set of forms, ranging from hybrid books and flashcard systems [31, 77], robots [68], toys, puppets and scenes [30, 79, 81], sewable circuits, paper electronics and augmented drawings [3, 61], and tangible objects such as blocks or modules [13, 39, 62, 73, 76]. These types of systems open up new avenues for exploring storytelling with users with SEND [3, 31, 62], as research suggests that storytelling can be a beneficial approach for supporting learning inclusion for both adults and children [36, 64]).

In this paper, we focus on how storytelling activities can lead to more engaging and collaborative learning experiences for children with VI. We extend the prior work on interactive and tangible storytelling to address co-designing multisensory story mapping with mixed-visual ability groups. Whilst multisensory storytelling has been explored in special education, where it is known as MMST [50, 63, 82], little work has been done in the field of HCI in the design of tangible, multisensory technologies for mixed visual abilities.

3 CO-DESIGN WORKSHOPS

Over a full school year, we conducted ten co-design workshops with a group of children (aged 8-10 years old) at a local primary school in the UK. The sessions included children with mixed visual abilities, the Teaching Assistants (TAs) of the participants with VIs, the school's Special Educational Needs Coordinator (SENCo), and two researchers.

The school is a mainstream primary school in the the United Kingdom, which, whilst considered mainstream, has a higher than average percentage of children attending who have an Education, Health and Care Plan (EHCP) for Special Educational Needs and Disabilities (SEND). The school therefore has specially resourced provision for children with special educational needs relating to physical disabilities and visual impairments. Three of the children who took part in the co-design study have an EHCP for visual impairment, and are supported by a dedicated Teaching Assistant (TA). The school also operates a "buddy system", whereby students with additional needs are further supported by a class peer. The main goals of the co-design sessions were to i) establish design requirements for a story mapping system; ii) to jointly come up with design ideas and solutions for the system, and iii) to develop and extend co-design methods for working with children in mixed visual abilities.

Name*	Gender	Group	Participant	Level of Vision
Aaron	M	1	Child	Blind
Connor	M	1	Child	Fully sighted
Roxy	F	1	Child	Fully sighted
Laila	F	2	Child	Blind
Mabel	F	2	Child	Fully sighted
Eva	F	2	Child	Fully sighted
Alberto	M	2	Child	Partially sighted
Lisa	F	1	TA	Fully sighted
Kerri	F	2	TA	Fully sighted
Jess	F	None	SENCo	Fully sighted

Table 1: Details of participants involved in the co-design study. *All names have been changed.

Participants

We engaged with seven children (4 female, 3 male), aged between 7-10 years over the course of the one-year study. The child participants had mixed visual abilities, ranging from congenital blindness, to full-sight (see Table 1). The sighted children were part of the school's "buddy" system, and were accustomed to supporting their visually-impaired peers. During the co-design study, two to three Teaching Assistants (TAs) and one Special Educational Needs Coordinator (SENCo) played an active role in facilitating sessions and contributing to design ideas. Each child with VI is always supported by a TA in school, so at least one TA, or the SENCo, was present and actively supporting in each session.

Co-design Procedure

Throughout the program we communicated with the SENCo and TAs about the workshop activities and adjusted aspects to aid the children with VI. For most of the design sessions, the children worked in two groups, depending on their class (Year 3, *7-8 years*, or Year 4, *8-9 years*). However, the group sizes varied throughout the course of the workshops, with small group work involving two to three children, and larger group work involving all of the children (up to seven). We often varied the group size depending on the learning and design objectives we wanted to achieve for that session, as some activities worked better with larger or smaller groups. The procedure and materials for each stage of the co-design process are outlined below.

Preliminary workshops. During the first two sessions, the participants were introduced to the main themes for the workshops (design, storytelling, multisensory crafting). We first aimed to explore how using multiple sensory modalities could make storytelling more inclusive and fun for both children with and without VIs. In groups of two to three, the children were asked to discuss a storybook, which they had previously read in class, and think about how the story could be augmented with multisensory craft materials. The stories chosen by the groups were *Sharing a Shell*, *What the Ladybird Heard* and *Little Red Riding Hood*.

In the second session, participants were tasked with thinking about what schools might be like in the year 2117, and in particular, what new technologies for collaborative storytelling might exist. Following an imaginative discussion, participants were asked to make a mock-up of the ideas discussed, which they chose to do through drawings. The overall aims of these first two sessions were to establish initial design requirements for the story mapping tool through low-tech prototyping, future workshop techniques and discussion. In both workshops, the children were presented with materials from a modified version of the Bag of Stuff technique [25], in which we provided a range of multisensory craft materials supporting the senses of touch, hearing, smell, taste and vision, presented as a "multisensory box of stuff" [54] (see Table 2).

Main design workshops. During workshops 3-7, we conducted the main design sessions, which aimed to explore, expand and fine-tune the ideas established in the preliminary stage. Most of the design workshops were structured in two parts, with the children first learning about storytelling (character, narrative structure, scenes and settings), before exploring and discussing design ideas and prototypes in the second half. Most sessions began with a "minute of listening", in which we asked participants to close their eyes and listen to a soundscape for one minute. The soundscapes included a *seascape*, *rainforest* and a *prehistoric swamp*, and aimed to shift focus towards non-visual senses (hearing), whilst encouraging the children to volunteer and discuss ideas and opinions. Following the "minute of listening" we presented an audio recording of a story, and asked the children questions about comprehension, structure, characters and scenes. The stories discussed included *How the Whale Got His Throat*, *The Very Quiet Cricket* and *Varjak Paw*.

Modality	**Example materials**
Vision / Touch	Fabric, cotton, feathers, cardboard, foam sheets, play doh, strings, rubber bands, polystyrene, shapes, lego
Hearing	Recording pegs, recording cards, dictaphones
Smell / Taste	Candle scents, scented pens, food flavouring, cinnamon bars
Other materials	*Scissors, Glue, Glitter, Tape, Coloured tape, Blu Tack*

Table 2: Examples of the multisensory crafting materials used in the preliminary workshops.

In the second half of these workshops we focused on design activities, which mainly covered: audio input and output (particularly voice recording/playback and sound effects); tactile elements (physical characters and story objects, textures); how smell could be incorporated (e.g. use of smell jars); units of control (touch points, buttons, pots, sliders); spatial navigation and orientation; sites of interaction (number, and whether static or dynamic).

The overall aims of these design sessions were to develop design ideas and iteratively generate prototypes for the story mapping tool, whilst facilitating the childrens' understanding of story composition in an effort to lead to a more well-considered, holistic technology design. In order to achieve this, we used a combination of lo- and hi-fi prototypes, probes and prompts (for both story creation and design), multisensory crafting and embedded learning objectives. We also adapted the sessions to incorporate individual participants' interests and abilities throughout.

Concluding workshops. At the end of the co-design process we ran three concluding workshops (8-10) in which the participants first composed a new story and then recorded it using the preliminary prototype. For the first session we arranged a field trip to a local museum, where the participants explored the museum exhibits (dinosaurs, wildlife and African fabrics), before they took part in an hour long workshop, *Dinosaur Detectives*, which was led by museum educators and adapted to include more tactile, hands-on

Figure 2: Multisensory story prompt boxes used in the field trip for collaborative story composition.

activities. The workshop activities included *paleontologists and their tools*, *fossils*, *dinosaur diets*, and *history of a local dinosaur*, and each activity involved tactile exploration of objects, such as fossils and dinosaur teeth. The main aims for the museum visit were, i) to provide information and inspiration for the children's stories in the story activity; ii) to encourage imagination and creativity by getting out of the school environment and iii) as a thank you to the participants for their contributions in the co-design study.

Following the museum trip, the school group came to visit the university for a story composition workshop. The children worked in groups of three, (Group 1 - two children with VI and one fully sighted; Group 2 - one child with VI, two fully sighted) with the involvement and support of two Teaching Assistants or the SENCo per group. First, we gave each group a closed box containing several objects to be used as story prompts. Inside the box was a toy dinosaur, a polystyrene egg, some sea shells, a "smell" jar and some lichen (see Figure 2). The groups were asked to explore the objects in the box and work together to compose a story in twenty minutes. After initial discussion and exploration of the story prompts, we provided multisensory craft materials which had been prepared as story scenes (eg. *ocean, volcano, forest*) in a previous co-design workshop. The children then worked collaboratively to compose a story, with eight parts each mapped out on a coloured grid, before performing their story to the rest of the group.

The last workshop took place at the school. The children worked in the same groups as during the museum visit and were asked to record their dinosaur stories using the final story mapping prototype (shown in Figure 3). Group 1 worked with two TAs, and Group 2 worked with one SENCo and one TA. Following the story recording, each group performed their stories using the prototype to the rest of the group, before we had a group discussion about the prototype and the co-design process overall.

4 WORKSHOP OUTPUTS

***Story Mapping Prototype*.** The system resulting from the co-design sessions is a multisensory story mapping prototype for facilitating storytelling tasks (including mapping, sequencing, composition and performance) with groups of primary-aged children with mixed visual abilities. The system is comprised of four main components; i) an audio sampler and playback unit; ii) a grid for organising the narrative structure; iii) a character module for exploring the narrative; and iv) a scene module, which introduces further multisensory elements to the story.

Sampler: The sampler controls the audio recording and playback for the story map. There are eight arcade buttons for recording and three sliders for audio effects (reverb, delay and pitchshifting). Additional outputs include an RGB LED for visual feedback (with red for recording, green for playback and white for idle) and auditory feedback to signal the start and end points for the recording function. At its core, the sampler uses *Bela*, an embedded hardware platform for low latency audio and sensor processing which is built on the *BeagleBone Black*, a Linux-based single-board computer.

Grid: The grid is comprised of eight grid sections, with two rows of four sections. Each grid space has an embedded RFID tag, which is readable by the RFID module, and is covered with contrasting coloured card. The colours are also matched with the arcade button colours on the sampler.

Character module: In the current prototype, a physical toy character is attached to a transmitter module, which contains an RFID reader that reads the tags on the grid and transmits the tag data wirelessly to a receiving device inside the sampler unit. The receiving device then communicates this data to the *Bela*, so playback can be triggered by moving the character module across the grid spaces. Outputs include an RGB LED for visual feedback (matching the colour of the selected grid square) and vibrotactile feedback, to indicate when the module approaches a tag.

Scene module: The scene module generates audiovisual and olfactory output for representing different story settings. Currently it supports four scenes: *ocean*, *forest*, *desert* and *volcano*, which can be selected by placing a textured scene selection lid onto the module. The lids light up with the corresponding scene colour (eg. blue for the *ocean* scene), plays a soundscape, and diffuses scents via a computer fan inside the module.

Overall, the prototype addressed the main requirements which arose from the workshops, for a primarily non-visual story mapping technology using a grid-based approach, incorporating multisensory crafting, and employing different units of control to facilitate cooperation in group work. These findings will be discussed in the next section.

Figure 3: Left: the current story mapping prototype, with (clockwise) the scene module, the grid, the character module and the sampler. Right: children with mixed visual abilities interacting with the multisensory prototype.

Group 1	Group 2
Roxy: Once there was an egg and one day it hatched into a dinosaur. The dinosaur walked over to the beach. After the beach he immediately found some footprints, and he followed the footprints into the woods. *Connor:* The woods were very rough. He was trying to get through all the trees when he smelt something weird. Then he found some footprints and he followed them. *Aaron:* The footprints ended, but "I wonder what's in this patch" said the dinosaur. The bud opened, and there was a great big patch of flowers. "I wonder what's in this patch." Repeated the dinosaur. In fact, it was a great big patch of his friends, *The Shape People*, and there was also a lost horse. "He has saved the day!"	*Alberto:* One day there was a dinosaur nest with eggs in it. It hatched and there was a baby dinosaur inside. It walked through the forest. *Mabel:* The dinosaur went to the forest and it smelt a funny smell, it smelt like the forest. Then it wondered off through the forest into the beach and he was really hungry so he went to find some food. *Laila:* He ate a tiger first, then had a tummy-ache. So he found some stones and gobbled them up, then he went to have a lie down. A meteorite fell from the sky and covered the dinosaur in sand. *Mabel:* Then loads of layers of sand and rock fell on him and he became a fossil. 65 million years later, a little girl was on the beach and she was digging when she found some fossils.
	

Table 3: Above: stories composed by each group after the museum workshop. Below: The accompanying story maps crafted by the children.

The Stories. The children's stories, which were composed during the museum workshop are presented in Table 3, along with the multisensory-crafted story maps.

5 FINDINGS

In this section we provide an overview of the main findings from the ten workshops, for both the story mapping technology and the co-design process with children and educators with mixed visual abilities. Data gathered from the workshops included video recordings of the sessions and researchers notes. One researcher produced initial codes and labels of data segments. We conducted regular peer validation throughout the co-design process [4], where two researchers met regularly to review and clarify decisions and directions analytically, as well critically reflect on how they related to the produced technology. The following findings were informed by these iterative discussions. Here we provide a detailed account of how ideas emerged, unfolded and fed into the design of the prototype in order to trace their origins and subsequent development.

Technology design findings

The Grid. A significant feature of the produced prototype is the grid structure, which forms the main platform for organising story elements and for interactive control of the audio playback.

Origin of the grid idea. During the futures workshop, Group 2 came up with some ideas for the design of the story mapping tool. Using their multisensory crafted story map of *Little Red Riding Hood* from the first session (see Figure 4a), the group began to think of how they could augment this map with digital capabilities. When prompted by the TA, Laila suggested: *"We could have a wolf."* Researcher 1, Laila and Mabel then expanded this idea by discussing the possibility of having a physical wolf character, which could pop up out of the map and *"growl at you"* (Laila). Kerri, the TA, then suggested that the character could move or walk around the story map, eg. Little Red Riding Hood moving through the forest. Following this suggestion, Eva, one of the sighted participants, proposed that they could code the characters to move around, mentioning their recent coding experience with Bee-Bots in school. With this idea of movable characters, Kerri started to think about how children with VI could spatially orient and move the characters, and navigate around the story map: *"The only thing with that Laila, if you needed it to move forward six spaces, what sort of board would we need to plan this story map on?... you would need maybe like a grid, so a tactile grid, wouldn't you?"* The grid idea was then expanded by all of the participants, discussing augmenting grid squares with voice recordings of the story narrative, as well as sound effects and smells.

Development of the grid idea. The grid idea then became central in the design process and was developed over the rest of the design sessions, constituting both an effective solution to non-visual navigation and a way to structure and order story parts. Initially, we tried to follow the flow of the story

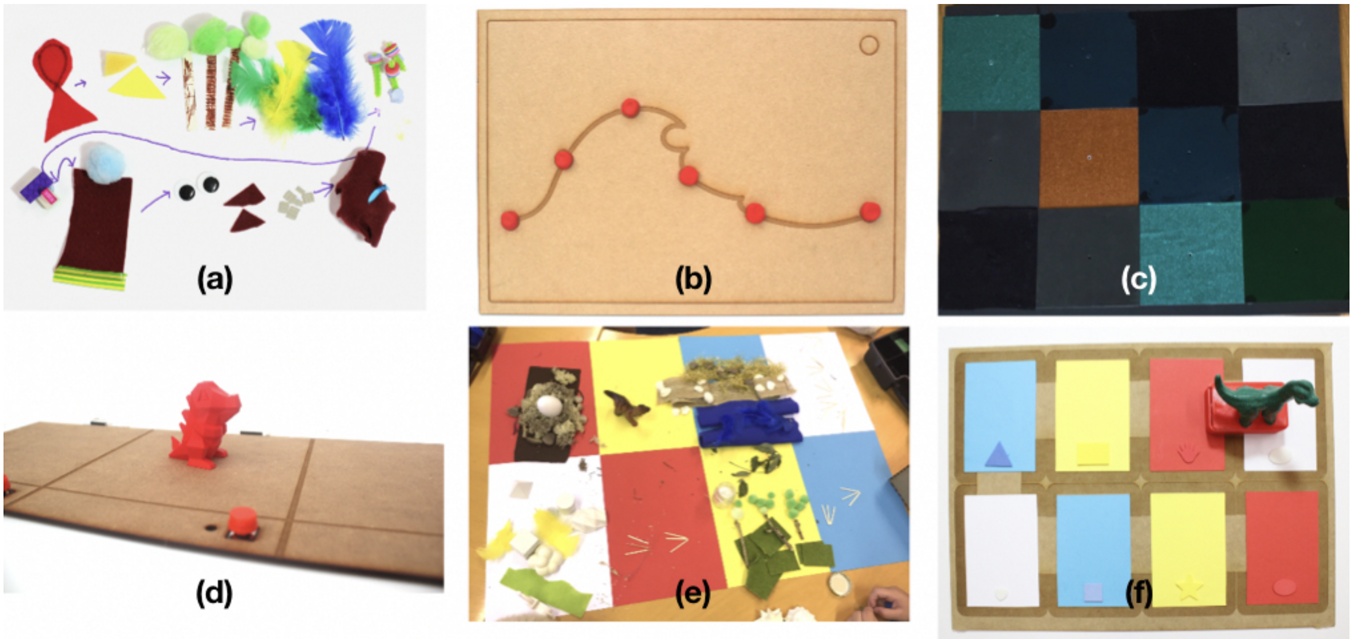

Figure 4: a) Group 2's multisensory-crafted story map for *Little Red Riding Hood* (WS1), b) Initial story wave hi-fi prototype for story mapping, using capacitive touch sensing and play-doh (WS3), c) Tactile lo-fi grid prototype (WS3), d) RFID character grid with recording buttons (WS5), e) Group 1's multisensory-crafted story map, on coloured grid, for their dinosaur story composed after the museum visit (WS8), f) Current prototype with moveable character playback on coloured, tactile grid.

map crafted by the children in the first workshop (4a) to represent the narrative arc (exposition, rising action, climax, falling action, denouement, resolution). We presented this as a "story wave" (4b), which we brought in as a working prototype for recording and playing back story components using capacitive touch sensing. Whilst the participants seemed to find this easy to follow, we also brought in a lo-fidelity tactile grid prototype (4c), which the TA and the child with VI preferred as they felt would be easier to navigate. The grid would also allow for more complex narrative development. In the next workshop we returned with another hi-fi prototype, a laser-cut grid with audio-recording capabilities (via in-built buttons on each grid square) and a moveable RFID-tagged character, which could play back the audio recorded by the children for their stories (see Figure 4d). Interesting design challenges also arose from using the grid structure. For example, some suggestions were made to improve the differentiation of the grid squares by having raised lines, rather than engraved, to improve navigation, and considerations were explored about how this would impact the mobility of the character. The children also suggested including textures on the grid squares, as in (4c), eg. Laila: *"they could be made of foil"*, and Eva *"Or different materials."*. However, Aaron was happy with the smoothness of the existing material (MDF). It also was suggested by the TAs that the grid should use contrasting colours to aid navigation for visually-impaired children with some light perception, which we implemented later on in (4e) and (4f).

In the concluding workshops, we presented a paper prototype grid with contrasting colours and space for crafting (Figure 4e), and the current working prototype, with tactile shapes and an engraved track to differentiate the grid spaces, and a moveable character piece to play back the narrative (Figure 4f). Following participants' suggestions in the final workshop, further adjustments will need to be made (e.g. the raised track, and addition of more textures) in future iterations.

Distributed Control. The current prototype has four units of control and sites of interaction: the grid, the sampler, the character module and the scene module. Initially we began with the idea of having all functionality built into the grid directly, but over time, the design requirements and technical constraints shifted, and we learned more about the group dynamics and how the children worked best collaboratively, which also had an impact.

During the workshops, the children were keen to continuously explore the prototypes with their hands, and often, more than one child wanted to do this at once. In earlier prototypes (eg. using capacitive touch-sensing in the story-wave (4b) and with the RFID grid (4e)), this led to problems with the audio playback (eg. deleting story parts by accident and rapid re-triggering of samples). A finding from these workshops was the need to have more deliberate record functions. To overcome the issue, the researchers suggested having a designated, separate control unit of buttons for recording, rather than have recording on the grid itself. The children and TAs responded positively to the idea of separate controls for the recording and playback, Kerri: *"If they have a button that's for record and stop record, and this [moving the character] is for it to read it out, that's quite nice to have the differentiation between the two."*

A further reason for this physical separation of controls was also to separate out the learning tasks, so either composing (or mapping out) a narrative using the sampler, or performing the narrative using the character module. It was thought that having the audio recording and playback unified in one place would make it easier for users to follow the progression of the story (either in mapping or composing), whereas having the recording spread out across the grid might make the story composition or mapping process more disjointed. Additionally, we noticed during the workshop sessions that the children worked best collaboratively when they each had a different role, for example one participant recording, another crafting and another moving the character. Whilst this also presents certain problems for cohesive technology design in having multiple sites of interaction, the trade-off was that the children could work more collaboratively through negotiating the different units of control. We also linked the controls through colour coding, with the grid squares, arcade buttons and character module all using the contrasting colours.

Multisensory Output. The multisensory output focussed heavily on audio, with participants demonstrating an interest in sound effects early on, for example wanting to have teeth that *"chomp"*, floorboards that *"creak"* and a forest with birds *"chirping"* in the Red Riding Hood Story. Equally, throughout the process, the children were keen to record and hear their own voices, and audio recording became one of the most engaging aspects of the workshops. As Eva mentioned, *"I wanted to put sound in every single part of the story to tell the story"*. They also wanted to be able to change their voices and we ran an entire session on audio effects in which the children had a lot of fun trying out and discussing different effects (including pitchshifting, delay and reverb). Also, the children's focus and engagement during the "minute of listening" soundscapes led to the idea of including them as part of a multisensory scene module, which could support more immersive stories through sound.

The scene modules were also developed to capture some of the multisensory elements that were explored effectively in the co-design sessions. The use of "smell" jars were some of the most engaging and collaborative aspects for the children. The participants liked the tangible, analogue aspect of sharing, opening and discussing the "smell" jars, and we tried to integrate this into the design of a story scene module. Crafting was also a key focus in the design. Early on, Kerri, the TA suggested *"You could stick tactile things [on the grid spaces] for them to help retell stories and things"*, and we also saw how well the children responded to the crafting activities in Workshops 1, 2, 4 and 7, where we noticed a high level of engagement and discussion. We thought it was really important to retain this element of crafting, learning and generating ideas through crafting and making, and decided to incorporate this into the design of the grid (see Figure 4e).

Co-design findings

Embedded learning objectives. Workshop activities were designed to be engaging and encourage creativity, using scaffolding and embedded learning objectives so that children could learn more about the subject matter being explored. The children learned about storytelling (character, narrative structure, scenes and settings), and design (mockups, prototypes, iteration, design teams, and being critical). Story activities were often used as proxy activities to further explore design challenges, for example extending storybooks to be multisensory in order to think about multisensory design, and imagining how to extend the story maps with digital capabilities in order to think about designing multisensory technology. During the concluding workshops, especially the museum visit, the children also learned a lot about dinosaurs, and some of the facts appeared in their final stories, for example dinosaurs eating stones to aid digestion, or the asteroid leading to their extinction (see Table 3). However, whilst it was important for us and for the educators that we embedded learning objectives, we were not assessing learning outcomes in this study.

Multisensory crafting for storytelling and design. We focused on multisensory materials for both the design of the activities and the selection of materials. We used sound as much as possible, for example with soundscapes and audiobooks, to engage non-visual senses and promote imaginative thinking and creativity. Using the *box of multisensory stuff*, the children also started to think about incorporating tactile and olfactory experiences into the design of the system. Overall we found that it was important for mixed ability groups to have tactile and multisensory prompts to trigger collaborative discussion and generation of ideas.

Leveraging individual participants abilities and interests. We looked out for the emergence of individual interests and abilities and made sure they were integrated in the process. We were able to leverage the detailed knowledge we developed about the specific needs of each child with a VI, for example Laila's low light perception and Aaron's fascination with audio recording, both of which became crucial to the design workshops and design of the technology itself. We found that the specific interests of one child could be explored with everyone, for example Aaron's interest in audio recording led to a group workshop on audio effects, which was engaging to all the children. Equally Laila and Mabel's interest in multisensory crafting became a key part of our story creation and design processes for all participants.

Group dynamics. We often varied the group size depending on the learning and design objectives we wanted to achieve for that session, as some activities worked better with larger or smaller groups. This led to parallel (and sometimes diverging) discussions in small group work, which we then had to reconcile in the design of the system. Sometimes suggestions would be different between groups. For example, the suggestion of having more than one character was liked by Group 2 because they wanted to record the story from different character perspectives. However, Connor, from Group 1 (during a different session) envisaged problems with group dynamics if more characters were introduced: *"I'm thinking if there's more than one, you'll keep putting them down and eventually there'll be too many characters on the board. Someone might want another character on the board and they might push someone else's off to put theirs on."* Some key aspects which helped us to structure equal contribution in the group and ensure a more level playing field were: i) the use of multisensory materials which were engaging and generated discussion; ii) designing workshops around individual abilities and interests; iii) having flexibility with switching between large and small group work to facilitate design and iv) sharing of roles with TAs as facilitators. The use of prompts, probes and prototypes also really supported participation and discussion, providing a common frame of reference for all our participants, which supports prior work on the importance of making in design [70].

Sharing roles with TAs. Involving specialist educators in design proved to be invaluable in our process, and the TAs and SENCo were able to help with planning, structuring and scaffolding activities, and facilitating and moderating the group work. Sometimes it was difficult to get the children to reflect critically on design ideas without TA facilitation. For example, when asked what they thought of one of the prototypes, Laila responded *"I liked all of it...Mabel?"*, Mabel: *"Same as Laila."* Responses such as this were fairly common, but TA support helped the children to elaborate on their opinions and ideas and contribute more fully to the design. Also, the knowledge of the TAs of specific challenges for each participant with a VI was invaluable in the exploration of better design solutions for mixed ability groups. Further examination is required to understand and characterise the various roles and relationships when co-designing with mixed-ability groups.

6 DISCUSSION

Tangibility and multisensory materials. In our experience, the use of tactile prompts and multisensory materials made it easier for the children to come up with story ideas and also to elaborate on those ideas. This supports other work on physicality and creativity in tangible design for storytelling [19, 20]. In this case it also facilitated both collaborative exploration and explanation amongst participants with different visual abilities, and this seemed to also be the case with fostering child-educator discussion, for example with the animated and engaging discussions arising around the olfactory experiences presented through the "box of stuff" and the scent jars. There has been some work on physicality and its subtle effects on group dynamics in design work [65, 66] and further research could explore these effects for design in an educational setting, particularly for multisensory materials.

Inclusive learning, inclusive design. Tangible and multisensory story mapping was an engaging way to facilitate inclusive learning experiences for our primary-aged participants. Whilst there are not many practical recommendations in the literature on how tangibles can support inclusive educational practices and learning strategies for children, Garzotto and Bordogna make some useful suggestions, for example using familiar learning materials and limiting activities to shorter timeframes [32]. Additionally, they discuss the importance of tailoring content and activities to the individual child to account for their specific cognitive, linguistic and motor abilities, which is an idea also supported in SEN research on adapting participatory design methods and techniques to individual participants [7, 29, 44, 54, 78], and something which we have explored in this research. To engage the whole class, researchers have also involved the classmates of children with disabilities in the design of the learning materials for their peers.

It is important to extend this idea to the design of technology itself, also including peers of users with SEND in design.

Buehler, Kane and Hurst [14] make a key point about stigma and the adoption of assistive technologies for children, highlighting peer perception as a factor in why some devices are not successfully adopted by young users. This is why it is crucial for the design of collaborative technologies for mixed-ability groups to consider elements that appeal to both children with and without SEND, who have different needs and preferences. Tangible, multisensory technologies may be able to overcome some of these barriers and present novel and engaging learning opportunities for mixed ability groups.

In recent years, co-design has become common practice in technology design for developing products and services which better support the needs of users. This has also been the case for designing assistive technologies. More recently, work has been done on co-designing with people with visual impairments[34, 47, 54], and there is growing evidence to suggest that designing with mixed visual ability groups have better outcomes for not just more accessible, but also more inclusive technology. In this study we sought to apply this new research to working with children in a primary school setting to create a more inclusive story mapping tool.

Throughout the process we used several co-design techniques, including the Bag of Stuff, fictional inquiry and future workshops [25, 43, 80], and extended these methods to adapt to the needs and interests of our participants [6]. We also designed engaging activities which were scaffolded, and used embedding learning objectives to facilitate learning beyond design. This research builds on previous work exploring the need to adapt and extend techniques depending on the participants' levels of design expertise for children with and without SEND [6, 25, 29, 54], for example the adaptation of the Bag of Stuff to the "box of multisensory stuff" as a more appropriate technique for our visually-impaired participants. We also integrated the individual interests and abilities of participants into our design [6], including audio recording and contrasting colours to support VI learners.

Co-design with groups of mixed-abilities is an under-explored area and very few design tools and examples of design practice have been shared in this space. In this paper, we have presented a detailed account of designing with groups of participants with mixed-visual abilities, tracing how ideas emerge, develop and become embedded in design decisions and direction. Accounts of our design process and outcomes therefore extend existing work with descriptions that could serve as additional starting points for eliciting insights and guidance for research and design in this area.

Additionally, we have shown that involving different stakeholders is also necessary in supporting the design process and achieving inclusive design. We found that the role of the TA was crucial in the co-design process, in interpreting activities, structuring discussion, supporting the children in elaborating on their ideas, keeping things on track and at the right level, mediating disagreements, and occasionally moderating behaviour. The TAs also provided invaluable insight into practical implications and educational issues for children with VIs, voicing ideas or concerns which were outside the children's scope, or frame of reference.

In a broader context, our investigations build on the important role that TAs play in inclusive education[26], while pointing to interesting challenges that should be explored in relation to the acceptability of learning technology in general [2] and assistive technology in particular [41], and how these could be designed to support TAs and children in inclusive learning environments. What is raised, therefore, are questions to further investigate through using and observing the technology in-situ in a way that tries to understand what happens when a multisensory tool, of the sort developed in this research, is introduced to support inclusion. For example, how does multisensory technology impact and change physical and sensory spaces, be that classroom environments or public school spaces? How might they work in busy, noisy environments? 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 in general, and interaction design with children in particular.

7 CONCLUSION

In this paper we have presented our work on tangible storytelling and design with children with mixed visual abilities, reporting on our co-design process and the design of a multisensory story mapping prototype for primary-aged learners. Tangible technologies are a promising line of enquiry for storytelling activities, particularly for collaborative work with children with special educational needs and disabilities. We also contribute to the growing body of work on co-design with mixed visual abilities, suggesting that involving all learners and stakeholders in the design process leads not only to more accessible, but also more inclusive design. Overall, this work has shown that providing multisensory learning experiences can be a beneficial approach for working with mixed-ability groups. Further, we propose that incorporating multisensory elements into the design of technology for children with mixed abilities can facilitate collaboration and group discussion, and lead to more engaging experiences for primary-aged learners.

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Selection and Participation of Children

Children who participated in this research were selected by the school Special Education Need Coordinator (SENCo). As per the school’s instruction, we used a combination of two mechanisms to obtain consent, a school-based consent system where parents expressed their willingness for their children to take part in research activities, and our own institutional consent mechanism, which was cleared by the authors’ institution Ethics Committee, which included commitment to adhere to Data Protection legislation). We provided the SENCo with consent forms and information sheets, which they distributed to parents prior to the work being carried out. We also obtained children’s assent to take part in the workshops at the start of each individual workshop.

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