A Tangible Tool for Visual Impaired Users to Learn Geometry

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TEI '16, February 14-17, 2016, Eindhoven, Netherlands
© 2016 ACM. ISBN 978-1-4503-3582-9/16/02 $15.00
DOI: http://dx.doi.org/10.1145/2839462.2856536

Abstract

This paper explores how an Android application used in combination with a tangible appcessory can facilitate learning for visually impaired students of geometry. This paper presents the status of this ongoing project. It describes the application, the physical appcessory as well as early stage user studies. The application enables visually impaired users to explore simple geometric forms displayed on a tablet through sound and vibrotactile feedback. A deformable physical appcessory that can be manipulated to adopt these forms and its shape sensed by the tablet adds an additional tactile layer to the application and experience. Three user engagements with visually impaired serve as early validations of our project and ideas and provide feedback that directs design and development of future work. Current avenues for the future work will include additional interaction modes in the application, e.g. the ability to digitize real world forms, and improving the robustness of the tangible appcessory.

Author Keywords

Visually impaired; geometry; application; appcessory

ACM Classification Keywords

D.2.1. Requirements / Specification: Elicitation methods (e.g. User Studies); D.2.2. Design Tools and Technique: User interfaces; Accessibility.

Figure 1: A geoboard. This is used as an aid for VI students to be able to explore geometric shapes through touch.

Introduction

Worldwide, there are an estimated 285 million people who are Visually Impaired (VI), 19 million of whom are children below the age of 15 [12]. These children are widely acknowledged to face educational challenges with material that is spatial or visual in character. However, in order to prevent educational disparities, recent research and policymaking is promoting the inclusion/integration of people with visual impairments into regular classrooms [10]. Consequently, there is a growing research interest in new tools to support the learning activities of these individuals. Within this space, this paper focuses on geometry, an important part of school curricula. In current school settings, VI students use systems such as a geoboard (cf. Figure 1), a braille printer or physical objects they can explore to advance their geometry learning. However, though these tools are valuable, they also suffer from disadvantages: they are imprecise, can be laborious to arrange and configure and they are expensive [7][7][7].

In this paper, we explore an alternative approach to facilitate the geometry learning by visually impaired children. This solution is based on cheap, widely available tablet PCs in combination with adjustable tangible objects that act as proxies for geometrical forms. The idea is to allow children to manipulate the physical object into different geometric forms, sense these shapes using the tablet and then provide interactive digital feedback and further information using modalities such as sound. We argue the learning can be facilitated not only through the intrinsic properties of the system but also by fostering communication between visually impaired children and other learners - in other words, the system becomes a focal point that all learners can understand and explore.

The remainder of this paper briefly reviews related work, highlights the objectives for this project and describes initial prototypes and field tests. We close by summarizing future avenues for this research.

Background

Research suggests that the use of multimodality in interactive learning environments and the utilization of distinct external representations to convey information are beneficial for learning (see for example, [9]). However, the judicious use of multiple external representations and modalities in interactive learning environments is, in itself, an important issue to take into consideration (see, for example, [6]). For example, Ainsworth [1],[2] has found that providing multiple representations can hinder learning, as it requires students translating from one to the other. To aid further research in this area she has provided a taxonomy of the different functions of different forms of external representations. Her taxonomy addresses the important issue of the distinct types of relationships that different external representations might establish between themselves in a learning environment and how these might be used to foster learning. Ainsworth considers that a crucial part of the evaluation of a learning environment that uses multiple-external representations is to understand clearly which functions are present and how they fit with the learning goals. Although this is an important perspective, we note that relatively little work has applied these ideas about external representations to the context of VI learners.

Figure 2: Application **for** iteration 1

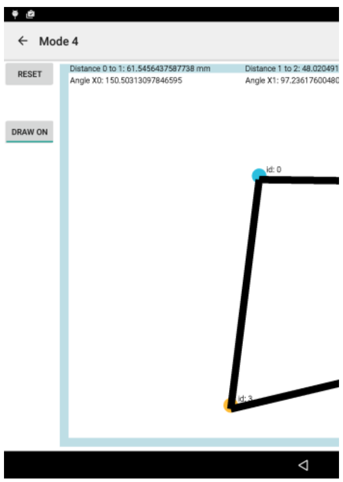

Figure 3: Application **after** iteration 1; new functional buttons and thicker lines

Auditory-feedback is an important element to be considered when creating learning tools for visually impaired children [5]. For example, visually impaired learners are very able at picking information encoded in diagrams through the use of variations of sound, tones and loudness [3]. Furthermore, applications are being designed especially for children (age 8-12) [5], which suggest a need for a target-specific application. More recently, researchers started to explore the potential of tangible user interfaces for the visually impaired. For example, McGookin, Robertson and Brewster [8] present a tangible user interface that not only allows visually impaired users to explore data conveyed in graphs and charts but also to create their own graphs and charts. The interface designed uses phicons and non-speech audio on a grid system. The evaluation conducted showed much promise regarding the possibilities offered by the physical manipulation of the tokens and the sonification of system's state changes.

Nevertheless, although these digital artifacts may facilitate the learning of visually impaired children, the context in which learning happens is very important and the proper integration of VI children in the classroom learning activities is crucial so that knowledge construction can take place (see, for example [11]. However, Droumeva *et al.* [5] consider that more research is needed to explore the design of complex auditory displays for children's interactive learning technologies.

Current Research Focus

This paper aims to shed light on the following issues:

a) What features should a tangible digital system have to effectively facilitate the understanding of mathematical geometry for visually impaired children?

b) How can tangible user interfaces and tablets be combined to effectively support the learning of mathematical geometry by visually impaired children?

Prototype

The prototype consists of an Android tablet application and a physical "appcessory" that can be manipulated, placed on the tablet and detected by the application.

Android Application

The Android application is designed to run on a Google Nexus 10 tablet. The application uses the tablet's ability to detect multiple on-screen touches – it creates geometric shapes that correspond to the angles and distances between the sensed points. It also has the ability to display audio and vibrotactile feedback.

The prototype has the following features. It has two modes: draw and explore. In the draw mode, it creates and shows an enclosed shape between the current set of touch points and visually displays the length of each of the lines and angles at the points. For example, if four points are placed on the screen, the application will draw and annote the corresponding quadrilateral. The lines are thick (25 pixels) and at maximum contrast: white lines on a black background. In explore mode, the on-screen shape is frozen and subsequent screen touches can be used to explore it. Touching the lines results in a vibration while touching either the outside or inside of the shape results in, respectively, one of two distinct sounds (currently a birdsong and a mechanical sound).

Figure 4: App with black theme (for 2nd user study), main screen

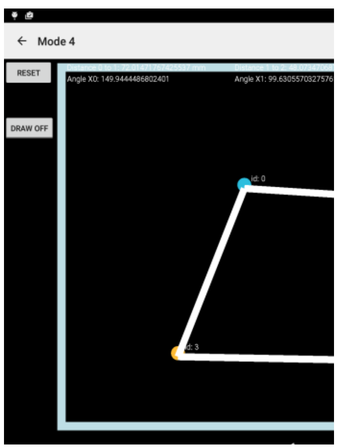

Figure 5: Application for iteration 2, interactive screen

There is also a menu area on a sidebar. This contains buttons for toggling the mode, for resetting the displayed shape and for toggling audio feedback (currently used only for the button names). The development of the application can be seen in the Figure 2, Figure 3, Figure 4 and Figure 5.

Appcessory

While shapes can be formed on the application using a set of finger touches, it was designed to be used with a tangible accessory. This takes the form of a 3D printed object that is composed of a set of ball-and-spoke components. Each component features a corner node connected to one narrow (5 mm) rod and one wide (11 mm) hollow rod. The top and bottom of the nodes are flattened, to sit squarely on the tablet, and covered with copper tape. The two pieces of tape are internally connected such that contact with the top piece will be sensed by a touchscreen under the bottom. The central portion of the node is a cylinder with three freely rotating rings on it. One of the two rods is glued to the central ring, the other to the top and bottom rings. In this way, both rods can rotate around the node. Multiple components can be combined together by slotting the narrow rod of one into the wide rod of another. If there are three components, a triangle can be formed; four makes a quadrilateral. As both the angles and lengths of the pieces can be manipulated, a wide range of shapes can be produced. Touching the tops of the nodes causes the tablet to sense their position and the application to record the shape. Figure 6 and Figure 7 show the components of the nodes, while Figure 8 shows an assembled prototype forming a quadrilateral.

User Study

At this point one informal meeting as well as two user studies have been performed. All of these were held with visually impaired individuals. We have established communications with a youth VI community (US SYD[1]) and arranged meetings with their members and affiliates. The first meeting was to establish contact with the community as well as verifying the general idea, thoughts and research so far. Attending this meeting were two VI, one man in his mid-30's as well as one woman in her late-40's. We received broadly positive feedback and responses regarding the concept and physical prototype, not only from the VI attendees but also from the sighted facilitator. Concrete comments covered the feasibility of the physical design: the VI attendees confirmed that the object was understandable and manipulable. Furthermore, the key functional sites (the conductive cooper tape surfaces that need to be touched for the object to be sensed) had a unique feel that was clearly and readily distinguishable from the rest of the model.

Following this meeting, a first user study was scheduled in which the tablet application would be tested. In this session, we presented the vibration and sound output features during interacting with a created shape. The testers were two VI individuals, a mid-30 man and a 20-year old woman. Both testers were positive about the concept and general application design. Comments included recommendations to maximize the contrast of the line against the background and to maximize the width of the lines - these suggestions were integrated into the prototype described in the previous section. Using a combination of cues, the testers stated they

[1] Their website can be found here: http://www.ussyd.se/

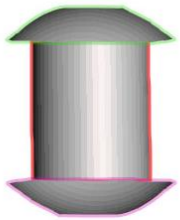

Figure 6: Schematic of center of the node

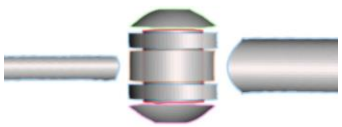

Figure 7: Schematic of corner piece for the appcessory

Figure 8: Appcessory with connectors and copper tape

were able to understand the shape on the screen and seemed to be able to gather a good understanding what the square "looks" like. This feedback enabled us to develop the application further to fulfill the VI's needs as well as validate our idea further.

The second user study was performed with three VI individuals. This included the same individuals from the first session and one additional 40-year old male. The session was video-recorded[2]. In addition to presenting the updated application, the model and testing the interaction, we presented them with imaginary scenarios concerning learning geometry as a VI. These were inspired by the speed dating method [4] – the scenarios expressed a range of different ways the system could be used and, served as a focus for gathering feedback on prospective design directions.

This session revealed some practical problems. Although the participants appreciated changes such as the high contrast visuals, other features were more problematic. The voice over function, enhancing the interactions with sound support, only reacts within the application. It is a self-programmed and not a part the operating system. This internal function needs to be extended to convey a better understanding of where on the screen the VI "are". Furthermore, it became obvious that system features encumber the interactions. Specifically, system level features from Android (such as the main app menu) repeatedly opened during the VI users' exploration of the screen with their fingers. This was problematic as it stopped the interactions with the shape and our app. It is clear that necessary system controls will have to be designed very carefully in order to support free exploration of a scene by VI users.

[2] Spoken languages are English, German and some Swedish. The video is accessible here.

They also commented on the tangible object in more detail. Specifically, they noted it feels too flexible and not robust enough. This lead to feelings of nervousness while using it – its perceived fragility made them uncomfortable. This problem was exemplified by one incident where one of the individual rods became disconnected from its node. It is clear the appcessory needs to be more robust to convey a feeling of security to the VI users. Whilst reviewing the scenarios we presented during the session, we observed a strong preference for the VI's to use equipment that is similar to other students and learners. They were also adamant that learning technologies need to be mobile and accessible to VI individuals without assistance from a sighted assistant. Participants were also positive about different ways that data could be digitized for them to feel, such as taking a snapshot of a shape in order to feel its digital representation in the application.

In conclusion, the user studies and meetings led to generally positive feedback and a validation of the approach. The visual impaired individuals we worked with are positive about including the application and model in classrooms to make it easier to learn geometry and improve the integration of VI students.

Future Work & Conclusion

One area that future work on this project will focus on is in terms of improvements to the physical model. We are pursuing several approaches and strategies. These include using high-fidelity fabrication techniques to increase the strength and stability of the rod components in the current design and exploring alternative designs that are more stable but less flexible. One approach is to create compound shapes from fixed elements that robustly snap together, in a similar way to Lego. Evaluations to determine which of these approaches best fits the needs and capabilities of VI learners will be required. We are also continuing to develop the software application to include a range of different modes and use scenarios such as exploring a shape, problem solving or capturing a digital representation based on a snapshot. On the empirical side, next steps will involve assessing the system with VI children, ideally in a classroom setting, in order to formally determine whether it provides an enhanced learning experience and increases classroom integration.

In conclusion, the work-in-progress paper has presented the design and development of a novel tangible system intended to aid VI users in learning geometry. Through a series of user engagements, we have refined our design and validated the basic approach. Future work will continue to develop the design and involve more formal studies to establish its value. We believe that tangible educational tools have much to offer the visually impaired learners and that this paper outlines a promising design candidate in this space.

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