‘Clicks’ Appcessory for Visually Impaired Children

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Abstract
Visually impaired children face challenges in learning spatial contents and materials, such as geometry. While many existing tools, such as string boards, or protractors with physical angle markers, can facilitate learning, these devices are highly specific. This problem contributes to low levels numeracy levels in visually impaired individuals. Addressing these problems, this paper presents Clicks, a digital manipulative for visually impaired children (KG to grade 3) that supports a range of geometry education tasks and ties physical adjustments to the device to a dynamic digital representation and additional audio feedback. The tool is a construction kit of simple geometric primitives that snap together to produce a range of more complex forms such as lines, angles, triangles and rectangles. When placed on a tablet computer, the geometry of these objects is sensed (via the capacitive touch screen and electrodes embedded in the objects) and audio feedback provided.

Author Keywords
Innovation; Visually Impaired; Educational Toy; Tangible Interface; Multimodal Interaction; Geometry

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

The World Health Organization estimates that 1.4 million children under the age of 15 are irreversibly blind [10]. A wide range of specialized tools have been designed to cater to their educational needs. Many, such as the common corkboards that enable creation and exploration of lines and graphs from pins and string [7] or the Orion TI-84 Plush Talking graphing calculator [8] that is capable of speaking or sonifying charts, focus on replacing traditionally visual STEM (Science, Technology, Engineering and Mathematics) contents with physical, tactile or audio equivalents. This focus on technical education is critical as, given appropriate support, blind students are widely recognized to have the potential to meet same learning goals as their sighted peers [4].

This paper contributes to this area by investigating the design space of a digital manipulative [9] – a tool to support playful exploration and learning that ties work with a physical artefact to dynamic digitally mediated responses – that aids blind individuals in understanding geometric concepts. The current article describes the background and motivations for the work and the design and fabrication of the physical prototype. It closes with a set of use scenarios exploring how the system could be deployed to support playful and exploratory educational experiences

Related Work

Students with vision impairments face major challenges in learning STEM contents compared to their visually able counterparts. There are many facets to this problem, such as a lack of suitable trained educators and the fact that the many traditional aids, such as charts and figures, are predominantly visual. Some scholars argue there are more foundational differences. According to Jackson [6], for example, blind people learn geometry in a fundamentally different way than sighted people as they analyze information obtained through touch and hearing rather than vision. Jackson argues the result is that blind individuals have a powerful spatial imagination and an increased ability to visualize spatial orientations that are difficult for sighted people to understand. Information and Communication Technologies (ICTs) are widely recognized to have substantial potential to bridge educational gaps between visually impaired persons and their visual counterparts by providing rich, interactive presentations of concepts in alternative modalities such as audio and touch [3].

Tangible systems offer a more natural experience. Typically involving a set of freestanding physical objects that are tracked by a digital system, they are capable of presenting dynamic cues as the objects are adjusted, manipulated or configured. Authors have deployed such systems to present graphs non-visually through the arrangement of thin stick-like objects [7] or to allow visually impaired users to experience and recreate spatial data relating to maps [5]. This paper argues that tangible systems have strong potential to support geometry learning in visually impaired students by combining natural physical manipulation of objects with digital feedback as to geometric state and forms of the objects. The reminder of this paper describes the design of a tangible system to achieve that objective.

User Interview

To inform our design process, we first opted to conduct a formative interview session with a blind educator. This individual has been blind from childhood and has


Figure 1. Initial prototypes include both fixed system (left), and extendable system (right).

over seven years' experience teaching visually impaired children. To get the most value from this session we finalized initial design decisions in order to present a high-level candidate system prototype for discussion. We prepared simple physical mockups of a strut based construction kit that would enable users to snap together a range of simple geometric shapes. We opted to use a standard tablet computer and capacitive markers as the tracking system [2]. At this stage our system was neither functional, nor fully designed and the goal of preparing these materials was to better solicit critique and comments.

A key result from this session was confirmation that visually impaired students struggle with geometry (and math in general). The interviewee reported that a high percentage of the visually impaired students he tutors give up on mathematical learning goals, particularly in the area of geometry and primarily due to challenges in visualization of the concepts. However, in line with formal statistics [4], he noted that visually impaired students do have the potential to excel in this area. These comments validate our choice of application area. Additional comments cautioned about the use of technologies such as touch-screen tablets, as these can be challenging for visually impaired students to operate. We interpret this as supporting our design goal of an interactive system controlled solely by physical, tangible objects. In terms of the physical prototypes, feedback was towards increasing physical markers on the objects so that learners would be able to easily and unambiguously identify them. For example, including Braille text that describes each object on its surface. This comment highlighted the need to focus on careful physical design of the tangible objects to maximize their comprehensibility.

Prototype

With this feedback in mind, we designed Clicks, a digital manipulative for visually impaired children that supports a range of geometry education tasks and ties physical adjustments to the device to a dynamic digital representation supported by audio feedback. The tool is a construction kit of simple geometric primitives that snap together to produce a range of more complex forms such as lines, angles, triangles and rectangles. When placed on a tablet computer, the geometry of these objects is sensed (via the capacitive touch screen and electrodes embedded in the objects) and audio feedback is provided. In the next section of the paper we describe the design and construction of the Clicks prototype and its accompaniments in detail.

Design Exploration and Form

Our initial design exploration considered two options. In the first, simple fixed line primitives were snapped together to produce shapes. In the second, '*Clicks'* objects took the form of rotary joints each featuring an extendable rod and a socket that another *Clicks* rod could be attached to. This allowed *Clicks* to be arranged into a large number of forms with only a small number of pieces. Initial prototypes of both approaches were produced and are shown in Figure 1. After initial tests, we opted to pursue the first design. The is because of its simplicity, an important quality when designing tools for visually impaired individuals. Static forms would also increase ease of fabrication. After settling on a form factor, we began to explore its function in detail. Through iterative prototyping, we identified a number of key properties our design should maintain. First, the design should feature only a single type of component that is available in a number of different sizes. Second, each component should have only one way it can be

Figure 2. Clicks working prototype. Three pieces joined together

connected to another. Third, the design should have a clear top and bottom, so that it can be unambiguously assembled. These three properties are intended to make using the prototype as simple as possible. Finally, we should maximize the angles at which two components can be connected together. This allows *Clicks* to support creation of a wide range of geometric forms. The final forms are illustrated in Figure 2. Each object is composed of a base assembly connected by a strut to a top assembly. Objects are joined by connecting bases to tops. The strut that connects the base to the top is slanted upwards to maximize the angles at which two components can be connected.

Construction and Functioning

Clicks is intended to operate in conjunction with a tablet computer capable of sensing the configuration of its parts – its geometric form. In order to achieve this objective, we use a capacitive tracking system on a standard tablet [2]. This simply leverages the ability of modern multi-touch tablet computers to track not just fingers, but any conductive object placed firmly against their screen and in contact with a human user. Figure 3 shows the current prototype construction. In order to maintain a good connection with the screen, each *Clicks* base assembly consists of a conductive rubber screen contact point and a magnet mounted above it. This is connected by a cooper wire to the top assembly at the

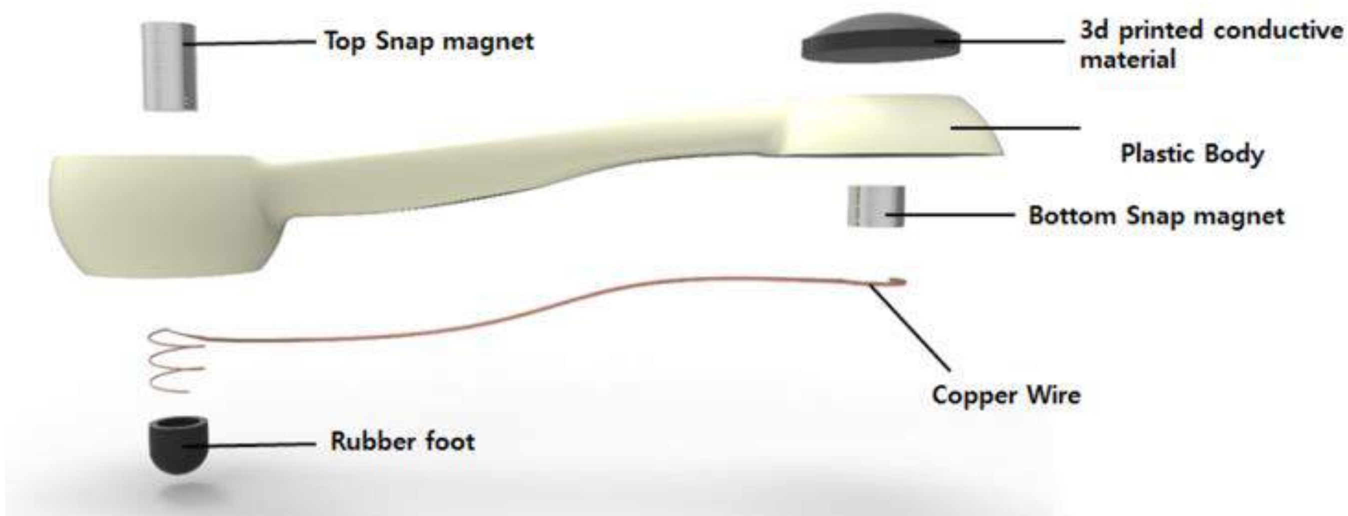

Figure 3. Clicks first working prototype. Three pieces joined together

Figure 4. Clicks packaging (top), and initial design for tablet holding plate (bottom)

Figure 4. Final tablet holder with a tablet and Clicks product

other end of the strut. The top features another magnet (with the polarity inverted) and a conductive cap. When Clicks is used, base assemblies are magnetically snapped to top assemblies to make shapes. The magnets and wire serve to transmit touches to any of the conductive caps at the top of a Clicks shape to all of the screen contact points on the bottom. In this way, a tablet computer can sense a complete form, even when a user touches only one part of a shape. The body of the Clicks prototype is 3D printed in standard PLA while the conductive cap is 3D printed using a carbon impregnated PLA with a high resistance that is optimal for use with touch-screens. The current prototype is rendered in three lengths (6cm, 9cm and 12cm) capable of supporting construction of a range of different shapes (squares, rectangles, triangles).

Navigation System Design (Accompaniment)

In the user interview one key piece of feedback was that the tablet and system setup would need to be designed for use by a visually impaired individual. Accordingly, we designed a holder for the tablet that integrated a physical navigation system to support the application. This was placed alongside the Clicks objects in a custom package (consisting of two separate boxes) that included milled foam insets for each piece. The goal of this package was to support unsupervised play – so that visually impaired learners could open, assemble and start to use the system without support from educators or other sighted individuals. Our initial design was a 3d printed tray that would hold the tablet and include the navigation system on one side. It was designed to serve as part of a wooden package for the product (Figure 4). To reduce size, the tablet holder in our final design consisted of a pair of bars that each fit underneath one end of the tablet to provide a flat, raised play area (Figure 5). One bar incorporated three hinged flaps, each of which lay flat on the tablet surface during play, but could be raised to support assembly. The flaps extended over the tablet surface and were terminated by a hollow ring-shaped form that enabled finger access to the touchscreen at its center. In this way, each of the hinges physically marked an on-screen location and was intended to support standard touchscreen input by visually impaired users. The hinges were also labeled with Braille.

Interface Conceptualization

We generated use scenarios that explored how *Clicks* could be deployed in a learning context. Our current ideas focuses on the concept of a quiz. The target age group for this system is from kindergarten to grade three and the content was based on school curricula in the US [1]. These scenarios also formed the basis for our interface software prototype (Figure 6).

The application has three modes of difficulty:

- Size identification and basic shape making (level 1) – Quiz questions focus on the user identifying differently sized Clicks pieces and putting them together to make shapes.
- Geometric term identification and modification of shapes (level 2) – Users are asked to produce shapes that feature different geometric properties such as parallel lines or right angles.
- Problem solving (level 3) – in this advanced stage users are given a riddle they have to solve by producing a shape with specific properties on the tablet surface.

Figure 5. Interface to support the struts for easy manipulation by the child when game starts.

Validation and Future Work

We conducted an additional evaluation to gather feedback on the design and provide directions for future software development and product refinement. This took the form of an interview based on the physical prototypes and was followed by a think aloud session using the wizard of Oz technique (where audio samples were prepared in advance to take the users through the task they were to complete). The participants were one blind instructor and one blind adult student. We acknowledge that future studies need be conducted with our target users (visually impaired students in KG to grade 3).

We received detailed feedback from the evaluation including:

- Although the navigation achieves its purpose the design of the product should be adjusted to make the play process easier as there were some challenges in assembling the base unit.
- The system should be extended to tasks such as making measurements and more open ended puzzles to provide a wide range of content that visually impaired students can work and play with.
- Comments on the software application prototype in both the interview and the think aloud session suggested the application could be made more interesting by, for example, including a timer as the game progresses to make it more challenging and by adding ludic features (e.g. characters) that aim to keep children engaged.
- In order to accommodate children unable to read Braille, use different numbers of simple raised points to depict the lengths of the pieces.

While this session highlighted the potential value of the Clicks prototype and concept, this project is still in the initial stages and further design of the product will take place to accommodate the feedback captured in the evaluation session.

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