Gesture-based Interaction for Individuals with Developmental Disabilities in India

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ABSTRACT
Gesture-based interaction provides a multitude of benefits to individuals with disabilities, for example, enhancing social, motor and cognitive skills. However, applications that encourage self-efficacy by promoting a life-skill through simulations of real world scenarios are largely missing. We explore the benefits of using a gesture-based application for individuals with developmental disabilities. The context is a special school in New Delhi, Nai Disha, where we designed and developed an application, *Kirana*, that integrates arithmetic and social interaction to teach purchasing of items from a local grocery store. In our study, 18 participants with developmental disabilities, previously unable to visit a grocery store, used *Kirana* for three weeks. Our results indicate that gesture-based applications can teach a life skill and enable self-efficacy for individuals with developmental disabilities by breaking down complex tasks that require social, mathematical and decision-making skills.

Keywords
Gesture-based interaction; Developing countries; Individuals with developmental disabilities

1. INTRODUCTION
Individuals with developmental disabilities require personalized care when using conventional educational methods. They face challenges in learning skills that promote self-efficacy – including the danger of being misunderstood and mistreated outside the classroom environment. In this work, we consider individuals with development disabilities as individuals with cognitive challenges, autism, or Down syndrome. Previous research has shown that interactive technology offers several desirable advantages for such individuals, including (a) controllable input stimuli ([5],[18],[32],[33]), (b) multisensory and safer learning environment ([1],[2],[3],[37]), (c) opportunities for customization for individualized learning ([1],[2],[7],[18],[19]), (d) structured, predicable and consistent learning environment ([1],[2],[18],[32]), (e) the possibility to introduce controlled modifications or difficulty levels ([1],[2],[7],[18],[19]), (f) assistance in generalizations between scenarios ([1],[2],[31],[32],[33]), and (g) possibility for self-paced repetition of learning activities ([18],[19],[32],[33],[37]).

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However, research on gesture-based applications for individuals with developmental disabilities is mainly focused on therapeutic interventions and specific social, motor and cognitive skills. The potential benefits of designing and developing real world task-based interactive applications that promote essential life skills for self-efficacy are largely under-researched. For the purposes of interventions, complex social and cognitive tasks can be broken down. For example, buying something from a local store requires social interaction - talking or asking for something, and cognitive skills, like knowing what to ask for, knowing how much money there is to spend, and deciding if the item and cost are comparable.

There are several options for implementing interactive applications. Although virtual reality applications are known to assist individuals with developmental disabilities in understanding real world challenges [6] and [23], it can be argued that for children on the autism spectrum the fidelity of the representation is less important [32], and visual, auditory and motor experiences and feedback, when used together, result in more efficient learning and information retention [6]. This notion is also supported by the theory of embodied cognition [42]. Thus, simpler 2D interfaces employing immersive gesture-based interaction can potentially be sufficient to simulate real world environments.

However, novel technologies are often perceived to not be cost-effective, as catering to a limited group of people, and difficult to maintain and integrate into existing systems. This is particularly true in developing regions, including India, where access to such technologies is still limited, especially for individuals with developmental disabilities. Moreover, available resources are low, integration and inclusion of individuals with development disabilities into mainstream society is strained, and the digital divide – technical and economic barriers – is more pronounced. To overcome these challenges and perceptions, it is important to substantiate the potential of such technologies to build a stronger case for their mainstream adoption. These applications also need to consider the cultural implications of the real environment, as “what constitutes appropriate behavior is largely a social construct” [3]. Thus, it is important to collaborate with the different stakeholders, for example, teachers, therapists and caregivers, and follow a user-centered design approach.

This paper presents the potential benefits of using a gesture-based application that simulates a real world scenario to impart a life skill to individuals with developmental disabilities. We first conducted a user-centered design study to identify a suitable gesture vocabulary and life-skill. We designed and developed an application for mimicking the real world scenario of buying groceries from a local mom-and-pop store, ***Kirana,*** in New Delhi. We evaluated *Kirana* with 18 individuals with developmental disabilities, who were unable to shop independently. Our findings suggest that applications that employ gesture-based interaction to simulate real world scenarios in a safe and controlled environment can provide learning that is translatable from the virtual to real world. Our main contribution is demonstrating the potential of gesture-based applications to facilitate self-efficacy in individuals with developmental disabilities.

In the following, we first contextualize the research with the related work in this domain. This is followed by a detailed description of our user-centered design study and its results. We then present the application description, evaluation methodology and its results. We conclude by discussing our findings.

2. RELATED WORK

In the related research we (a) discuss gesture-based interactions for individuals with developmental disabilities and its potential benefits vis-à-vis the theory of embodied cognition, (b) present an overview of assistive technologies for Indian children, and (c) differentiate our work from previous work on virtual reality applications for learnings real world skills.

2.1 Gesture-based interaction

Employing gesture-based, *embodied* interaction for social, therapeutic and educational applications for individuals with developmental disabilities has gained momentum in recent years. There is strong evidence in support of embodied learning paradigms based on the theory of embodied cognition, whereby cognition is situated within the environment and learning occurs also through bodily interaction with the environment [22], [42]. The embodied learning paradigm has been extensively studied in neuroscience and cognitive sciences ([10],[15],[21],[40]), and has been adopted by research in educational technologies within the human-computer interaction (HCI) domain [11].

Studies by Bartoli et al. [1],[2] showcase the benefits of embodied learning via gesture-based interaction for children with autism. Our work expands Bartoli's work by extending it to individuals with developmental disabilities (including autism and Down syndrome), and to children from developing countries, by focusing on a life-skill. In line with Bartoli's findings, we also purport that learning from gesture-based interaction is applicable to real world scenarios where selection via pointing and moving of physical objects simulates interactions in everyday life.

Previous research in this space is largely focused on individuals with autism and in improving social, motor and cognitive skills. The focus of the research has been on attention and memory or the concept of self, and it has employed tangible interaction and/or sensory motor perception. For example, SensoryPaint is multimodal application that incorporates tangible interaction and whole–body interaction for therapeutic interventions to encourage social interaction [35]. Research by the Lakeside Center for Autism[1] and Kinems.com[2], taps into the potential of gesture-based interaction and its inherent affordances for kinesthetic learning experiences within the classroom environment. MEDIATE [13] is a multisensory interactive environment that utilizes real-time visual, aural and vibrotactile stimuli. There are also studies on gesture-based applications to match visual facial expressions [7], improve hand-eye coordination, attention and focus [1], detect repetitive behavior or tantrums [13], for promoting joint attention [38], and for cognitive rehabilitation and exercising [14]. However, there is limited research on using gesture-based applications to impart life skills, such as purchasing items. In this context, incorporating culturally sensitive gestures and interactions is particularly important [3].

2.2 Assistive technologies in India

There is a culturally misguided attitude towards children with disabilities in India. A study of teachers' attitude towards children with disabilities in schools in Mumbai showed that prior acquaintance with a person with a disability was a governing factor for teachers' to be more positive and welcoming towards inclusive education [29]. A World Bank survey in 14 developing countries, including India, indicated a "worrisome vicious cycle of low schooling attainment and subsequent poverty among people with disabilities in developing countries" [12]. While there are several schools for children with special needs across India, very few of them employ technology within their classrooms and there is limited research examining the role of assistive technologies. One study proposed developing assistive communication technologies for individuals with autism or dyslexia in India [37]. Another, called Jollymate, is a digital notepad for children with dyslexia that emulates a "phonetics system of teaching letter sounds and letter formation" [19].

There are challenges in introducing new technological interventions, especially for individuals with development disabilities in the developing world: (a) resource constrains within the environment, for example, infrastructure and access to electricity, (b) a huge digital divide, thus communities that can benefit the most from technology have the least access to it, (c) inclusivity and integration among children with disabilities and typically developed is low, (d) technologies are too costly, especially for individualized use, and (e) stronger cultural barriers for individuals with disabilities that lead to more pronounced digital exclusion even within the technology-capable communities. For example, economically stable and educated parents might provide a mobile phone to a typically developed child and but not to a child with autism. In fact, studies have shown that cultural, societal and socio-economic factors largely affect "the experience of autism" [3] [16]. However, we believe that several emerging technologies are now affordable and one device can cater to a larger number of children, so that a whole school can time-share the resource.

2.3 Simulating real world scenarios

Simulations of real world scenarios to provide learning tools for individuals with special needs have been studied from the late 90s. This work has primarily focused on virtual reality environments (VR) utilizing computer generated three dimensional (3D) worlds. Applications include therapeutic, social and skill-based learning, including solutions for individuals with developmental disabilities, most notably autism and ADHD [8]. Studies have examined the benefits for social interactions [20] [18], collaborations with peers [31], or avatars [27], understanding facial expressions [17], pediatric rehabilitation [33], physical rehabilitation [23] [34], sense of presence [26], [31], [41], and skill based learnings [39]. For example, Coles et al. [6] and [28]

[1] http://lakesideautism.com/tag/kinect/

[2] www.kinems.com

taught road and fire safety skills to children affected by prenatal alcohol exposure using. However, much of this research is focused in the developed world, and so the applications are possibly socially and culturally unsuitable for developing countries [3]. Our work does not utilize 3D virtual reality, but a simplified 2D graphical representation with gesture-based interaction. The graphics and gestures for interaction are designed from a real world scenario.

3. USER-CENTERED DESIGN STUDY

We worked with one of India's oldest and most established special schools, called Nai Disha. Nai Disha is a part of Tamana.org, a nonprofit organization with four centers across Delhi. Nai Disha is dedicated towards providing young adults with developmental disabilities physical, emotional and functional independence by imparting vocational training and skill development. During the school's annual Diwali Mela (fair celebrating the Indian festival of lights), we conducted a user-centered design study by setting up two games in one of the school's classroom. The study had several purposes:

1. Capturing teachers', students' and their parents' initial reactions to such a system
2. Defining a gesture vocabulary for three main interaction goals, namely navigation, selection and object manipulation
3. Identifying application areas or topics where gesture-based interaction can assist the students.

Setting up the installation during the Diwali Mela provided an event to introduce the researchers to various stakeholders - school staff, teachers, children and their parents - in an informal public gathering. This helped create an open and relaxed atmosphere to experience and discuss gesture-based applications, and an opportunity to gain insights into the stakeholders' expectation and acceptance of such technology.

We designed two applications for the study to understand how the children interact with the screen space and select objects using free form gestures. The games provided an opportunity to identify gestures, which are fun, enjoyable and comfortable. The trials were recorded in short video clips, photos, questionnaires and observations. The data was analyzed by the researchers. The two applications and our findings from the user-centered design study are described next.

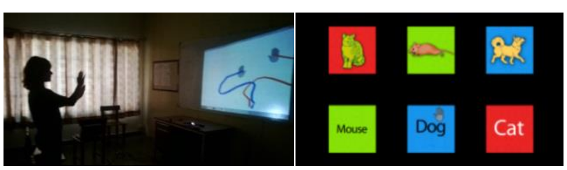

Figure 1: left) a researcher demoing the painting game, (right) interface of the flash card based animal matching game.

3.1 Free-form painting

The free-form painting application was used as an introduction to gesture-based interaction without pre-defined tasks. The objective was to observe natural, comfortable and intuitive hand gestures, a novelty in the educational setting, and to derive gestures for navigating the screen space. Participants could use their hands as paint brushes and draw on a white canvas. The right hand would draw in red while the left in blue. The width of the hand-brush was controlled by moving the hand away (thinner) or towards (thicker) the white canvas. The participants were free to draw any shape or image they liked, as shown in Figure 1(left).

3.2 Animal matching game

The animal matching game was based on flash cards used extensively in Autism interventions, and for example also in the TOBY Playpad [43]. The game used pointing, with a dwell time of one second for selection, and drag-and-drop for object manipulation. There were three cards on the top row and three placeholders on the bottom row (Figure 1, right). The top row of cards was initially stacked and opened up after a swipe gesture was made, similar to the gesture of spreading out a deck of cards.

Participants selected a card by pointing at it using their right hand for one second. A successful selection attached the card to the cursor following the right hand. The attached card had to be dragged close to the correct placeholder in the row below. Thus, when a card (animal picture) was near its correct placeholder (text), the card animatedly flew on top of the placeholder, resembling magnetism [25]. To make the game simpler for students who could not spell, the flash cards could also be matched based on the background colors.

3.3 System description

Both of the applications were based on an in-house framework, utilizing the Microsoft Kinect sensor for gesture recognition, and consisting of three main processes; a Kinect service, graphics engine and application core logic. The Kinect service is a thin client over the Microsoft Kinect SDK that connects to the core logic. The Kinect is used to track the user's body movements. For the two applications, we tracked only the upper body joints for the gestures. The graphical content is rendered using the Panda 3D[3] engine. The core logic is a Python[4] based application that takes the Kinect data as input, based on which the relevant content is displayed via the graphics engine.

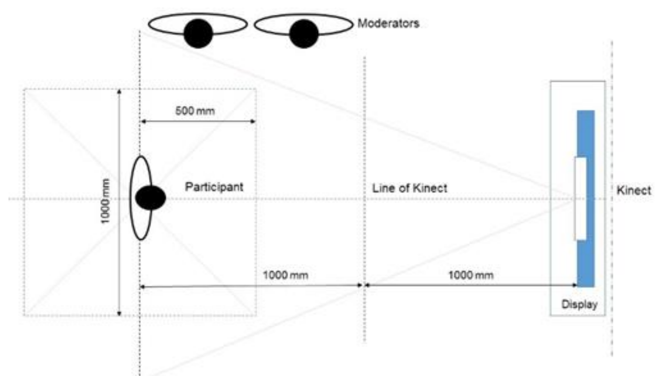

Figure 2: Game Setup showing the interaction space

The system responds to the user closest to the device in front of it in a 1 meter by 1 meter area, 1.5 meters away from the Kinect (see Figure 2). We call this the active area, that is, the area in which a user can interact with the application using gestures. An onscreen hand cursor was present in both the applications to help guide the gesture interaction. Each applications starts with a verbal welcome message when a user enters the active area, followed by a short music clip and the screen fades out from black to the game screen. While the user is in the active area, the system responds to her gestures as defined by the game. When there is no longer a user in the active area, the game screen goes back to black.

[3] https://www.panda3d.org/

[4] https://www.python.org/

3.4 Procedure

The students visited the Diwali Mela setup with their parents and were encouraged to try both applications. Students interacted one by one, first with the free form painting, and then the animal matching game. Students were asked to 'paint' something with the first application and their parents usually suggested an object, such as a tree, or to write their name. Instructions were kept brief to identify gestures that are intuitive and natural. Students interacted for as long as they liked, usually stopping once the white canvas was colored over 70%. For the second application, students were asked to 'match the animals'. The matching game was based on the already familiar flash cards, and students understood the task quite easily, and were able to finish the task.

Waiting students and parents, and other audience members were instructed to clap after every student interacted with an application. This was done as a reward for the students who tried out the unfamiliar environment and as a motivation for subsequent participants. Parents were interviewed after their child interacted with both of the applications and requested to fill in a feedback form. The feedback questionnaire aimed to understand the parents' experience of watching their child try the applications and their own expectations and initial reactions to the technology.

3.5 Findings

In total, 18 students with developmental disabilities, that is, individuals with mental retardation, autism, or Down syndrome, (IQ *M*=49.78, *SD*=10; SCQ M=51.6, *SD*=10) [36] participated in our user-centered design study out of which parents of 14 of them filled in the responses after their child had interacted with both the applications. For the remaining four parents' responses, either the parent was in a hurry or their child had interacted very briefly with only one of the applications.

3.5.1 Gestures for navigating the screen space

The onscreen cursor made it visually possible to imagine the hand-cursor as a brush to paint a red or blue line on the white canvas. From our observations of the gestures performed, the students formed circles using both hands with ease, as shown in Figure 3. Several participants, on the insistence of their parents, would try to write their name with large alphabetical gestures. Thus, we decided to design interaction-gestures using both hands with onscreen cursors for our main application.

3.5.2 Gesture for selection

There were two main gestures that were performed for selection: dwelling on an object or punching a fist towards the object. The punching gesture was popular and fun, but was not considered socially appropriate by the parents and teachers present. This is because the school experts shared concerns over the students' tendency towards repetitive behavior and the socially negative impact of a punching gesture outside of gameplay. This finding resonates with the role of culture and context in defining socially acceptable gestures [3].

For selection via pointing with a dwell-time, we observed that the dwell time of one second was too short for the participants and it triggered several unintentional selections, as the several participants verbally exclaimed 'oh' when a card was attached to their onscreen cursor. Thus, for our main application, we decided to use the dwell time of 1.5 seconds for selection. A participant making a selection by pointing is shown in Figure 4(left). Our applications also worked well for a participant using a wheelchair without using the Microsoft Kinect SDK's seated mode for gesture recognitions. Thus, with gestures requiring only upper body motion tracking, applications can be inclusive and comfortable for a larger group of participants.

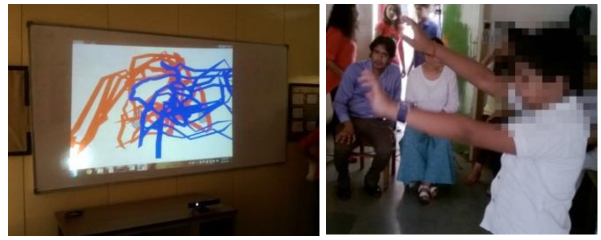

Figure 3: Participant creating midair circles

Figure 4: (left) Selection gesture with a one second dwell time and (right) parent helping a child with drag and drop gesture

3.5.3 Gesture for object manipulation

The animal matching game required moving a selected animal picture from the top row to a placeholder on the bottom row using the gesture inspired by the desktop drag and drop metaphor. Although all participants matched the three animal pictures to their placeholders, it was observed to be rather by chance than by choice, since the placeholders were *magnetic*. Thus, for object manipulation drag and drop was observed to be difficult. Figure 4 shows a participant being guided by her mother for the animal matching game. For our main application, we decided not to employ the drag and drop. Further research is required to identify a suitable gesture for this purpose.

3.5.4 Parent questionnaire

All of the parents agreed that their child enjoyed using the system and only 21% said it was tiring to use. Three out of the 14 children had used some form of gesture interaction before. Initial reaction of parents included excitement (50%) or being impressed (50%) by the games. 79% of the parents were enthusiastic about using gestures for educational interventions, while only one parent was skeptical and two did not comment. All but one parent had a positive overall impression of the system and that one parent had neither negative nor positive impression. 12 out of the 14 parents said they would consider using gestures for educational interventions in the future, while one parent wished the system worked better. Several parents, and also teachers, appreciated the inherent physical nature of the interaction, and commented that such games are good for body movement and encouraging physical activity. They hoped to see more rewards and motivation within the gameplay to encourage their child.

3.5.5 Potential application topics

Together with the teachers and parents at the Diwali Mela, we conducted a short focus group exercise to identify topics that are currently difficult to teach with traditional pedagogical methods and would greatly benefit from real world simulations with gesture-based interaction. These topics included monetary transactions, time management, planning or scheduling of events, working with constraints such as time or a budget, and the concept of currency (mainly because the size/shape/weight of Indian coins and notes does not relate to its value). Moreover, several teachers suggested designing an application that can simulate real world scenarios to assist in learning a life skill.

One of the life skills deemed important by the parents and teachers, was being able to purchase day to day items from a local *kirana* store, which are grocery stores in India (refer to Figure 5). The teachers explained that several students, who are able to communicate with strangers, are taken to the nearby market to practice buying an item, such as toothpaste, from the local store using a certain amount of money. However, sometimes a student is socially mistreated by strangers or the shopkeeper. Moreover, not all students are comfortable with all the processes involved in a visit to the local store, and the teachers are unable to extend the visit to these students. The school does not employ any other methods for teaching transactional calculations than traditional math classes and the occasional field trips to the local market.

Based on these discussions, it was decided that the real world scenario of buying an item from a *Kirana* store would be simulated in a gesture-based application and evaluated with the students who were not included in the monthly visits to the local store near the school. The details of the application, its interaction and design decisions are explained next.

Figure 5: A kirana store in India

4. KIRANA APPLICATION

In designing the *Kirana* application we broke down the life-skill into several smaller tasks: knowing the items to buy (decision making), asking for them from the shopkeeper (social interactions), looking up the price for each item, knowing if an item can be bought with the available cash (arithmetic), handing over the cash (social interaction), calculating the balance (arithmetic), and taking the balance and items (social interaction). In India, each item has an *M.R.P.* (maximum retail price), which is required by law to be printed on the item cover, and is usually the price charged by stores in New Delhi for the item. Therefore, students are also taught the concept of *M.R.P.*, which is contextually and culturally relevant for them.

These smaller tasks, which are independently achievable, bring out the bigger goal of ‘buying groceries’. Furthermore, the application aimed to promote socially acceptable and expected behaviors within the Indian context of *Kirana* shops, making the learning from the application, when translated to the real world environment, culturally appropriate. We did not include a shopkeeper–avatar in the application, as simulating social interactions to the required degree is complex. The application was designed to allow a teacher or moderator to imitate the social interactions based on individual needs.

Our research goal was to *validate the potential of gesture-based interaction in translation of learning of a life skill from an application to real world scenarios for individuals with developmental disabilities,* with a focus on the Indian social and cultural context.

The *Kirana* interface simulates a typical store layout. Customers stand outside the counter of the store and point to items they want to purchase. The screen has two shelves behind a table counter-top containing food items that can be bought, as shown in Figure 6. The items are randomly arranged at the start of the sessions, removing learnability of item placements. The application was built on the same in-house framework as the games in the user-centered design study applications described in section 3.3. The setup was also similar, that is, participants could interact within the 1 m^2 active area 1.5 meters from the Kinect (see Figure 2).

Figure 6: *Kirana*- buying items on the table by paying using a 10 rupees note

Based on the user-centered design study findings (section 3.4), gestures for interacting with the screen space and object selection used an onscreen cursor. Pointing with a dwell time of 1.5 second selects an object (item and money), which then animatedly slides to the table. This interaction eliminated the need of an explicit drag and drop gesture, which was found to be difficult (section 3.5.3). Moreover, since the application focus is primarily on three aspects of purchasing (decision making, social interaction and mathematics) the explicit gesture of handing over money was simplified in the application.

The session starts when a participant stands in front of the Kinect and is greeted by a female voice welcoming her to *Kirana*. The right side of the screen has the available money with the total amount displayed at the bottom. The left side shows the billing of items as they are bought allowing the participants to see the list of items they have bought and the total bill. The bill format is in line with *Kirana* shopkeepers who provide a written bill for all items purchased. The item’s price is automatically added to the bill on the left. Once there is at least one item to pay for, the participant can select any denomination of money using her right hand. This two-handed selection mechanism was added to encourage increased bodily movement and isolate the item selection from the money selection. Each item and money is accompanied by its spoken name and each transaction process has audio feedback. For example, when the balance is returned, the female voice says *here is your balance*. The application caters to the various endings: running out of money, or not enough money left to buy an item. For these scenarios, the female voice informs, for example, *you have no money left*. This is followed by a textual *well done* and an audio feedback to indicate the end of the session.

The animations of items and money were slow and sequential: there was only one item or money movement, from the shelves or the wallet, to the table at a time. Once an animation was finished, the balance was returned back from the table to the wallet. Updating the bill and total amounts was also in sync with the series of animation. The application also supports customization; the type of item, its price and total available money in the wallet on the right hand side could be changed between sessions. However, this feature was not used in the evaluations.

5. EVALUATION AND RESULTS

The evaluation consisted of four phases. In the phases I and III, we conducted manual mathematical tests as a part of pre and post evaluation trials. These tests aimed to ascertain the mathematical ability (addition and subtraction) of the participant. The tests included single-digit subtractions, 2-4 digit additions, and single digit multiplications. The mathematical tests were evaluated by a teacher and a score was provided for each participant.

In phase II, *Kirana* was installed in a classrooms and sessions were conducted for three weeks - with every participant once per week. The setup is shown in Figure 2. A line was marked 1.5 meters away from the Kinect to help the students' positon themselves for good gesture recognition. The participant was given a grocery list by the teacher and a fixed amount of money which she had to use to purchase the items from *Kirana*. Each participant was asked to complete the following tasks per session:

(i) You need to select items for yourself for breakfast from *Kirana* using your grocery list. For example bread, chips, milk and biscuits.
(ii) You have a budget of 100 Rupees to pay for the items you selected. Also check the balance returned by shopkeeper.

Data from the sessions included automated system logs with task times, items bought and monetary transaction details, moderator observations and a behavioral analysis of the participant to record positive and negative emotional behaviors or signals.

In phase IV, participants visited an actual *kirana* store near the school and were asked to buy several items. A moderator observed participant behavior with respect to the three sub-tasks: decision making (choosing an item from the list to buy), social interaction (talking to the shopkeeper and asking for an item) and mathematical ability (knowing how much to pay and balance to expect). Pre-shopping evaluations were not carried out because all participants were previously unable to shop according to their parents and teachers, and we did not want to make them uncomfortable. In order to understand the learning offered by the application, participants were not taught mathematical concepts in other class sessions during the evaluation.

The evaluations were conducted by two school teachers. This reduced any anxiety and complex social dynamics the participant might experience due to an unfamiliar presence. Teachers are also better equipped to understood nuances and implications of the participants' behavior and reaction to the application or its tasks, responsible for and involved in all technical educational interventions within the school, and had participated in the design and development of the application. A workshop was conducted to discuss the evaluation goals and data collection requirements.

5.1 Participants

18 individuals (identified as P1-P18 in the following) with developmental disabilities participated in our evaluation (5 individuals with Down syndrome, 8 individuals with mental retardation, 3 individuals with autism and 2 individuals with cerebral palsy and mental retardation). There were 14 males and 4 females aged between 16 to 39 years (*M*=26, *SD*=5.4) with IQ (*M*=46, *SD*=11) and SCQ [36] (*M*=58, *SD*=16). The participants were recruited from the eighth grade of the school and they (a) understood the concept of left and right, (b) communicated verbally with the mediators, (c) understood instructions given to them, (d) had an awareness of self and body, (e) did not participate in the user-centered design study (mentioned in section 3), and (f) were previously unable to shop independently.

5.2 Results: Overview

While almost all the participants were excited and happy to play the game, two of them reported interaction fatigue. Four participants were observed to have limited left hand movement for two-hand interactions (items were selected using the left hand) although they did not explicitly mention any fatigue or pain. We also observed that the time taken to select items at the center of the screen was longer because five other participants first pointed to top-left corner of the screen and then moved towards the bottom right. Further research in required to identify optimum interaction gesture paths for individuals with varying motor capabilities.

The sessions were conducted during an Indian summer, and so surprisingly we observed that two participants expressed their desire to be able to buy cold beverages instead of food items from *Kirana*. One of the participants was upset at not being able to play more frequently because of her therapy schedules. We also observed that most of the participants felt bad if they were unable to complete a task or if they felt they were slow. At one instance, we noticed a participant slap her left hand to express her frustration.

With each progressive session, participants were more expressive and verbal than usual, and as expected, also showed improvements in the sub-tasks. For example, several participants navigated more carefully to items in the later trials. During the sessions, a line was drawn on the floor to enable participants to know the exact location from where to interact. In the later trials, we observed improvements in terms of understanding where to stand and reposition themselves.

5.3 Results: phase I and III

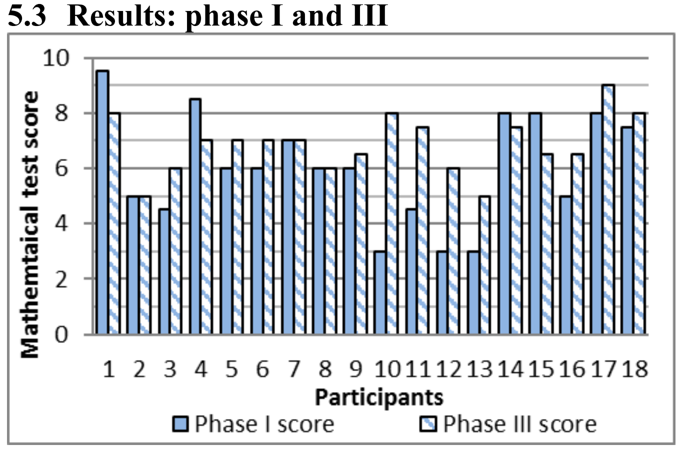

Figure 7: Phase I mathematical test scores with improvements seen in Phase III for participants P1 – P18

Figure 7 shows mathematical scores from phases I and III for each of the participants. In phase I (pre-trial) the highest score was 9.5 and lowest was 3 from a maximum 10 marks. In phase III, the lowest score was 5 and highest was 8. A score of 3 indicates knowledge of numbers from 1-10 and familiarity with money mainly notes, while a score of 6 indicates knowledge of numbers from 1-100, familiarity with notes and coins, and simple two-digit additions and single-digit subtractions. A score of 10 would ideally mean that the participant has knowledge of numbers from 1-100, is familiar with notes and coins, and is comfortable with mental arithmetic including single-digit multiplication.

We observed an average improvement of 8.3% between phases I and III. Four participants showed a decrease in performance. It can also be noted that participants with a lower score benefitted more from the application than those with a score of 6 or above in phase I. Further research is required to observe whether long term evaluations would be beneficial for participants with a score of 6 or above, or whether they require increased difficultly in tasks.

5.4 Results: phase II

A total of 218 items were purchased by the participants in the three-week pilot. During the first week, the participants spent an average of 9.3 minutes (*SD*=4.5) per session buying while during the second and third week they spent 6 minutes (*SD*=4.4) and 4.5 minutes (*SD*=2.2) respectively. Consequently, participants spent an average of 2 minutes 34 seconds per item (*SD*=1.39) during the first week, 1 minute 43 seconds (*SD*=1.94) during the second week and 1 minute 13 seconds (*SD*=0.57) during the third week. This reduction in buying time per item indicates that participants became comfortable with the transactions and interactions with the application, over the course of the evaluations. We note here the limitation in measuring task time; we cannot differentiate the time taken for decision making and that of the actual interaction.

The participants spent an average of 71 Rupees during the first week, 80 Rupees during the second week and 63 Rupees during the third week. The moderators gave each participant an option to either select the items to purchase from the list or to select on their own. Surprisingly, we observed a steady increase in the preference to buy the items from the list (16% in session 1, 50% in session 2 and 73% in session 3) over the three sessions.

5.5 Results: phase IV

Actual store visits in phase IV provided highly ecologically valid way of translating the learning from virtual to real world scenarios. 12 of the 18 participants were taken to a local *kirana* store near the school in one session. Four participants (P3, P5, P16 and P18) were not a part of this activity because the teachers assessed they needed more practice with the application and two participants (P2 and P11) had moved to another school after phase III. It should be noted this was the first time the participants had come to an actual store by themselves. A moderator observed the participants interact with the shopkeeper and buy items from a given list – similar to the task in phase II.

5.5.1 Decision-making

Participants were able to connect the tasks during the visit to the tasks in *Kirana,* and purchase items from the given shopping list. The moderator observed a high degree of cooperation among the participants and they helped each other out wherever possible. This included, for example, crossing the road. The most popular items during the visit were cold beverages due to the Indian summer.

5.5.2 Social interaction

Participants who were feeling shy would observe the others interact with the shopkeeper before approaching the store (P9, P12, P15, and P17). One participant (P17) made the valid observation that everyone should take a bill from the shopkeeper so that the purchasing amounts can be checked by an adult later. Surprisingly, three usually nonverbal participants (P12, P13 and P14) were very responsive and able to interact with the shopkeeper.

5.5.3 Mathematical ability

Participants who had a high mathematical score (greater than 6) were comfortable with the concept of money and transaction involving arithmetic (P1, P4, P6 and P9). However, two participants gave all money with them to the shopkeeper: one out of nervousness (P12) and the other (P7) had problems reading the decimal place in price because of the small font size on the packet.

Overall, all the participants were able to locate an item's M.R.P., understood that money is exchanged when *purchasing* the item, and expressed a positive attitude towards purchasing. However, as expected, the arithmetic aspect of calculating costs and balance was observed to be highly dependent on one's mathematical ability. Several participants understood the relation between items and costs such that they only selected items they knew they would be able to purchase with the amount of money they had.

6. DISCUSSION

The following summarizes the benefits of our work as uncovered during our user-centered design process and *Kirana* evaluations. With our promising findings, we wish to encourage others researchers to work on applications that simulate real world environments to promote self-efficacy for individuals with developmental disabilities.

6.1 Promoting self-efficacy

In our evaluations, we observed improvements in mathematical ability, based on the teacher's assessment, and translatable learning from the application to an actual local store. We believe that our application does the necessary groundwork in preparing individuals with developmental disabilities for purchasing items of need from local stores, thereby teaching them a valuable life skill that promotes self-efficacy.

However, when real life skills are being taught, particularly to individuals with developmental disabilities, cultural aspects must be considered. This is particularly relevant in the developing world where social awareness about individuals with disabilities varies greatly. The socio-cultural norms of a society dictate the degree of inclusivity and integration of individuals with developmental disabilities [3] and [16]. Additionally, individuals with developmental disabilities, such as autism, display a tendency towards repetitive behavior and teaching socially unacceptable gestures might increase their isolation, even if the gesture is fun during gameplay [1].

We developed an application that was culturally relevant and socially acceptable to the community by following a user-centered design approach and including the various stakeholders and decision makers – parents, caregivers, teachers, and therapists. Thus, applications that promote self-efficacy should employ gestures and interactions that are socially and culturally relevant and acceptable for the specific life-skill.

6.2 Simulating real world scenarios

Gesture-based applications can simulate real world scenarios in a safe and controlled environment through interactions that are appropriate and relevant to a life-skill. Using free form body gestures provides a mechanism for more inclusive social interaction and team work, especially when compared with touch screens that have limited form factor and surface area to support multiple users. The inherent nature of embodied interaction [42] makes for an immersive and engaging experience. In *Kirana*, even though it only supported a single active user, the interaction was visible to the moderators who could then prompt and encourage the participant, thus also involving them in the scenario.

6.3 Designing for technology acceptance

We note here the collaborative nature of our work, from the user-centered design study to the *Kirana* evaluations and analysis. Since the application was designed and developed with teachers, therapists and parents, who provided valuable insights and experience, there was no resistance towards technology acceptance or adoption. Thus, the technology was integrated within the classroom environment with ease.

Additionally, we identified ways to address the challenges in introducing new technological interventions for individuals with development disabilities in the developing world. First, economic barriers for technologies that are too costly can be overcome by designing applications that can be integrated within schools, and can be personalized and customized for use by a larger group of individuals. Second, resource constrains can be overcome through collaborations between schools, universities and industry partners. Third, the digital divide can be reduced by spreading awareness of the benefits of technology within schools and to parents.

Our main contribution is not the technology behind the *Kirana* application as such, but rather the focus on the currently overlooked potential of interactive technology for providing translatable learnings to real world scenarios, when using contextually appropriated gesture-based applications to teach life skills. In India, this technology is rare and novel, and thus its acceptance remains largely unexplored. Based on our findings, we can assume that following a user centered design approach helps reduce the challenges in technology integration.

6.4 Providing control to the teacher

Due to the wide range of abilities of an individual, the teacher or moderator should be able to customize the application based on individual capabilities and interest, as also stated in previous research by Bartoli et al. [1], [2], [38]. In *Kirana*, the teacher guided the social interaction and the task, for example, by giving a shopping list. This enabled the teacher to customize the learning, even on the fly. Moreover, number, type and price of items, and the total amount of money in the wallet could be changed easily between sessions. By providing control to the teachers, we believe we also increased the acceptance of technology within the classroom environment.

6.5 Providing multimodal feedback

Individuals with developmental difficulties find it easier to select items that have both visual (change in size) and auditory (name of the item is said aloud) feedback, instead of only one. This reinforced multimodal feedback helps overcome visual or auditory impairments, if any, and provides multiple stimuli for attention [1] [2]. In *Kirana*, each visual object, upon being selected, also had an auditory feedback.

6.6 Providing clear start and end of gameplay

To avoid ambiguity and confusion during interaction, it is extremely important to provide a clear start and end of gameplay. In *Kirana*, when the participant moves out of the Kinect's active area, the application screen turns black to indicate an end of interaction. The application also catered to various end-scenarios such as not enough money left to buy an item, or running out of money or items to buy. Each of these scenarios stated the reason for the end, followed by a visual and audio "well done" feedback to conclude the session.

6.7 Providing serial and structured content

Overall, our findings show that gesture-based applications that simulate real world scenarios can be used to teach a life skill to individuals with developmental disabilities. This is achieved by designing interaction that is socially and culturally appropriate and breaking down complex tasks that require social, mathematical and decision-making skills. We recommend such complex tasks to be broken down into a sequence of smaller achievable steps. If the animation and other visual media content also follow the same step by step order, individuals with developmental disabilities can follow the progress of the tasks with ease. As an example, in *Kirana*, the purchasing animations were slow and sequential.

7. CONCLUSION

This paper presented an application that employs gesture-based interaction for teaching a real world skill, of buying groceries, to individuals with developmental disabilities in India. By following a user-centered approach and including various stakeholders and decision makers – parents, caregivers, teachers, and therapists – we developed an application that was culturally relevant and socially acceptable by the community. *Kirana* simulated the real world scenario of pointing to an item to buy it, while interacting with a shopkeeper at a local grocery store in New Delhi. The results of our evaluations show promising translations of learnings from the application to a real world context. Our findings provide strong support in favor of gesture-based systems for enabling teachers and educationists across the globe to impart life skills to individuals with developmental disabilities.

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9. REFERENCES

[1] Bartoli, L., Corradi, C., Garzotto, F., & Valoriani, M. (2013, June). Exploring motion-based touchless games for autistic children's learning. Proc. Interaction Design and Children (IDC) (pp. 102-111). ACM.

[2] Bartoli, L., Garzotto, F., Gelsomini, M., Oliveto, L., & Valoriani, M. (2014). Designing and Evaluating Touchless Playful Interaction for ASD Children. Proc. Interaction Design and Children (IDC)

[3] Boujarwah, F. A., Hong, H., Abowd, G. D., & Arriaga, R. I. (2011). Towards a framework to situate assistive technology design in the context of culture. In The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility (pp. 19-26). ACM.

[4] Bauminger-Zviely, N., Eden, S., Zancanaro, M., Weiss, P. L., & Gal, E. (2013). Increasing social engagement in children with high-functioning autism spectrum disorder using collaborative technologies in the school environment. Autism, 17(3), 317-339.

[5] Chang, Y. J., Chen, S. F., & Huang, J. D. (2011). A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities. Research in developmental disabilities, 32(6), 2566-2570.

[6] Coles, C. D., Strickland, D. C., Padgett, L., & Bellmoff, L. (2007). Games that "work": Using computer games to teach alcohol-affected children about fire and street safety. Research in developmental disabilities, 28(5), 518-530.

[7] Christinaki, E., Triantafyllidis, G., & Vidakis, N. (2010). A gesture-controlled Serious Game for teaching emotion recognition skills to preschoolers with autism. In Proceedings of fdg. 2013, 417-418.

[8] Cromby, J. J., Standen, P. J., Newman, J., & Tasker, H. (1996). Successful transfer to the real world of skills practised in a virtual environment by students with severe learning difficulties. In Proc. 1st European Conference on Disability, Virtual Reality, and Associated Technologies (pp. 8-10).

[9] Dias, M. B., & Brewer, E. (2009). How computer science serves the developing world. Communications of the ACM, 52(6), 74-80.

[10] Damasio, A. R. (1999). The feeling of what happens: Body and emotion in the making of consciousness. Houghton Mifflin Harcourt.

[11] Dourish, P. (2004). Where the action is: the foundations of embodied interaction. MIT press.

[12] Filmer, D. (2008). Disability, poverty, and schooling in developing countries: results from 14 household surveys. The World Bank Economic Review, 22(1), 141-163.

[13] Firth, N. I. A. L. L. (2012). Kinect cameras watch for autism. New scientist, 214(2863), 17

[14] González-Ortega, D., Díaz-Pernas, F. J., Martínez-Zarzuela, M., & Antón-Rodríguez, M. (2014). A Kinect-based system for cognitive rehabilitation exercises monitoring. Computer methods and programs in biomedicine, 113(2), 620-631.

[15] Gover, M. R. (1996). The Embodied Mind: Cognitive Science and Human Experience (Book). Mind, Culture, and Activity, 3(4), 295-299.

[16] Grinker, R. R. (2008). Unstrange minds: Remapping the world of autism. Da Capo Press.

[17] Kandalaft, M. R., Didehbani, N., Krawczyk, D. C., Allen, T. T., & Chapman, S. B. (2013). Virtual reality social cognition training for young adults with high-functioning autism. Journal of autism and developmental disorders, 43(1), 34-44.

[18] Ke, F., & Im, T. (2013). Virtual-reality-based social interaction training for children with high-functioning autism. The Journal of Educational Research, 106(6), 441-461.

[19] Khakhar, J., & Madhvanath, S. (2010, November). Jollymate: Assistive technology for young children with dyslexia. In Frontiers in Handwriting Recognition (ICFHR), 2010 International Conference on (pp. 576-580). IEEE.

[20] Lahiri, U., Bekele, E., Dohrmann, E., Warren, Z., & Sarkar, N. (2013). Design of a virtual reality based adaptive response technology for children with autism. Neural Systems and Rehabilitation Engineering, IEEE Transactions on, 21(1), 55-64.

[21] Lakoff, G., & Johnson, M. (1999). Philosophy in the flesh: The embodied mind and its challenge to western thought. Basic books.

[22] Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment six precepts for research on embodied learning and mixed reality. Educational Researcher, 42(8), 445-452.

[23] Lotan, M., Yalon-Chamovitz, S., & Weiss, P. L. T. (2009). Improving physical fitness of individuals with intellectual and developmental disability through a Virtual Reality Intervention Program. Research in developmental disabilities, 30(2), 229-239.

[24] Malinverni, L., MoraGuiard, J., Padillo, V., Mairena, M., Hervás, A., & Pares, N. (2014, June). Participatory design strategies to enhance the creative contribution of children with special needs. Proc. Interaction Design and Children (IDC) (pp. 85-94). ACM.

[25] Mäkelä, V., Heimonen, T., & Turunen, M. (2014). Magnetic Cursor: Improving Target Selection in Freehand Pointing Interfaces. In Proceedings of The International Symposium on Pervasive Displays (PerDis '14), 112, ACM,

[26] Mennecke, B. E., Triplett, J. L., Hassall, L. M., Conde, Z. J., & Heer, R. (2011). An examination of a theory of embodied social presence in virtual worlds*. Decision Sciences, 42(2), 413-450.

[27] Moore, D., Cheng, Y., McGrath, P., & Powell, N. J. (2005). Collaborative virtual environment technology for people with autism. Focus on Autism and Other Developmental Disabilities, 20(4), 231-243.

[28] Padgett, L. S., Strickland, D., and Coles, C. D. (2006). Case study: Using a virtual reality computer game to teach fire safety skills to children diagnosed with fetal alcohol syndrome. Journal of Pediatric Psychology, 31(1), 65–70.

[29] Parasuram, K. (2006). Variables that affect teachers' attitudes towards disability and inclusive education in Mumbai, India. Disability & Society, 21(3), 231-242.

[30] Parés, N., Carreras, A., Durany, J., Ferrer, J., Freixa, P., Gómez, D., & Sanjurjo, À. (2005, June). Promotion of creative activity in children with severe autism through visuals in an interactive multisensory environment. In Proceedings of the 2005 conference on Interaction design and children (pp. 110-116). ACM.

[31] Parsons, S., Mitchell, P., & Leonard, A. (2004). The use and understanding of virtual environments by adolescents with autistic spectrum disorders. Journal of Autism and Developmental disorders, 34(4), 449-466.

[32] Parsons, S., & Cobb, S. (2011). State-of-the-art of virtual reality technologies for children on the autism spectrum. European Journal of Special Needs Education, 26(3), 355-366.

[33] Parsons, T. D., Rizzo, A. A., Rogers, S., & York, P. (2009). Virtual reality in paediatric rehabilitation: A review. Developmental Neurorehabilitation, 12(4), 224-238.

[34] Reid, D. (2002). Virtual reality and the person-environment experience. CyberPsychology & Behavior, 5(6), 559-564.

[35] Ringland, K. E., Zalapa, R., Neal, M., Escobedo, L., Tentori, M., & Hayes, G. R. (2014, September). SensoryPaint: a multimodal sensory intervention for children with neurodevelopmental disorders. In Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing (pp. 873-884). ACM.

[36] Michael Rutter, Anthony Bailey, and Cathrine Lord. 2003. The social communication questionnaire: Manual. Western Psychological Services.

[37] Sampath, H., Sivaswamy, J., & Indurkhya, B. (2010). Assistive systems for children with dyslexia and autism. ACM Sigaccess Accessibility and Computing, (96), 32-36.

[38] Sharma, S., Srivastava, S., Achary, K., Varkey, B., Heimonen, T., Hakulinen, J. S., ... & Rajput, N. (2016, February). Promoting Joint Attention with Computer Supported Collaboration in Children with Autism. In Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (pp. 1560-1571). ACM.

[39] Standen, P. J., & Brown, D. J. (2005). Virtual reality in the rehabilitation of people with intellectual disabilities: review. Cyberpsychology & behavior, 8(3), 272-282.

[40] Thompson, E. (2007). Mind in life: Biology, phenomenology, and the sciences of mind. Harvard University Press.

[41] Wallace, S., Parsons, S., Westbury, A., White, K., White, K., & Bailey, A. (2010). Sense of presence and atypical social judgments in immersive virtual environments Responses of adolescents with Autism Spectrum Disorders. Autism, 14(3), 199-213.

[42] Wilson, M. (2002). Six views of embodied cognition. Psychonomic bulletin & review, 9(4)

[43] Venkatesh, S., Phung, D., Duong, T., Greenhill, S., & Adams, B. (2013, April). TOBY: early intervention in autism through technology. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 3187-3196). ACM