Designing Interactive Visual Supports for Children with Special Needs in a School Setting

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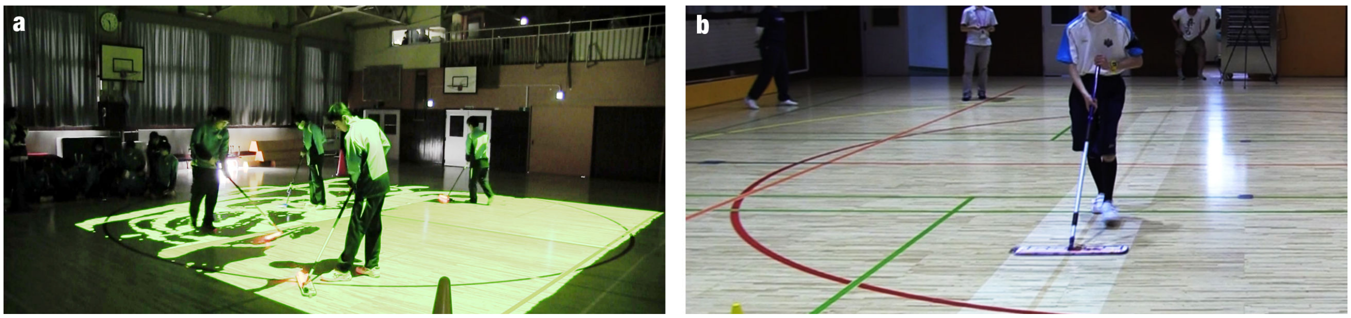

Figure 1. Interactive VS for cleaning in a special needs school. (a) Mop Game: a full-body interactive cleaning game. (b) Mop Guide: A floor-cleaning guidance tool.

ABSTRACT
Visual support (VS) is one of the effective ways of facilitating activities of children with neurodevelopmental disorder (ND). This paper reports on an interactive VS provided by a large-scale floor projection system in an augmented gymnasium called FUTUREGYM, designed for children with ND. The study focuses on students' cleaning, and two interactive VS activities—Mop Game, an exergame involving group cleaning, and Mop Guide, a VS for training about vocational cleaning—were designed with the teachers with the aim of motivating students toward cleaning and help them acquire fundamental cleaning skills. The study attempts to design a VS for cleaning that is suitable for the students by conducting an empathic design approach, which helps us understand what are the problems, obtain new perspectives, and gather ideas into demonstrative prototypes by sharing values and thoughts with the teachers and their students. This is a case study of deploying an empathic design approach in a special needs school setting.

Author Keywords
Interactive technology, Empathic design approach, visual support, autism spectrum disorder, special-needs education

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H.5.3 Group and Organization Interfaces; H.5.1 Multimedia Information Systems; K.4.2 Social Issues.

INTRODUCTION
Autism spectrum disorder (ASD) is a complex neuro-developmental disorder (ND). About one in 68 children is diagnosed with ASD according to the Center for Disease Control and Prevention [12]. Children with ASD display difficulty in communication; demonstrate hardship relating to people, things, or events; and show repetitive body movements or behaviors [2]. Children with ASD have been characterized as visual learners, in that they process visual information more effectively than auditory information [31][43]. Visual supports (VS) such as pictures, lines, and spots on the floor, timers, or activity schedules are helpful in maintaining attention, clarifying the meaning of instructions by verbal communication, and preparing for an activity or transition for children with ASD [7][28][32]. In the literature review, VS using digital methods such as large group displays [41], mobile devices [11][41], or personal recording technologies [38] were reported. These digital methods are not meant to replace the analog-based methods but to complement existing methods with its usability. They help reduce caregivers' difficulties and save time spent on creating, distributing, and using analog-based methods. In recent years, Mixed Reality (MR), which makes it possible to create and develop worlds in which physical and digital elements are merged in the same space [23], has offered a new type of physical support in the sense that they integrate the benefits of both analog and digital supports [16][25][26][30]. MR can support children with ASD in a variety of ways such as to facilitate social initiation and collaborative behaviors [26], to understand that children

with ASD are challenged by a sensory overload and by unwillingness to a variety of stimuli [22], or to sustain children's selective attention [16]. Although numerous studies using MR for VS have been conducted, designing MR-based VS for physical activities in a special needs school setting is challenging. This is because designing special needs education requires a careful decision-making process involving learning about the insights, problems, needs, or abilities of users in order to provide an appropriate solution for them. The main contribution of the work is designing interactive VS in a real context, which is a special needs school setting, by involving real users who are children with ND and their teachers.

This paper reports on a case study of designing interactive VS for tool use involving a mop, which are provided by a large-scale floor projection system installed in an augmented gymnasium called FUTUREGYM for children with ND [40]. The study focuses on cleaning, because it is one of the vocational skills that either individual with or without ND should acquire as they are growing up. In addition, cleaning at the school is related to accountability and social responsibility.

An empathic design approach was deployed in a special needs school at Otsuka (Otsuka School), which is affiliated with University of Tsukuba. The school provides systematic special education courses consistent throughout preschool to high school for children with special needs, mainly ASD and/or intellectual disorders (ID). As a result of the design exercise with the teachers, the VS in Figure 1 were confirmed to help children with mild to moderate ID and/or ASD with a very low cognitive profile to:

- participate in a cleaning activity willingly
- experience cooperative behaviors in cleaning
- understand the procedure of floor cleaning
- manipulate a mop to keep it within a track for cleaning the floor

The activities listed above are difficult to instruct children with ND in using verbal or paper-based descriptions, but the interactive VS provided by FUTUREGYM helps compensate for the difficulty. The former two findings can be applied for training group cleanings (i.e., Mop Game). The latter two findings would contribute to train vocational skills in cleaning (i.e., Mop Guide) for children with ND. The case study highlights the importance of the empathic design approach for designing technology-assisted VS for children with special needs in a school setting.

This paper begins by summarizing related works on technology-based VS. Then, the design process conducted in the study is described and the viability tests of two VS, "Mop Game" and "Mop Guide," are reported. A summarized discussion and conclusions of the outcomes obtained from the study are presented. Lastly, research prospects and future works are mentioned.

RELATED WORKS

The main challenge of this study is to design interactive VS for children's physical activities in a special needs school setting. The review starts from outlining the benefits of using technologies for children with ASD. Then, the study approach is illustrated by referring to findings of the prior works using MR and interactive technologies brought into school settings.

The use of technology in the research and treatment of ASD has been increasing since a publication in 1973 [14], appearing in broad fields from social to technical, and is highly accepted among individuals with ASD due to the predictable and structured feature of computer-based systems offering immediate and consistent feedback [3]. It also provides opportunities to access abundant information from various resources and to adapt contents and tasks to the demands and capabilities of each child with tailored feedbacks [24][35]. Among the use of technology for children with ASD, spatial MR is a strong and effective tool for providing VS. It enables overlaying graphical information on real-world objects [6], and makes it possible to scale naturally up to groups of children, which allows a collective experience among children. One of the first spatial MR projects for children with ASD is "MEDIATE," which provides a sense of control for children with severe autism. A safe and controlled space using interactive rear-projection screens gives the children a chance to play and explore enjoyably [30]. An exergame, "SpaceHunters," provides foot-eye coordination exercises for children with ASD in an interactive space [13]. The game facilitates the development of social interactions by requiring collaboration among the participants to achieve a goal. A full-body serious game, "Lands of Fog," fosters social interaction for children with ASD using a large floor projection 6 m in diameter made with two projectors [25][26]. The game uses interactive virtual elements to facilitate joint attention and collaborative behaviors among children. These prior studies have demonstrated the prospects for the use of interactive projection for children with ASD to enhance positive behaviors during physical movements in a large space.

However, many of the MR projects were deployed in a laboratory setting, which is not an environment children are familiar with in the course of normal, everyday activities. Specializing in the care of children with ASD, school settings can often benefit greatly from using a smart space equipped with interactive technologies [19][41]. These environments are primarily attached to the physical domain in which the children live and interact together with the teachers providing them care and support. Therefore, solutions using MR could be useful in assisting the children's and the teachers' needs. In the literature review, numerous interactive technologies were found to be brought into school settings. Tentori et al. developed three displays and brought them to a classroom to explore ways to increase behavioral awareness, trigger social interactions, and promote group work [42]. A serious game for children with ASD called ECHOES facilitates exploration and acquisition of social interaction skills with a system based on an avatar in a multi-touch display, which can interact with the users for practicing and learning joint attention abilities in a school setting [4]. Bhattacharya et al. designed motion-based activities using an electronic whiteboard with a Kinect to engage students with ASD in classroom settings [5]. They reported that the collaborative game supports the initiation of social activities between peers, and brings out new body movements that children were not observed to make outside of gameplay. Although these projects are successfully enhancing children's positive behaviors by using interactive displays, there are few projects deploying interactive technologies in a large space in a school setting. One of the spatial MR projects brought to a large school space is "Lü" from the Canadian company SAGA [34]. The project uses large interactive walls in a school gymnasium for providing spatial games for children. It introduced the concept of interactivity and visual feedback making physical activity more fun and accessible to all types of children. However, it is not a project that is specialized in the support of children with special needs. It focuses on providing enjoyment of physical activities to neuro-typical children through games. In addition, the project attempts to ensure children's attention to virtual elements provided on walls, and deploy an intervention in the context of the virtual environment. In contrast, FUTUREGYM aims to assist children in paying attention to objects or people around them. Furthermore, FUTUREGYM provides VS from the ceiling toward the floor; therefore, individual VS can be overlaid on objects around them. It helps users navigate or be guided to a certain state as well as facilitating voluntary and wayfinding behaviors.

Designing interactive VS for children with ND that help in their physical activities in a large school space is not present in the literature. Although there are some projects in the literature that applied VS for physical coaching or training such as basketball [1], bouldering [18], or table tennis [36], projects specialized for individuals with ND in a school setting have not been undertaken yet. Especially, VS that can be applied for group activities or vocational training in a school setting are beneficial in for children's daily life and their future careers. This study shows an example of designing interactive VS that give them these benefits.

DESIGN PROCESS

The teachers at the school were habituated to current conditions, and they did not often think to ask for a new solution and had difficulty envisaging solutions due to lack of familiarity with the possibilities offered by new technologies. Therefore, an empathic design approach, which is an effective design approach for such situation [21][15], was taken in this study. An empathic design approach relies on observations that demonstrates a kind of common-sense approach, which helps inspire researchers and users involved in creative challenges [37]. "Empathize" is often adopted as the first phase in a design formulation method that aims at problem finding, because building empathy toward end users and understanding what is important to them is the foundation of the design process. Although the expression differs among researchers or designers, there are five key phases to structuring the design process: "Problem finding," "Sense-making," "Ideation," "Prototype," and "Viability test." Usually, the design process starts from obtaining an empathetic view of what the problem is, to possible new interpretations, to assembling ideas into demonstrable tests and then examining the viability in a reasonable use case [8][20][29].

Five researchers from University of Tsukuba, 21 teachers ranging from preschool to high school, and 64 students at Otsuka School were involved in the design decision-making process. The activities were organized with the approval of the ethical committee of the Education Bureau of Laboratory Schools, University of Tsukuba.

Problem finding

More than half of the study period was spent in this first phase of the empathic design approach. The researchers visited the school 20 times in seven months and conducted eight occasional observations and interviews of daily school classes in the gymnasium, five research meetings with the teachers, and seven workshops using the FUTUREGYM environment. The environment in a special needs school setting helped the researchers to identify needs that the students and teachers themselves may not recognize. It also helped the researchers to find ways to meet those needs by conducting observation in the users' own environment — in the course of normal, everyday routines. The problem-finding phase started with onsite observations and oral interviews in daily classes to pick up some issues or interests children have, and confirmed the findings during meetings with teachers. Then, workshops were organized according to the findings obtained from the classrooms. Examples of activities used in the workshops are Constellation Game (Figure 2a), a group exergame with a shared goal, and Circle-Run, involving group running with animal-shaped pacemakers (Figure 2b). Constellation Game helped us to notice that a game with a shared goal has a potential to facilitate an opportunity to trigger helping

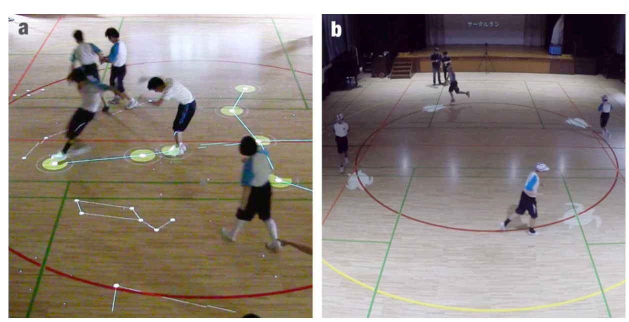


Figure 2. Examples of workshops for problem finding. (a) Constellation Game. (b) Circle-Run.

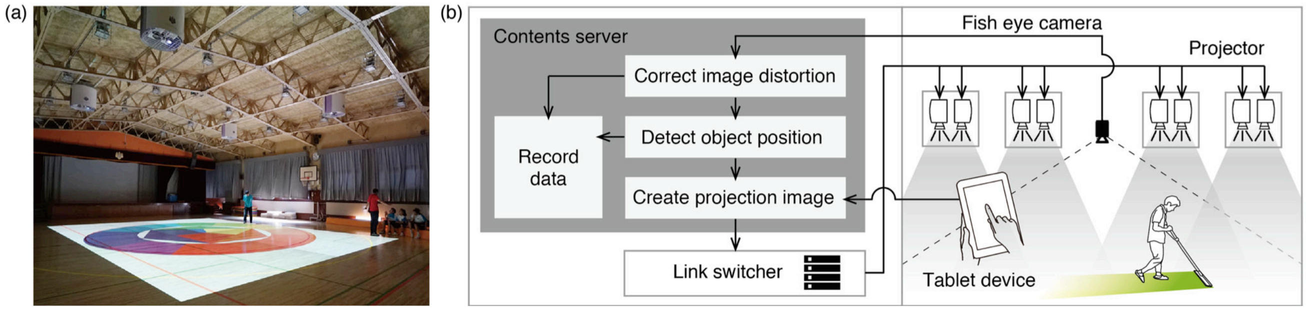


Figure 3. (a) Interactive floor projection of the FUTUREGYM (Projection size: 8 × 11 m). (b) Configuration of the interactive floor projection system.

behavior by providing a game with a shared goal. Circle-Run demonstrated the way of support in the context of interpersonal interaction among children through a group running. The visual guidance on the floor effectively escorted children to experience cooperative running. The researchers and teachers observed a trend that their running behavior improved after the experience of cooperative running with the visual guidance. More specific explanations of these activities are reported in [40].

By observing what the children do and how they interact with the FUTUREGYM environment in the workshops, the researchers and the teachers attempted to obtain clues about how the students react and feel as well as to learn their needs. Additionally, the workshops helped the researcher to show and explain the functioning of the system to the teachers and students to make them understand what can be done by the system. It also played an important role building a good partnership between the researchers and Otsuka School.

Sense-making and Ideation

In the problem-finding phase, the researchers and teachers confirmed that the students showed strong interests toward objects with various movements and colors projected on the floor. This finding made it possible to help the students practice complex actions such as moving and stopping at a certain spot or running through a zigzag course, which are difficult to instruct them in verbally. With this clue, the researchers and teachers came up with an idea to apply interactive VS for cleaning, in which the students often face difficulties.

Cleaning is an important activity not only for the students' daily lives, but also for their future careers. Many of the students at the school get a job related to cleaning after graduation. Prior studies also reported that one of the major postsecondary employment experiences among young individuals with ASD and ID is cleaning [33]. Therefore, training in cleaning skills is one of the important subjects at the school. However, the teachers encounter difficulties in teaching them cleaning skills. They require tremendous time and effort to teach and motivate them to clean using verbal and paper-based instructions at the school. Although a number of technology-based cleaning supports have been reported in the literature such as video instruction by an interactive white board [39] or cleaning training by a virtual reality system with a head-mounted display [9], the use of VS for cleaning with a floor projection system has not been investigated yet. One of the advantages of using a floor projection system is that it overlays visual aids on real objects, which creates a more intuitive VS compared to display-based applications.

In this phase of the design process, the researchers and teachers decided to develop a full-body interactive cleaning game named Mop Game (Figure 1a) and floor-cleaning guidance tool named Mop Guide (Figure 1b) using the interactive floor projection system in the FUTUREGYM. Mop Game aims to stimulate students' interests in cleaning tools and actions with a game that enables them to paint colors on the floor or erase objects on the floor with a lightning mop. Mop Guide helps the students understand the process of cleaning with a mop by providing a mop course on the floor as well as helping them manipulate a mop to keep inside a track on the floor.

The initial idea of Mop Game and Mop Guide was brought by the teachers who are responsible for vocational trainings in the school. They came up with an idea to apply the VS to cleaning after they experienced the workshops. Several idea illustrations and descriptions were made in ideate sessions with the teachers, and the prototypes were designed with their collaborative decision-making. The following sections describe prototype and viability test of Mop Game and Mop Guide.

A Prototype of Mop Game

A prototype of Mop Game was developed using the FUTUREGYM system. FUTUREYGYM has an interactive floor projection size of approximately 8 × 11 m (approx. 545 inches). There are eight digital light processing (DLP) projectors (Panasonic, PT-DW100W) equipped under the ceiling of the gymnasium (Figure 3a). Figure 3b shows the configuration of the floor projection system. The projection image created from the content server (CPU: 3.30 GHz, RAM: 16 GB, OS: Windows 8.1 Pro) is sent to the display server and monitored on a display using a graphics card (NVIDIA, NVS 510). The image on the display is projected by the projectors through a link switcher (Panasonic, ET-

Figure 4. Mop Game: erasing trash on the floor.

YFB200). A fish-eye camera (Point Grey BFLY-PGE-13S2M-CS, Lens: M13VM246) is fixed in the center of the ceiling. The images collected from the camera are used to observe children's behavior and movements. Distortion of the camera image was removed using OpenCV 3.2 in C++ (Visual Studio 2015). A router is connected to the content server; therefore, mobile devices can communicate wirelessly with the content server to control the projection images.

The mop, which is used in daily school cleaning, is equipped with an LED bar (Length: 600 mm) to increase the difference in light intensity from the surroundings in order to enhance the ceiling camera's ability to detect the mop position. The processing on the content sever is implemented as follows.

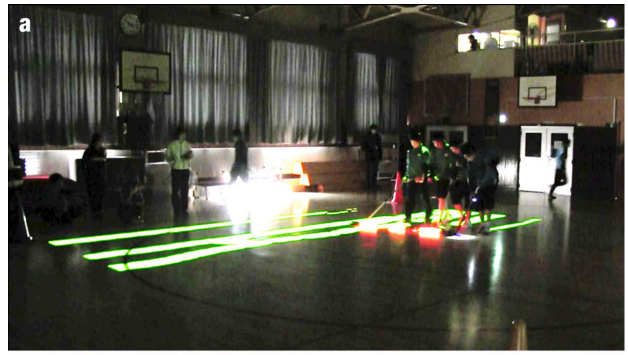
(a) Homography transformation
(b) Detection of mop position
(c) Reflecting the projection image according to the mop position

In step (a), the projection field in the camera image is cropped after binarization of the image according to the position of pylons located at the corners of the field. Then, the perspective distortion of the cropped image is corrected with a homography transformation matrix. In step (b), the contour of a moving object is detected after image frame differentiation of 10 Hz. A mop is recognized by the size of the region in the contour. The mop position is defined as the center of the contour. The projection image is projected at the mop position for the painting game and erased according to the mop position for the erasing game. These procedures were coded in Processing 3.3.1.

Although the prototype was developed by the researchers, game stories, rules, color layouts, and illustrations were designed by the teachers.

A Viability Test of Mop Game

A viability test was conducted with 24 high-school students with mild/moderate ASD and/or ID (15-18 years old) in order to confirm that they like it and it motivates them to participate voluntarily as well as facilitating social interactions. The high school students, who are taking vocational skill training classes, were selected in the test, because they are required to train cooperative working skill for their post graduation lives.



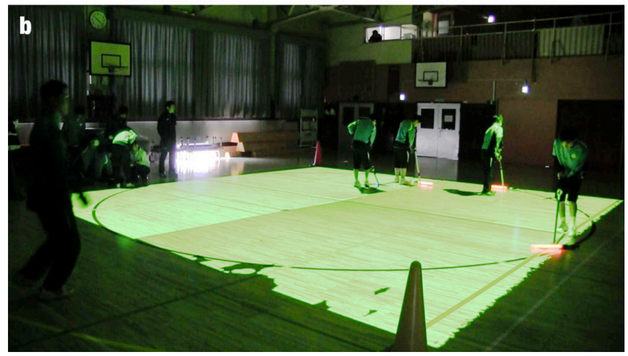


Figure 5. Examples of cooperative behaviors observed in Mop Game. (a) Sweeping a mop side by side with other members. (b) Collectively moving a mop to unswept areas.

Two types of games were organized in the test: floor painting (Figure 1a) and erasing trash on the floor (Figure 4). There were three rounds of each type of game with groups of four students. The students were instructed to paint a color all over the field (7.4 m^2) for the floor painting game or to erase the trash on the floor (500 objects) for the trash erasing game. By referring to Bratman's three features of cooperative activities [10], the game is designed as to have 1) mutual responsiveness, 2) commitment to the joint activity, and 3) commitment to mutual support, which are key elements to create a shared cooperative activity. The start and end of the game was announced to the students by a teacher's whistle. At the end of each game, the time took for the completion of the task was presented to the students.

Results

Even though many of the students have difficulty concentrating their attention on a task in daily classes, all the students completed the game tasks without giving up. Even a student with severe ID and rare interest in anything participated in the game with the other students. When changing participants between rounds, many students raised their hands to be picked. When their names were called by a teacher, they voluntarily grabbed the mops, something rarely seen in their daily cleaning situations. Moreover, soon after the time taken for task completion was announced to the students, they showed positive emotional expressions such as jumping, raising hands, or clapping. Accordingly, the game is assumed to attract the students and trigger their voluntary behaviors.

Furthermore, some social interactions were observed during the game such as sweeping a mop side by side with other members (Figure 5a) or collectively moving their mops to unswept areas (Figure 5b). These positive behaviors are important for developing their social skills, which the teachers always want to facilitate. It is considered to have been brought on by setting a shared goal in the game. The teachers were pleased with the result of the students showing positive behaviors through the game.

A Prototype of Mop Guide

The students often have difficulty remembering a mop route as well as manipulating a mop when there are no visual cues such as tapelines or spot makers on the floor. Therefore, the teachers requested the researchers to develop a function to provide mop courses on the floor.

A prototype of Mop Guide, which provides VS for learning about cleaning procedure and tool use, was developed using the FUTUREGYM system. A cleaning field was organized with a floor size of 4 × 8.7 m (Figure 6). Four pylons were placed at each corner of the field to indicate the cleaning area. A mop course was projected on the floor as shown in Figure 1b to guide students where to move the mop. The mop course was colored with white in order to increase the light intensity to have better visibility of the floor. A red line was drawn in the center of the mop course to indicate the center position of the mop head. The projection was controlled by a tablet device (Nexus 9, Android 5.1.1). An

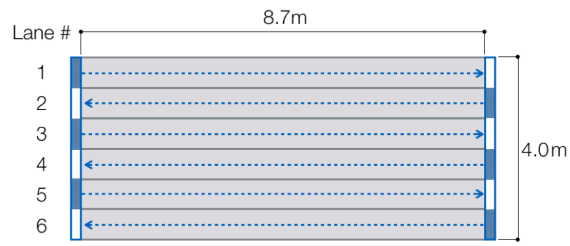


Figure 6. Size of the cleaning field and the direction of mop movement in each lane.

LED (red color) bar was equipped on the mop head in order to increase the precision of the mop position tracking for data analysis.

A Viability test of Mop Guide

In order to investigate whether Mop Guide helps them understand the procedure of cleaning and manipulating a mop to keep it inside a track for cleaning the floor, a viability test was conducted in cooperation with two male students with mild/moderate ASD and/or ID. Student A was 15 years old with FSIQ-50 and VCI-58 (WISC-IV), and student B was 16 years old with FSIQ-42 and VCI-51 (WISC-IV). They were selected as subjects of the test because they are willing to get a job related to cleaning after the graduation, but have difficulty leaning procedures of cleaning as well as tool use.

The feasibility of Mop Guide for cleaning instructions was investigated by comparing percentages of swept areas in the cleaning field before and after intervention with the VS indicating the sweeping lanes, as shown in Figure 1b. The

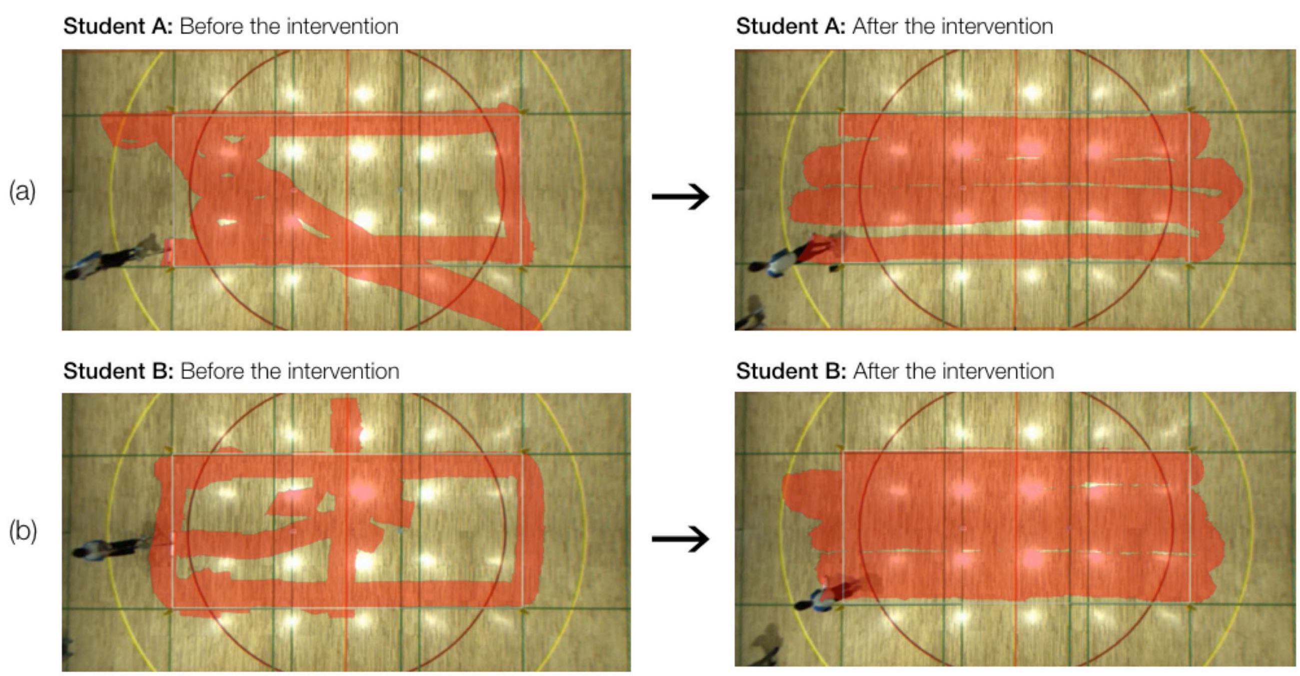


Figure 7 Trajectories of the mop in the cleaning field before and after the intervention using the VS (Red parts indicate the trajectory of the mop). (a) Student A. (b) Student B.

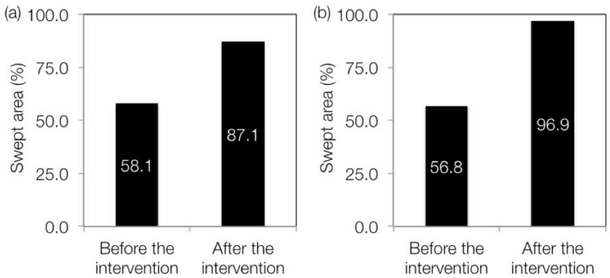


Figure 8. Comparisons of percentages of swept area between before and after the intervention with the VS. (a) Student A. (b) Student B.

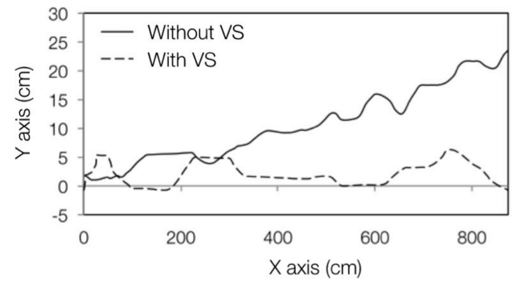


Figure 9. A representative example of walking out of sweeping lane (Student B) without the VS. Zero on the Y axis is the center of the lane.

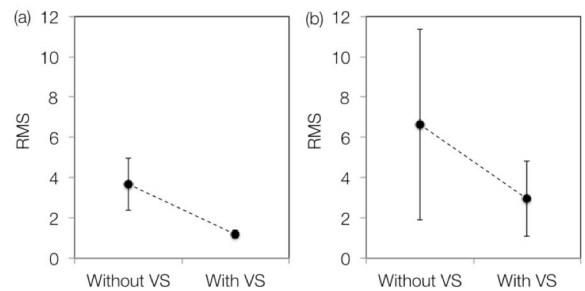


Figure 10. Comparisons of RMS with and without the VS. The bar represents the standard deviation. (a) Student A. (b) Student B.

students were verbally instructed by their teachers to sweep the whole area of the field with the mops before the intervention. The teachers instructed the students as they do in daily cleaning classes. Then, the intervention using Mop Guide was applied to the students. Each lane was highlighted on the floor one by one by the projection system with the direction indicated in Figure 6. The VS indicates the sweeping lane with a red line in the center as shown in Figure 1b. After the intervention, the students were verbally instructed to sweep the whole area of the field again. Then, the trajectories of the mop in the cleaning field and the percentages of swept areas in the field before and after the intervention were compared.

The second test, investigation of how well does Mop Guide help the students to manipulate a mop to keep in a track for cleaning the floor, was done by comparing deviations of distance between the center of a mop head and the center of the lane with (the intervention) and without (before the intervention) the VS.

Results

Figure 7 shows trajectories of the mop in the field (the highlighted parts) before and after the intervention using the VS. There are a lot of unswept areas in the field before the intervention. It is possibly because they did not understand the teachers' verbal instruction. However, the unswept areas decreased after the intervention. Figure 8 shows the comparison by using the percentages of swept areas by the mop in the field between before and after the intervention. Both students improved their coverage after the intervention using the VS. Mop Guide showed that it is potentially useful for helping the students understand a cleaning procedure compare to the instruction only with the verbal descriptions.

The viability test of the prototype also indicated that Mop Guide helps them to manipulate a mop to keep it inside a track for sweeping the floor. Figure 9 shows a representative example of walking out of a sweeping lane. The lines on the graph indicate trajectories of the center of the mop head. Zero on the Y-axis is the center of the lane. The mop head was largely driven out from the lane without the VS (solid line) compared to the trial with the VS (broken line). In the trial without the VS, the mop head drifted to the positive side of the Y axis, and the gap between the center of the mop head and the center of the lane was approximately 25 cm when the mop head reached the edge of the field. In order to quantify the deviation of the mop head, the RMS(i) (Root Mean Square) of the distance between the mop head and the lane for student i was calculated as follows:

$$RMS(i) = \sqrt{\frac{1}{N}\sum_{s}^{N} D_i(s)^2} \qquad (1)$$

Here, $D_i(s)$ represents the distance between the center of the mop and the center of the lane at frame s. i and N indicate the number of students and number of frames in the videos from the start line to the goal line, respectively.

Figure 10 shows comparisons of RMS with and without the VS obtained from lane number 2 to 5 in Figure 6. RMS for lane numbers 1 and 6 were not included in the graph because there are straight lines beside the lanes that could affect the result. The bars on the graph represent the standard deviation. Both of the students showed smaller RMS during sweeping trials with the VS. The result indicates that the VS prevents the mop being driven out of the lane. It potentially helps the students stabilize manipulation of the mop head.

DISCUSSION

The case study represented the empathic design approach, which shifts the design process from the researchers environment to the special needs school setting for designing an MR-based VS for children with ND. The field-dependent design decision-making process helped the researchers put information in context and find contextual cues from the school environment, which is crucial to understanding figurative and literal relations between objects in the environment. The careful observations of the students and repetitive consultations with the teachers led us to design Mop Game and Mop Guide. After the prototype was built, the viability of Mop Game was tested and we confirmed that the game attracts the students' attention and triggers their active participation in the game. It has also been confirmed that Mop Game has the potential to help students focus their attention on cleaning behaviors with an element of fun as well as to facilitate social interactions such as teamwork and cooperative behavior. One of the major differences compared to related games, for example, SpaceHunter [13] or Lands of Fog [25], is that Mop Game is deployed in a special needs school setting, which is a familiar environment for the students. It is one of the best places for the students who are sensitive to unfamiliar spaces or equipment. Mop Game is also advantageous for the teachers because the game can be organized simply by overlaying projection images over daily cleaning surfaces, which allows them to include the game in their daily cleaning classes.

Mop Guide was also tested for feasibility. The result showed that it is potentially useful for instructing them in cleaning procedures. The teachers involved in the cleaning experiment were surprised to see that just one trial with the VS made them understand the procedure of mop cleaning. They told us that the clear and simple instruction helped keep their concentration and motivation. The result implies that it is not only practical for teaching the procedure of floor cleaning, but also helps them maintain motivation to clean it. It is important to note that the VS does not directly improve their cleaning skill, but guides them to experience the ideal outcome of instruction given by the teachers. It helps children eliminate or minimize taking corrective actions, which contributes to the errorless learning and eliminates or reduces errors, thereby helping children maintain their motivation and reinforcing learning [27].

The prototype test of Mop Guide also indicated that the VS helps them manipulate a mop to keep it inside a track for sweeping the floor. This is useful for coaching precise cleaning. In the daily classes, the teachers use the edges of floorboards to teach them to sweep straight, but they find it difficult. Mop Guide has the possibility of making it more intuitive and easy for the students to practice the task. The teachers requested us to project the sweeping trajectories in real time for better understanding of their task results. They also suggested us to include furniture and partitions in the field to demonstrate a room-cleaning scenario to train in various types of cleaning skills. These requirements will be considered in the next step of our research.

In this study, the FUTUREGYM environment played an important role. The researchers could not have known the problems, values, thoughts, or requirements that the teachers and their students had without the environment. The relocation of the design platform from a laboratory setting to the school setting helped us design Mop Game and Mop Guide. It also gave us a physical advantage. Both of the VS required a large space, which could not have been possible without the environment. Moreover, conducting activities in the school setting, which is the students' accustomed environment, helped them get used to the floor projection and enabled the teachers to respond immediately to some issues or difficulties that might have been faced by their students. Because the school gymnasium is bound to the physical domain in which the students learn and receive support from the teachers, it is an ideal place to deploy the VS for their needs.

Limitations

The importance of the empathic design approach has been demonstrated for designing technology-assisted VS in the special needs school setting through this case study. However, it was also found that conducting design consultations in the users' environment included some challenges. It is difficult to evaluate the impact of participation on the outcomes of the process, as shown in [17], which was represented by the impact of setting a control condition in the from of a non-empathic approach to design. In addition, it is difficult to judge how the teachers and students contributed directly to the design process and to describe how their involvement varied over the different phases of design decision-making. It is difficult to quantify if the students' engagement toward daily cleaning improved or if their ideas, opinions, or actions were incorporated in the outcome. We believe that the importance of the design approach relies more on learning about users' insights, problems, needs, abilities, strengths, and providing an appropriate solution for them with a careful decision-making process. Each of the design phases helped us understand the teachers and their students, and improved the quality of the VS. Since it is difficult to determine exactly what is the best for children with ND, careful consultations with their close teachers are a reliable way to formulate the ideal solution.

CONCLUSION

This case study highlights the importance of empathy-centered practices for designing technology-assisted VS for children with special needs in a special needs school setting. It represents an example of how technology can be designed to accommodate human behavior in a school. Mop Game and Mop Guide were designed with the teachers through the design process of Problem finding, Sense-making, Ideation, and Prototype. The careful design consultation in the school setting helped the researchers and teachers know what the problem is, obtain new interpretations, gather ideas into demonstrable prototypes, and then test the viability in a real use case. As a result of the design process with the teachers, Mop Game has been confirmed to help children with mild or moderate ID and/or ASD with very low cognitive profiles to participate in a cleaning activity voluntarily as well as to experience cooperative behaviors in cleaning. Mop Guide has been tested to have the potential to help children understand the procedure of floor cleaning and manipulate a mop to keep it inside the track for cleaning floors. These activities are difficult to instruct children with ND by verbal or analog-based graphical descriptions, but the MR-based VS helps to compensate for this difficulty. Mop Game can be potentially applied to train team workouts or group activities as well. It can contribute to vocational training in cleaning for the students' future careers.

Although Mop Game and Mop Guide are assumed to be feasible, the VS are still under design and require repetitive design cycles to improve usability. Our future research is dedicated to improving the quality of these interactive VS. In addition, there are many kinds of cleaning tasks besides mop cleaning such as table polishing, vacuum cleaning, or toilet cleaning. We are planning to develop VS for the other cleaning tasks according to the cleaning textbook provided by Tokyo Metropolitan Board of Education [44].

Furthermore, we will keep exploring the extended use of MR-based VS that enables the children to improve in their school environment using the empathic design approach.

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REFERENCES

1. AKQA. 2017. Nike Rise 2.0. Retrieved August 30, 2017 from https://www.akqa.com/work/nike/rise-2015/
2. American Psychiatric Association. 2013. *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub. https://doi.org/10.1176/appi.books.9780890425596.dsm01
3. Nuria Aresti-bartolome and Begonya Garcia-zapirain. 2014. Technologies as Support Tools for Persons with Autistic Spectrum Disorder : A Systematic Review. *International Journal of Environmental Research and Public Health* 11, 8: 7767–7802. https://doi.org/10.3390/ijerph110807767
4. Sara Bernardini, Kas´ka Porayska-Pomsta, and Tim J. Smith. 2014. ECHOES : An intelligent serious game for fostering social communication in children with autism ECHOES : an Intelligent Serious Game for Fostering Social Communication in Children with Autism. *Information Sciences* 264: 41–60. https://doi.org/10.1016/j.ins.2013.10.027
5. Arpita Bhattacharya, Mirko Gelsomini, Patricia Pérez-Fuster, Gregory D. Abowd, and Agata Rozga. 2015. Designing motion-based activities to engage students with autism in classroom settings. In *Proceedings of the 14th International Conference on Interaction Design and Children - IDC '15*, 69–78. https://doi.org/10.1145/2771839.2771847
6. O Bimber and R Raskar. 2005. *Spatial Augmented Reality: Merging Real and Virtual Worlds*. CRC Press.
7. Nicole Blubaugh and Joanne Kohlmann. 2006. TEACCH Model and Children With Autism. *Teaching Elementary Physical Education* 17, 6: 16–19.
8. Thomas Both and Dave Baggereor. 2017. *d.school Bootcamp Bootleg*.
9. Lal Bozgeyikli, Evren Bozgeyikli, Matthew Clevenger, Andrew Raij, Redwan Alqasemi, Stephen Sundarrao, and Rajiv Dubey. 2015. VR4VR: Vocational Rehabilitation of Individuals with Disabilities in Immersive Virtual Reality Environments. In *PETRA '15 Proceedings of the 8th ACM International Conference on PErvasive Technologies Related to Assistive Environments*, 54:1-54:4. https://doi.org/10.1145/2769493.2769592
10. Michael E. Bratman. 1992. Shared Cooperative Activity. *The Philosophical Review* 101, 2: 327–341. https://doi.org/10.2307/2185537
11. Miao-en Chien, Cyun-meng Jheng, Ni-miao Lin, Hsien-hui Tang, Paul Taele, Wen-sheng Tseng, and Mike Y Chen. 2015. iCAN : A tablet-based pedagogical system for improving communication skills of children with autism. *Journal of Human Computer Studies* 73: 79–90. https://doi.org/10.1016/j.ijhcs.2014.06.001
12. Deborah L. Christensen, Jon Baio, Kim Van Naarden Braun, Deborah Bilder, Jane Charles, John N. Constantino, Julie Daniels, Maureen S. Durkin, Robert T. Fitzgerald, Margaret Kurzius-Spencer, Li-Ching Lee, Sydney Pettygrove, Cordelia Robinson, Eldon Schulz, Chris Wells, Martha S. Wingate, Walter Zahorodny, and Marshalyn Yeargin-Allsopp. 2016. *Prevalence and Characteristics of Autism Spectrum Disorder Among Children Aged 8 Years - Autism and Developmental Disabilities Monitoring Network, 11 Sites, United States, 2012.* https://doi.org/10.15585/mmwr.ss6503a1
13. Franceli L. Cibrian, Deysi H. Ortega, Lizbeth Escobedo, and Monica Tentori. 2015. Reflections from a Long-term Deployment Study to Design Novel Interactive Surfaces for Children with Autism. In *Springer International Publishing Switzerland*. 167–176. https://doi.org/10.1007/978-3-319-26508-7

14. Kenneth M Colby. 1973. The Rationale for Computer Based Treatment of Language Difficulties in Nonspeaking Austistic Children. *Journal of Autism and Childhood Schizophrenia* 3, 3: 254–260. https://doi.org/10.1007/BF01538283
15. Lee Crossley. 2003. Building Emotions in Design. *The Design Journal* 6, 3: 35–45. https://doi.org/10.2752/146069203789355264
16. Lizbeth Escobedo, Mónica Tentori, Eduardo Quintana, Jesus Favela, and Daniel Garcia-Rosas. 2014. Using Augmented Reality to Help Children with Autism Stay Focused. *IEEE Pervasive Computing* 13, 1: 38–46. https://doi.org/10.1109/MPRV.2014.19
17. Christopher Frauenberger, Judith Good, Geraldine Fitzpatrick, and Ole Sejer Iversen. 2015. In pursuit of rigour and accountability in participatory design. *International Journal of Human Computer Studies* 74: 93–106. https://doi.org/10.1016/j.ijhcs.2014.09.004
18. Raine Kajastila, Leo Holsti, and Perttu Hämäläinen. 2016. The Augmented Climbing Wall: High-Exertion Proximity Interaction on a Wall-Sized Interactive Surface. In *CHI '16 Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 758–769. https://doi.org/10.1145/2858036.2858450
19. Julie A Kientz, Gillian R Hayes, Tracy L Westeyn, Thad Starner, and Gregory D Abowd. 2007. Pervasive Computing and Autism: Assisting Caregivers of Children with Special Needs. *IEEE Pervasive Computing* 6, 1: 28–35. https://doi.org/10.1109/MPRV.2007.18
20. B Lawson. 2006. *How Designers Think: The Design Process Demystified*. Elsevier/Architectural.
21. Dorothy Leonard and Jeffrey F. Rayport. 1997. Spark Innovation Through Empathic Design. *Harvard Business Review* 75, 6: 102–115.
22. M L Max and J C Burke. 1997. Virtual reality for autism communication and education, with lessons for medical training simulators. *Studies in health technology and informatics* 39: 46—53.
23. Paul Milgram and Fumio Kishino. 1994. A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information Systems* E77–D, 12: 1321–1329.
24. T Mooij. 1999. Guidelines to pedagogical use of ICT in education. In *8th Conference of the European Association for Research on Learning and Instruction*, 1–15.
25. Joan Mora-guiard, Ciera Crowell, Narcis Pares, and Pamela Heaton. 2016. Lands of Fog: Helping Children with Autism in Social Interaction through a Full-Body Interactive Experience. In *IDC '16 Proceedings of the The 15th International Conference on Interaction Design and Children*, 262–274. https://doi.org/10.1145/2930674.2930695
26. Joan Mora-Guiard, Ciera Crowell, Narcis Pares, and Pamela Heaton. 2016. Sparking social initiation behaviors in children with Autism through full-body Interaction. *International Journal of Child-Computer Interaction*. https://doi.org/10.1016/j.ijcci.2016.10.006
27. Michael M Mueller, Christine M Palkovic, and Cynthia S Maynard. 2007. Errorless learning: review and practical application for teaching children with pervasive developmental disorders. *Psychology in the Schools* 44, 7: 691–700. https://doi.org/10.1002/pits.20258
28. Samuel L Odom, William H Brown, Timothy Frey, Necdet Karasu, Lora Lee Smith-canter, and Phillip S Strain. 2003. Evidence-Based Practices for Young Children with Autism: Contributions for Single-Subject Design Research. *Focus on Autism and Other Developmental Disabilities* 18, 3: 166–175. https://doi.org/10.1177/10883576030180030401
29. T Ogilvie and J Liedtka. 2011. *Designing for Growth: A Design Thinking Toolkit for Managers*. Columbia University Press.
30. Narcis Pares, Paul Masri, Gerard Van Wolferen, and Chris Creed. 2005. Achieving dialogue with children with severe autism in an adaptive multisensory interaction: The "MEDIATE" project. *IEEE Transactions on Visualization and Computer Graphics* 11, 6: 734–742. https://doi.org/10.1109/TVCG.2005.88
31. Kathleen Ann Quill. 1995. Visually Cued Instruction for Children with Autism and Pervasive Developmental Disorders. *Focus on Autistic Behavior* 10, 3: 10–20. https://doi.org/10.1177/108835769501000302
32. M. Rao, Shaila and Brenda Gagie. 2006. Learning Through Seeing and Doing : Visual Supports for Children With Autism. *Teaching Exceptional Children* 38, 6: 26–33. https://doi.org/10.1177/004005990603800604
33. Anne M Roux, Paul T Shattuck, Benjamin P Cooper, Kristy A Anderson, Mary Wagner, and Sarah C Narendorf. 2013. Postsecondary Employment Experiences Among Young Adults With an Autism Spectrum Disorder. *Journal of the American Academy of Child & Adolescent Psychiatry* 52, 9: 931–939. https://doi.org/10.1016/j.jaac.2013.05.019
34. SAGA. 2017. Lü - Interactive Playground. Retrieved August 24, 2017 from http://www.play-lu.com/
35. Ed Smeets and Ton Mooij. 2001. Pupil-centred learning, ICT, and teacher behaviour: observations in educational practice. *British Journal of Educational Technology* 32, 4: 403–417. https://doi.org/10.1111/1467-8535.00210

36. Ferdinand Streicher, Daniel Weiß, Jei Lee, Billy Boukis, and Thomas Mayer. 2017. T-T-T (Table Tennis Trainer). Retrieved August 30, 2017 from http://ttt3000.de/

37. Jane Fulton Suri. 2005. *Thoughtless acts?: Observations on intuitive design*. Chronicle Books.

38. Kenji Suzuki, Taku Hachisu, and Kazuki Iida. 2016. EnhancedTouch: A Smart Bracelet for Enhancing Human- Human Physical Touch. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, 1282–1293. https://doi.org/10.1145/2858036.2858439

39. Gulnoza Yakubova Teresa Taber-doughty. 2013. Brief Report : Learning Via the Electronic Interactive Whiteboard for Two Students with Autism and a Student with Moderate Intellectual Disability. 1465–1472. https://doi.org/10.1007/s10803-012-1682-x

40. Issey Takahashi, Mika Oki, Baptiste Bourreau, Itaru Kitahara, and Kenji Suzuki. 2017. FUTUREGYM: A gymnasium with interactive floor projection for children with special needs. *International Journal of Child-Computer Interaction* 15: 37–47. https://doi.org/10.1016/j.ijcci.2017.12.002

41. Monica Tentori, Lizbeth Escobedo, and Gabriela Balderas. 2015. A smart environment for children with autism. *IEEE Pervasive Computing* 14, 2: 42–50. https://doi.org/10.1109/MPRV.2015.22

42. Monica Tentori, Lizbeth Escobedo, Carlos Hernandez, Aleksandar Matic, and Gillian R Hayes. 2016. Pervasive Displays in Classrooms of Children with Severe Autism. *IEEE Pervasive Computing* 15, 3: 48–57. https://doi.org/10.1109/MPRV.2016.49

43. Catherine Tissot and Roy Evans. 2003. Visual Teaching Strategies for Children with Autism. *Early Child Development and Care* 173, 4: 425–433. https://doi.org/10.1080/0300443032000079104

44. Tokyo Metropolitan Board of Education. 2016. Text book for cleaning skills test in special needs school. Retrieved March 12, 2018 from http://www.kyoiku.metro.tokyo.jp/school/study_material/special_needs_education/cleaning_skills_test.html