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POTENTIAL OF LARGE-SCALE INTERACTIVE ENVIRONMENTS IN LEARNING AND EDUCATION

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Alla mia famiglia e ai miei amici più cari, senza il cui sostegno non sarei riuscito a raggiungere questo traguardo.

Abstract

In modern society, digital technology has a predominant role in several fields and it is used mostly to enhance transmission of information. Education and learning are currently taking steps into incorporating digital media for their purpose. This paper aims to provide an insight into a type of digital media that are still explored and are yet to become widespread in educational contexts: large-scale interactive environments. It will show how those systems can be helpful in learning by going over examples and projects of different interactive environments, their design principles, their testing phases and consequent observational results, in order to give an estimation of their possible value in an education setting such as primary schools.

Contents

Introduction to Large-Scale Interactive Environments

Technology is so pervasive in everyone's life nowadays, from utility to entertainment to social basic needs. It is essential for society as a whole. Many operations and tasks are now feasible through smartphone or PC only, we are in the midst of an economic transition towards globally preferring digital payments to cash payments, and the choice to live without smart devices is harder than ever. The 2020 Coronavirus pandemic further showed how technology is so needed in our lives, acting as a bridge to overcome social distancing limitations and allowing workers to continue their job and students their education remotely.

In an educational setting, technology has proved to be a strongly helpful support tool for both teachers and learners in recent years [1]. Transmission of knowledge can be massively enhanced by multimedia instead of frontal, verbal-only methods that have long been predominant in schools and academies. Adding non-verbal information to words such as pictures to convey knowledge can improve students' understanding, according to the multimedia principle [2, 3].

Additionally, 2020s youth are growing up in a much different social context compared to the one their parents lived in, and thus they have different needs as students. They were born in the Wi-fi era, they grew up accustomed to pervasive digital technology in their lives, in their homes, in their interests. They have been using smartphones and/or tablets since very young age for entertainment and interpersonal communication. They are heading into futures that are richer than ever in technology advancements and information. These are all more reasons why it is advisable for educators to constantly explore new ways of learning methods within digital technology [4] to improve students' engagement and focus.

The goal of this paper is to provide an insight into large-scale interactive environments, a type of digital media that has yet to become globally widespread in education settings and have the potential to being a powerful support tool in learning and teaching. This is done by introducing recent projects regarding such systems, with a closer look to their design choices, their hardware structure, their testing results, and their possibilities if used in learning and education. Chapter 1 describes types of interactive environments, including large-scale ones. Chapter 2 provides a central example of a large-scale interactive environment not designed entirely for education and still relevant in showing the ideal features of an interactive learning environment. Chapter 3 goes over additional selected projects including large-scale interactive environments and interactive learning environments. Finally, Chapter 4 sums up the advantageous factors and limitations of a global distribution of large-scale interactive learning environments.

1.1 Definition of Interactive Learning Environments

Any interface based on technology (software, hardware) that interacts with and depends on user's input can be considered an interactive environment, such as our everyday tech tools: smartphones, laptops, vacuum cleaner robots, smartwatches, and so on.

Interactive environments with learning and education purposes (interactive learning environments, or ILEs) have been researched and theorized since the early 2000s. According to the modality principle of instructional design [5], environments in learning are strongly successful when combining both verbal and non-verbal representations of the information using mixed modalities of presentation. The feature of combining verbal and non-verbal transmissions of information is peculiar to *multimodal* learning environments. Studies also suggested (and continue to suggest) that, in order to improve students' engagement in learning, new educational activities must include "Interaction, Exploration, Relevancy, Multimedia, and Instruction" [6], aspects that strongly pertain to interactive learning environments.

Initially, the broad definition of an *interactive* multimodal learning environment was one in which what happens is controlled by the learner's actions. In a non-interactive multimodal learning environment, the information is presented via visual and audio multimedia that is irresponsive to the learners. For example, a lesson in school can be explained by expository dialogue paired with slides or by a video from the teacher while students listen and watch but don't actively participate in the presentation: they are mostly on the receiving end of the exchange, they have no influence on what is introduced to them and how it is presented during the lesson, unless they interrupt the communication flow, for instance by asking a question. In an interactive environment, multimedia can instead change and adapt seamlessly in response to the learners' inputs and actions in real time: this way, the method of knowledge transmission is not purely unilateral anymore, the communication becomes multidirectional, and learners can directly see the impact of their actions on the educational message while engaging in the environment.

Types of interactivity can be summarized by five common categories: dialoguing, manipulating, controlling, searching, and navigating [7]. Interactivity by dialoguing means that the learner can ask something and receive a response or get more feedback: for example, the learner could get additional information by clicking on a highlighted word in a text. Interactivity by manipulating means that the learner can control aspects of the presentation, such as by zooming in or out and changing parameters. Interactivity by controlling consists in the ability to determine the pace of information transmission, for example by pausing-unpausing or rewinding a video. In interactivity by searching, the learner can find more information by using a search bar, entering a query, selecting options and so on. Lastly, interactivity by navigating is found when the student can choose a specific learning content by selecting it from a list of available sources, such as a menu. While it is possible that an interactive learning environment makes use of all five interactivity categories, the focus of this study is on environments which feature dialoguing, manipulating and controlling, since they are more widespread in research works.

1.2 Large-Scale Interactive Environments

Interactive environments included by the definition above can assume many forms, some of which are going to be analysed in a later chapter. This paper focuses mainly on multimodal environments that are composed by large-scale smart systems which consist of a combined network of PCs, touch-sensible surfaces, projectors, sensors, technology-augmented objects, and/or cameras. These large-scale interactive environments are defined by two important characteristics that can coexist or just be one between them:

- they implement full-body motion as input methods: by using motion sensors and computer vision, they can track the user's movements and acknowledge different inputs based on motion and gestures, which means using the physical world to interact with the digital world (embodied interaction). This involves users at multiple levels, such as sensorimotor experience and cognitive skills. If they are intended for a learning purpose, they are called full-body interaction learning environments, or FUBILEs;

- inputs can be entered by several users simultaneously: for example, a group of people can use one "smart board" touch screen all at once and the system elaborates those inputs together at the same time. In this type of large-scale interactive environments, a cooperation aspect can be present, which would invite users to teamwork and thus get to know each other and practice their social skills.

1.2.1 Benefits of ILEs and Large-Scale Interactive Environments in Education

If used in a learning setting, interactive environments (and large-scale interactive environments in particular) could have important advantages: the first one is the possibility to get students more involved in learning and studying. An interactive environment is a more interesting approach in learning compared to frontal lessons: children could be enticed by the idea of using a computer or a smart device to learn something, especially if said interaction is done in a playful manner.

This is proved by the vast research work done in recent years towards the concept of edutainment, which means learning through playing. Learning something new can sometimes feel difficult and tedious: it involves careful studying and constant practice. This becomes more complicated when learning is forced upon and is not dependent on the learner's preferences, aspirations, and attitude. The idea is to hide that tediousness behind an entertaining medium of learning, and this is the purpose of serious games. Serious games are designed to perfectly balance entertaining and learning and are not intended to be played exclusively for amusement. Nowadays, they are mostly associated to the digital world: they can be console games, mobile games, AR (*Augmented Reality*) or VR (*Virtual Reality*) games. Applications of serious games are multiple [8]: they range from military training to corporate training, from health rehabilitation to cultural education. They are useful for learning and practicing skills, training, problem solving, learning educational content, and more.

In addition, when serious games incorporate full-body interaction they tend to be more engaging and thus more effective in their purpose, for example in a rehabilitation context [9]. Choosing motion sensors as the input interface for a digital serious game gives the player more freedom and immersiveness compared to a joystick controller, not to mention the added intuitiveness.

A game design philosophy is not strictly required for the development of interactive learning environments: in a later chapter, this paper will go over some examples of interactive environments that do not necessarily fit that characteristic. However, serious games' qualities are highly beneficial for learning environments in order to facilitate students' motivation in engaging with the educational content and to make their initial approach to the system more appealing.

The fact that education can be digitally enhanced through interactive environments also allows educators and students to reliably record and track their progress between sessions. It is possible to monitor a child's interactive performance through analysing data gathered from the software in order to understand which areas to focus on in order to improve said performance and which areas is the student confident in.

An additional advantage regarding the use of large-scale interactive environments in schools is related to the second possible feature of those environments, which is the cooperation aspect that emerges when the system accepts inputs that are made by more than one person at a time. Fostering collaboration between children or students can enhance their social skills and help them socialize, which should be especially helpful for shy children or kids with disabilities such as Autism that often need a little push to start getting acquainted with others.

Adaptability is another strong point of these systems: interactive environments are extremely versatile since their hardware and systems can differ for situation and purpose. By implementing appropriate design choices and multiple settings that specifically suit a child's needs, interactive environments are a useful tool when teaching children with disabilities that range from mental, such as Down syndrome or Autism, to physical, such as visual impairment.

In some design choices, tangibleness and intuitiveness can also play a remarkable role as positive factors to large-scale interactive environments. The previously mentioned advantages can be applied in part to PCs as well, as in using PC serious games as a learning medium. However, sometimes PCs lack intuitiveness in their use: children, especially the younger ones, can feel discouraged to utilize keyboard and mouse, since they generally are not familiar with that hardware and lack the practice to operate them properly. Large-scale interactive environments instead can be more user-friendly and quicker to understand since they mainly implement body motion gestures or a touch-sensitive surface as input methods. These tangible ways of "inputting" information effectively reduce the difference between that information and its visual representation, there is virtually no delay between those moments and their correlation is immediate, similarly to an abacus in which moving the dots is part of the representation itself [10].

The See-Sound Project

In this section an analysis of the See-Sound Project is presented in view of methods, participants, systems, and results. The See-Sound Project [11] consisted in a joint collaboration between University of Padua and a non-profit organization that assists children with visual impairment. The goal for the project was to conceive and realize a playful full-body interactive environment to help children with their visual rehabilitation exercises. This project was chosen for this paper as a central example for adaptable large-scale interactive environments, whose design choices could be applied to an interactive environment in a learning context.

2.1 Concept

The Robert Hollman Foundation is a global non-profit organization created by a Dutch entrepreneur to help children with visual impairment and their families [12]. Its centres are located all over the world, including Padua. In 2021 a collaboration started between the University of Padua and the Robert Hollman Foundation centre located in Padua: the goal was to find a way to make visual rehabilitation exercises more appealing and more enjoyable for the children who are encouraged to do them mostly every day.

The university's researchers from the Department of Information Engineering designed three mini-games to be played by the children in a full-body interactive environment system at the foundation centre in Padua. The design, realization, and testing phases followed the indications suggested by the therapists who explained to the researchers the kind of exercises children were used to do and their visual impairment details, since the children did not all have the same visual disability and the same degree of impairment.

2.2 Children and Visual Impairment

Visual impairment consists in limited actions and functions of the eyes or visual system [13].

People affected by visual impairment can have different disabilities, ranging from having a reduced field of view to struggling to distinguish colours, from being more sensitive to light sources to having difficulty to orient themselves in relation to space and objects.

If visually impaired since very young age, a person can have important hardships in their life and growth. A visual disability could lead to strong consequences in relation to socializing and learning. That is the reason why children affected by visual impairment symptoms should be promptly checked by an optometrist and are strongly recommended to start treatment as soon as the diagnosis occurs.

Therapeutic approaches for these children include neuro-visual, visual-motor and psycho-motor therapies, which focus mostly on making them relate to what is around them. Thus, they improve their other means besides the visual ones to navigate space, such as memorizing a room layout or using sounds for orientation, and gaining additional body awareness in relation to the environment and others; for this reason, in a rehabilitation course a lot of emphasis is put in exploration, mostly in a playful form in order to establish an easier personal connection between the patient and the therapist, who acts as a guide. The therapy activities also differ from child to child since the visual impairment disability can take varying forms and degrees of severeness.

2.3 Realization of the Project

In collaboration with the psychologists and optometrists of the facility, the University team designed three different full-body interactive environment mini-games: *Bubbles*, *Sound Explorer*, and *Ping Pong*. *Bubbles* was taken in consideration the most for the purpose of this study, as it proved to be the most effective example of a visual rehabilitation game in the project.

2.3.1 The Kinect sensor

The central part of the hardware structure of the project was the Kinect. Initially developed by Microsoft in 2010 as a peripheral unit for the Xbox 360 console, it is a motion sensor device that tracks user body movements and gestures, allowing them to be treated as inputs by the console or by a computer. In subsequent years, Kinect grew in popularity among research environments thanks to its portability, its low cost and its customizability enabled by official and open-source libraries. Implementations vary from gaming to robotics, to medical and rehabilitation. In particular, some physical rehabilitation therapies took advantage of Kinect, with many research studies suggesting that the motion sensor and its flexibility can make physical exercises more successful and efficient by providing a way to tell the user in real time if, for example, the posture or the gesture is correct

[14]. When adopting Kinect in a system, designers should be careful on its positioning relative to the user, since it has some range limitations and tracking accuracy loss approximately after a distance of 2.5 meters. It is also important to note that Microsoft ceased production of the device in 2017, which is currently causing scarcity of buyable models.

2.3.2 Room Setup

The Kinect sensor was mounted on the ceiling and positioned towards the ground (see Figure 2.1). It tracked the child's movements in the room from a top-down perspective and sent their coordinates to a main computer in real time. Next to the Kinect, a projector displayed the game HUD (*heads-up display*) on the floor: in *Bubbles*, the HUD was a black or white background with coloured circles (the bubbles) moving on the screen, whereas in *Ping Pong*, it was the "game court". Audio feedback was also provided through speakers in the room, for example game sounds like bubbles popping when the child would stand on them or an alert sound indicating the end of the game.

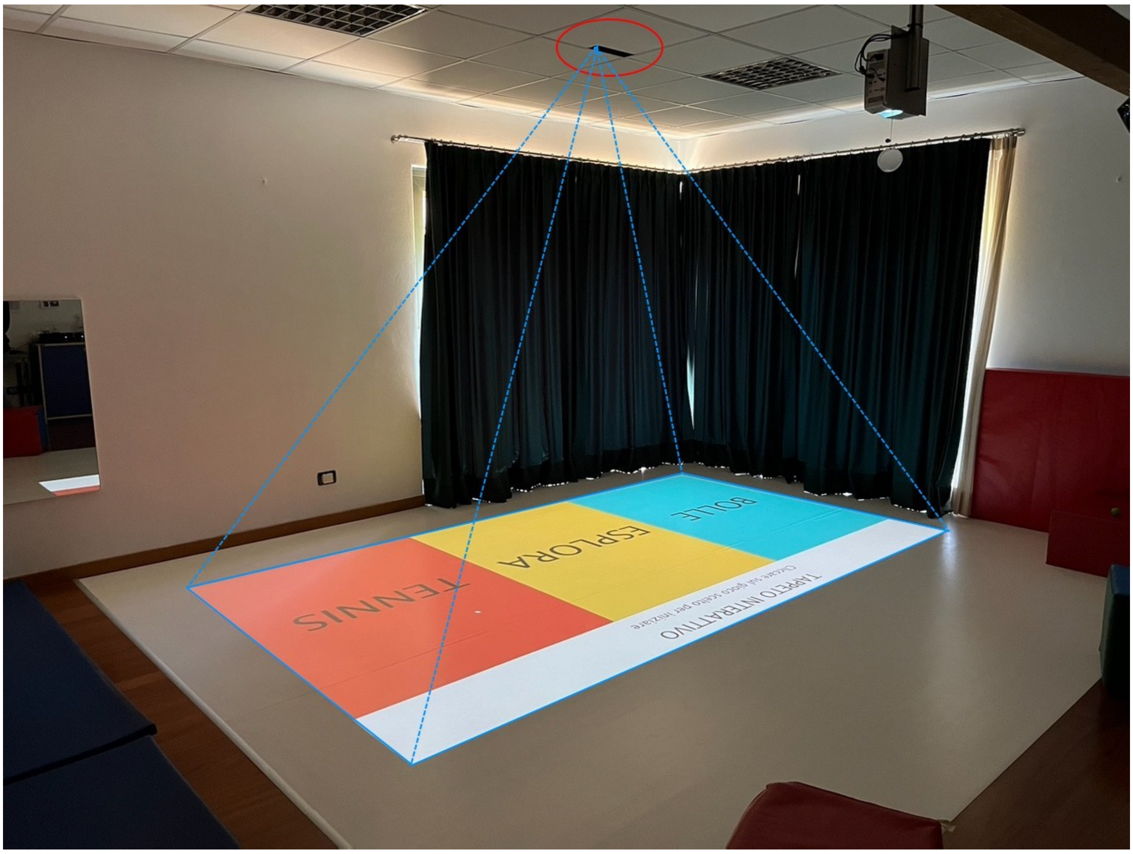

Figure 2.1: Layout of the playtesting room. The Kinect is circled in red. The blue lines give an approximate indication of the tracking range. Next to the Kinect on the top right, the projector and a speaker can also be seen.

The room chosen for the project was large, without obstacles for the children, and kept with as little sunlight as possible by covering the windows with thick curtains, in order to improve the system's visual quality and contrast on the floor and to reduce light obstruction to the Kinect sensor.

2.3.3 The Bubbles Mini-game

Bubbles is one of the three mini-games developed for the See-Sound Project. Its gameplay focused on movement all over the gaming field: colourful bubbles continuously spawned and moved on a black or white background, the goal for the player was to make bubbles pop as fast as possible.

The main computer ran the program containing the games' code, written in Processing language, and it was operated by the therapist, who could choose different settings and aspects of the game to suit the child's specific visual impairment type and characteristics. Examples of options included setting the bubbles' colours strongly in contrast with the background and making them bigger in order to be recognised more easily by the child.

At the start of the mini-game *Bubbles*, the main computer sent the specific settings to the projector which would then display the game on the floor. While the game was playing, the main computer constantly received the child's two-dimensional coordinates and elaborated those data correlating the child's position and movements with the moving circles' position, assigning points whenever the child managed to make a bubble pop by standing on it (see Figure 2.2). Higher score is awarded based on timing performance.

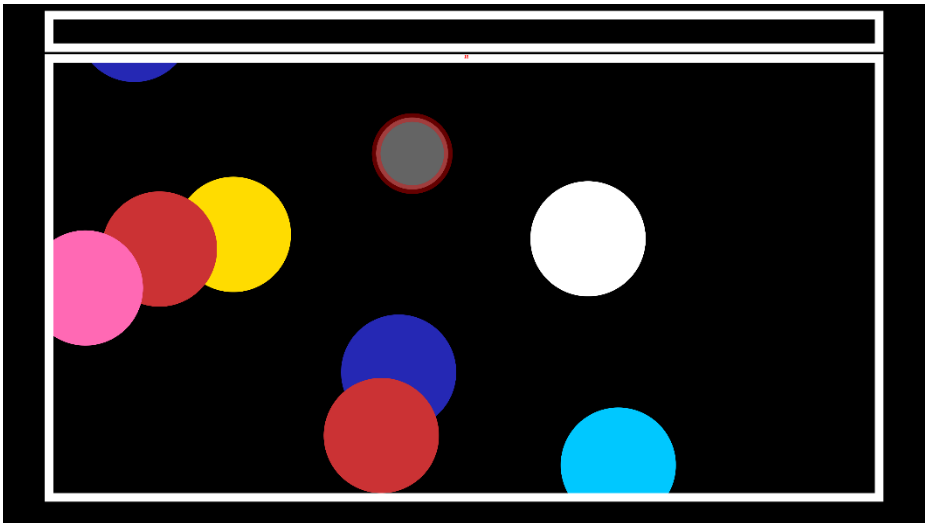

Figure 2.2: Example of the projected screen during a *Bubbles* game. The child can make a moving bubble pop by standing on it in order to gain points.

2.4 Testing Phase

Out of all children assisted by the Foundation, after explaining the goal of the study to their families and obtaining their consent, 11 children between 3 and 8 years old were selected to take part in project testing according to criteria chosen by the therapists, such as the visual impairment type (9 with moderate to severe Low Vision and 2 monocular blind) and general attitude to new experiences.

While the testing phase was designed to be run in 5 sessions for each child, the COVID-19 pandemic and related consequences did not allow for regular testing. Consequentially no tester was able to attend all 5 sessions. Additionally, one of the youngest children dropped out at the beginning of the testing phase after being scared of the games' lights.

Each See-Sound session lasted for 15 minutes at most and was included in the therapy activities for the patients once a week. Testing lasted for about 2 months, from November to December 2021. Therapists were instructed beforehand on the mini-games' functionalities and how to operate them.

The first round was equal for all children and involved the *Bubbles* mini-game, preconfigured with standard settings. However, the following sessions were customized around each child by the therapists, according to the child's preferences and rehabilitation goals, and included playing *Sound Explorer*, *Ping Pong*, or *Bubbles* again with different settings. When deciding which game to play and the settings, a major attention was dedicated to ensure that the gameplay would neither become too easy nor too hard for that patient on the basis of their skill level: an easy game would have just bored the child, while a game that was too difficult would have created frustration (see Figure 2.3); in both cases the playing experience would not have been optimal or enjoyable by the tester.

In each session, the team took specific care to give the child as much freedom as possible during the playing phase, interfering and helping them out only when necessary.

At the end of the session the patient was asked for their opinion about the game and their feelings towards playing it and the overall experience by using a visual-tactile scale graph made by three coloured stylized faces (smileys ranging from sad to happy) which was designed specifically for visual impairment patients.

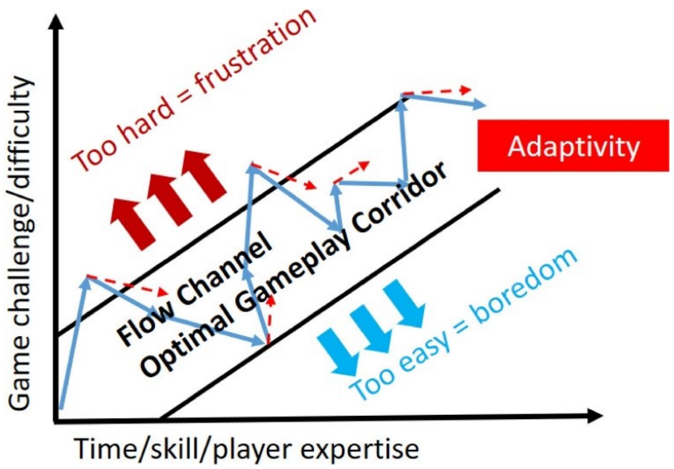

Figure 2.3: Choosing a difficulty setting for an educational game should consider the child's skill level in order to optimize gameplay flow and avoid making the game too frustrating or too boring.

2.5 Results and Feedback

Although the overall participation was subject to external factors such as the COVID-19 pandemic, the team managed to do sufficient sessions with the children and gathered enough data to roughly give an estimate on the See-Sound Project interactive environment value as a support tool for visual impairment rehabilitation programs. These observations are useful when designing large-scale ILEs as well.

2.5.1 Positive Observations

First, playing the games was really appreciated by the children. They found them fun and engaging especially in the beginning sessions; however, towards the end of the testing period the older ones lacked interest in and the motivation to play because of repetition and the simplistic nature of the games. To solve this issue, harder difficulties could potentially be implemented through the games' settings or, better yet, the introduction of new game mechanics or entirely new game types could help spark interest again among the patients.

As for the rehabilitation goal for the project, even considering the low number of testing sessions it should be safe to say that the interactive environment designed for the project can be a support tool to be utilized in a visual-motor coordination rehabilitation therapy. This is theorized by the fact that every child who played *Bubbles* for more than one session managed to slightly improve their reaction times in the game: these times were tracked and saved by the system over the course of the testing period. According to therapists, they also improved their orientation, their perception of space, and the directionality and accuracy of their trajectories.

Another conclusion reached was that in order to stimulate interest and make the experience effective it was fundamental to adapt the game specifically to each player by taking their characteristics (age, mood, skill level) and the severeness of their visual impairment into consideration. For example, clear audio feedback when bursting a bubble was really appreciated by the more visually impaired players and was treated by everyone like an accomplishment that motivated them to play more; choosing a font that was big and clear to read helped getting the players more involved, especially when showing them the various settings and showing how the therapists operated the system.

Furthermore, the accessibility of the interactive environment was confirmed by the overall positive performance of two players who have additional disabilities other than visual impairment: specifically, one was diagnosed with dyspraxia, a disorder that affects motor coordination, and one has Down syndrome and cognitive delay. Both children manifested interest and enthusiasm while playing the games and according to the therapists both improved some of their visual-motor coordination skills session by session.

2.5.2 Critical Points

Although the overall experience was positive and the See-Sound Project made a point to therapists to consider interactive environments as a support tool for visual rehabilitation activities, it had some issues that need to be addressed when designing such systems, even in a possible educational context.

First of all, the games needed precise tracking to work: while the Kinect sensor was serviceable for this project, it had some limitations in its sensitivity which failed to correctly detect the children in some circumstances, such as when the player was positioned at the edge of the game field and when they moved too fast. This issue can be easily solved by upgrading the hardware: a more modern but more expensive motion sensor or a multi-sensor system could be more precise in similar large-scale interactive environments.

Another problem that initially turned out was the low longevity of the games: as previously mentioned, the oversimplistic gameplay became repetitive and boring to some patients after just a couple of sessions. Since the system was meant to be used recurringly in a rehabilitation course, the fact that patients were not eager to use it could be really detrimental to the therapy. By adding more settings and making the games customizable for later sessions, the replay value can be greatly increased even for older children and the longevity problem can be solved.

Finally, the last weak point of the interactive environment was its lack of user-friendliness in the first versions. The therapists lacked the technical background to operate the system by themselves since the initial system had a very basic UI (*user interface*) that needed keyboard shortcuts and commands. Later versions implemented a Game Launcher system that streamlined the process and made it easier to use, allowing the therapists to be more independent. When developing an interactive environment, which for example is intended for a school setting, a clear and accessible UI should be a design priority for both the operator and the users since they generally do not have the background knowledge to use complex systems by themselves.

Other Projects and Evaluations

The focus of this chapter is to provide some study examples of interactive environments that have strong applicability in a learning setting. Paragraphs feature different projects and inform the reader about their goals, hardware structure and setting, testing phase, and results.

3.1 Pico's Adventure

Another example of a full-body interactive environment that uses a Kinect sensor to capture user inputs was the videogame *Pico's Adventure* [15]. It was designed in 2014 as a study for the European Project M4all with the goal of promoting new motion-based adaptable learning activities for children with disabilities. In particular, this game was aimed at helping ASD (Autism Spectrum Disorder) children socialize with peers or parents through cooperative gameplay.

Autistic people are affected by a lifelong neurological disorder that impacts their social interaction and communication skills significantly since childhood [16]. They tend to have repetitive behaviours, restricted interests, and sensory abnormalities. Regarding treatments, studies mainly suggest cognitive-behavioural therapies and social skills training, however their methods are constantly being researched. In recent years, a lot of research work has been focusing on digital games, after acknowledging that game-based interventions and technology can facilitate learning processes and motivation in ASD patients [17].

Pico's Adventure entailed a journey in a virtual world with the protagonist named Pico, a friendly alien that landed on Earth. The player controlled the game through gestures and motion recognition. The TV display and the Kinect sensor were positioned in front of the child in order to capture the child's whole body image and movements.

The goals of the game were multiple, including gathering spaceship parts to help Pico rebuild his ship and return to his homeland, and assisting Pico's friends against traps located in their planet. Puzzles and obstacles were present in the virtual landscape and they sometimes needed two players playing together in order to overcome them, thus requiring collaboration and teamwork to progress the game. The software also implemented the player's image as a world element, which allowed the child to see themselves playing in the virtual world, improving their immersion and making them more conscious of the impact their real-life motion and actions had in the game.

3.1.1 Testing and Results

15 boys with ASD between ages 4 and 6 participated in playtesting in four sessions. Testing occurred in 2014 in the span of two months. In each session, the child progressed a bit into the game, which was divided in sections with different gameplay, such a single-user stage and cooperative stages. Sessions also included 10 minutes of free play before or after gameplay testing, where children could play with each other in an ordinary play room with toys.

Observational results led to the theory that a full-body interactive environment is able to foster more social initiation between autistic children compared to free play. Children were enthusiastic about playing the game and they were eager to cooperate not only with a parent but, in the last session, also with another ASD child that they had never met before. The virtual world allowed them to socialize in a "safe" setting and with a goal in mind, thus breaking the social barriers which sometimes are obstacles for people affected by ASD when getting to know someone new. Another good note about this system is that it helped reducing repetitive behaviours and increasing gestures for autistic children.

3.2 Learning Disorders and Kinect-based Learning Games

Accessibility and adaptability can be strong qualities of large-scale interactive environments when it comes to children with disabilities, as showed by the See-Sound Project and *Pico's Adventure*. An additional example of these properties is a study [18] conducted in Athens, Greece in 2014 regarding children with learning disorders, specifically ADHD (Attention Deficit Hyperactivity Disorder), and Kinect-based learning games.

ADHD is one of the most common neurodevelopmental disorders in recent years [16]. It is mainly diagnosed during childhood and is a lifelong disorder that impacts the person's social life and learning skills. Symptoms vary from child to child and have different degrees of severeness; they include impulsivity, difficulty in paying attention and in staying focused for a task, failing often to recall information and to remember previously read material, making careless mistakes, lack of time management and organization skills.

Treatment research for learning disorders has become stronger in recent years since the surge of diagnosis cases globally, and it has encouraged an approach through serious games in order to train and improve certain skills more effectively in ADHD children [19]. More specifically, Kinect motion-based serious games have been studied and proved to be appropriate for that kind of patients. Thus, the idea of testing Kinect learning games with children with ADHD started this study in order to evaluate their effectiveness as an accessible educational medium.

A multicultural team of educators and researchers studied testing of *Kinems* games with young patients with ADHD at the children's University Hospital in Athens in 2014. *Kinems* [20] is a commercialized software that includes multiple Kinect-controlled, single-player learning mini-games designed for primary school students; their design choices also take children with learning disorders in consideration, such as by implementing carefully designed UI. Before that study, *Kinems* had already been tested in various learning and therapeutic environments with positive results [21]. The software trains eye-hand coordination, memory, concentration, execution skills and motor planning while playing an educational mini-game about various subjects, such as mathematics, logic, language comprehension and writing. For example, the *Mathloons* mini-game consists of practicing math calculations up to 100 by moving air balloons containing numbers through hand motion; *Farm Walks* trains body coordination and concentration by making the player control a running animal avatar that has to touch a specific kind of numbers on its track.

3.2.1 Testing and Results

11 children with ADHD aged between 4 and 9 years old participated in playtesting. The 30 minutes playing sessions occurred 2-3 times a week for one month for each child. Sessions were administered by psychologists who also chose the game to play in each session from a five *Kinems* games pool according to the children's needs and preferences.

Children showed strong interest to play and learn via the Kinect-based games throughout the entire testing period. Observational findings led to the hypothesis that full-body interactive games improve children's executive functions and accomplishment of specific learning objectives. ADHD children were able to train both their motor and cognitive skills in an engaging and playful way, despite their inclination to lose focus and get bored easily. Still, researchers felt that more testing should be expected in order to further prove the effectiveness of these learning mediums and offer new insights on how to assist children with learning disorders.

3.3 Archimedes

Archimedes [22] was the name of a full-body interaction learning environment that made use of the Interactive Slide platform [23].

The Interactive Slide is a large inflatable slide for children which incorporates projection on its sliding surface and interactiveness with the projected content through sliding down. It is composed by four parts: a sliding surface on which a video or game HUD is projected, an upper part where children can stand before sliding down, side stairs to climb in order to get to the upper part, and a landing space to be reached after sliding. Inputs reading is enabled by computer vision technology, which detects the position and movements of several people on the slide.

In 2015 a team from the University of Barcelona designed the videogame *Archimedes* to work with the Interactive Slide in order to create a full-body interaction learning environment aimed at educating children about the Archimedes principle and the concept of buoyancy. *Archimedes* was an exergame, a type of videogame that includes physical activity in order to be played. In this case, the inflatable slide offered a great opportunity for physical exercise since sliding down is entertaining for children and requires climbing stairs to reach the starting platform.

The projection in *Archimedes* consisted in a colourful and cartoonish screen which depicted two separate pools of water at different water levels, a cat standing on the split between the pools, and two fishes each positioned in one pool (see Figure 3.1). On the top of the screen above the pools, a group of various objects such as rocks, balls, and logs moved horizontally and continuously in one direction.

Figure 3.1: The *Archimedes* game on the Interactive Slide.

The game had two objectives: the first one was to create a bridge to let the cat cross one of the pools and go to the edge of the game screen. This was accomplished by putting the right objects on the water surface. The second objective was to raise the water level of one of the pools to allow a fish to jump to the other pool and reunite with his fish friend. This was accomplished by choosing the right objects that would sink in the pool and thus raise the water level.

Children could put the objects down by choosing one among those that moved horizontally above the pools and dragging it down by sliding. Heavy dense objects such as rocks would sink while buoyant objects such as logs would float. Therefore, the game required the children to think and plan their actions and choice of objects in order to accomplish the objectives.

3.3.1 Testing and Results

Testing was based on 6 minutes sessions by groups of four children, a total of 48 children (aged 11 on average) participated in playtesting, which was recorded and observed thoroughly. The concept of buoyancy and the Archimedes principle were already introduced to the children at school, so the participants were not totally unfamiliar with the game's theme. Before the session, a short video tutorial explained the game to the group of players. After the session, feedback was gathered from the children through a simple questionnaire regarding the experience and the understanding of the game's objectives and mechanics.

Reported results showed that all participants enjoyed the activity, mostly because of the opportunity to play on the slide, and understood the game's objectives; most of them managed to figure out the interaction between their sliding and the digital game, between the objects and the water pools, although not all groups managed to accomplish both objectives. The approaches changed from child to child: the most common initial approach was to slide repetitively without observing what happened to the game screen after reaching the bottom, their main focus was to play and enjoy sliding. The majority of the children started to think about their actions only after some trials and after noticing some audio/visual feedback, such as the cat making a cry of complaint when hit by a dragged object or seeing the rocks sinking but the logs floating. At that point, some of the students started observing the other children in the group in order to better understand how the game worked and what should have been done in order to "win" the game, sharing their findings with the others as well and cooperating. Other children instead engaged in a trial-and-error approach to see the effects of their actions and still managed to understand the game's mechanics, although they did not complete both objectives, either because of the time limit or because they did not comprehend the objects' different properties.

The study highlighted how the link between actions and thinking, between cause and consequence could be introduced effectively to students and experienced through a large-scale interactive environment. The experiential part of the game led most children to think about their actions and reflect upon the objects' properties and influence on the game state.

It also made most participants assume different points of view in order to observe the others and the game screen to try to reach a conclusive theory. This way, the game facilitated instances and conditions for reflection by making the children explore new perspectives in order to reach a goal, which can be an important skill to learn as well. They also shared their findings with the others, suggesting that the interactive environment can be stimulating and facilitate teamwork and collaboration, and can make them experience first-hand various group roles such as leader and observer.

A large-scale interactive learning environment such as *Archimedes* has the additional benefit of promoting physical activity to children not only in a playful manner, but also with a learning purpose.

Furthermore, *Archimedes* testing showed a critical point in designing a full-body interactive learning environment: the fun part of the system needs to not overcome the overall purpose of learning through playing. Indeed, a small minority of players focused on just going on the slide without caring about the game, since sliding was already interesting enough to them. When designing such systems, the risk of a disconnect between the designer's intentions and the child's interpretation needs to be taken in consideration, and it should be tackled on by giving the players clear hints towards the educational goals and being careful about the overlap between the playful side of the experience and the learning content.

3.4 A Math Graph Drawing Software

At primary and secondary schools, mathematics is often one of the hardest subjects to teach, since the most effective approach to it consists in a more emphasized importance to practice compared to theory reading and learning; therefore, mathematics as a subject is generally less intuitive for children to understand and can be challenging to teach and learn [24].

Using the Kinect, a team of Mexican computer science educators designed a motion-guided interactive learning environment that allowed students to better understand the Cartesian plane and to replicate simple graphs using physical gestures [25]. The project was submitted to the 2013 International Conference on Virtual and Augmented Reality in Education. It was created as a way to explore possibilities of the use of Kinect and physical interactiveness within a learning environment.

The first screen of the program displays instructions and the option to “capture” the hand gestures. After selecting “Capture”, the screen becomes an empty Cartesian coordinate plane and the student can control the pointer using their right hand to test and gauge the sensitivity of the motion sensor (see Figure 3.2).

The student can then press a “Start” button with their left hand, after doing so a countdown starts and the program tracks the right-hand movements which are used to draw on the Cartesian plane in real time. At the end of the countdown, a series of graphs created by the application are presented to the student, including their right hand XY coordinates over time, their velocity and acceleration.

Figure 3.2: The Capture screen with the Start button.

Feedback was mostly positive: students appreciated participating in testing the application and managed to replicate several graphs and patterns correctly. The project showed that, although limited in its functions, the application could be useful in practicing graph drawing in a different and more enjoyable way compared to pen and paper drawing, as well as more intuitive compared to using a PC.

3.5 A Motion-based Game About Recycling

Another particular use of a full-body interactive learning environment was an educational recycling game [26] which was tested by primary school students. By taking advantage of the technological possibility of relating students with a natural and realistic environment through a virtual user interface, the designers of this game tried to educate children about the importance of recycling and how to do it correctly. A Kinect sensor, positioned in front of the student, took the child's gestures as inputs and made their virtual avatar complete recycling tasks in the game world. The goal of this project was to evaluate the effective potential of learning through movement and actions compared to traditional visual-audio approach.

The observational results were overall positive. The children appreciated learning through a digital game and showed preference over traditional learning methods. It was also noted that, as a multiplayer game, male students were more motivated in playing the game competitively whereas the female students preferred a cooperative approach. This interactive learning environment also had the additional benefit of promoting physical activity to primary school children, through the virtual recycling tasks required by the game.

3.6 Tabletop Music Learning

When it comes to music education, it should be noted that it can be considered another complicated subject to teach and learn for the uninitiated. Music can be difficult to perceive and understand since it is an inherently abstract phenomenon that is theorized to exist only inside the mind of the listener [27]. Composing and making music through instruments requires a significant amount of constant practice that can easily bore the learner after some sessions. In addition, music reading needs learning a specific, exclusive language. These factors can discourage novice students on their approach to music learning and make them miss the chance to become a better listener or perhaps even a musician.

As technology improved its flexibility and the cost of it became more accessible over the past 15 years, it started to be regarded as a strong support tool to be integrated in music education, especially with a cooperation mindset and an emphasis towards learning by doing instead of just reading. First examples of this include a 2004 project that involved primary students into composing music as a group through a computer [28]. In particular, digital games began to be considered the most effective technological approach when teaching children music [29].

When considering large-scale interactive environments, a platform that can be suggested when designing such systems for music education is the Digital Tabletop Interface [30]. DTIs are a type of user interface that can be interacted through a touchable screen or projection and provide visual feedback from the touch inputs. Their surface is flat and is large enough to be used by at least two people, who can operate independently or cooperatively. For music learning, they can run a synthesiser that users play by interacting with the screen, which allows to improvise and compose music.

Digital tabletops may be able to assist beginners in approaching music, since they are flexible of the digital medium [31] and they provoke reflection or action through different types of feedback by linking the physical and the digital world [32]. They are great at exploring the effects of different choices and showing complex simulations such as music composing in an intuitive way.

3.6.1 The Reactable

A commercial DTI product that adheres to these goals and aims at being flexible in various contexts is the *Reactable*. It is a real-time modular synthesizer [33] that reads inputs from a multitouch circular surface combined with tangible object manipulation. Objects include cubes, circles, and rounded squares which can be positioned on the flat display and act as customizable buttons for various functions, such as generating sound effects and music samples in a loop and controlling global audio parameters. By linking multiple objects together, the user can create a “thread” that acts as an audio channel (see Figure 3.3). Tempo can be set manually and it is a global parameter for all active threads.

One of the strongest points of *Reactable* that sets it apart from visual programming musical languages, is its ability to be dynamic in real-time: music can be edited and played at the same time, which promotes musical improvisation to a considerable extent. Additionally, the fact that it is intuitive to use and large enough to be played comfortably by two to four users at once emphasizes how supportive it can be as a social, hands-on learning tool in educational contexts. The device is also able to be run in a professional music setting.

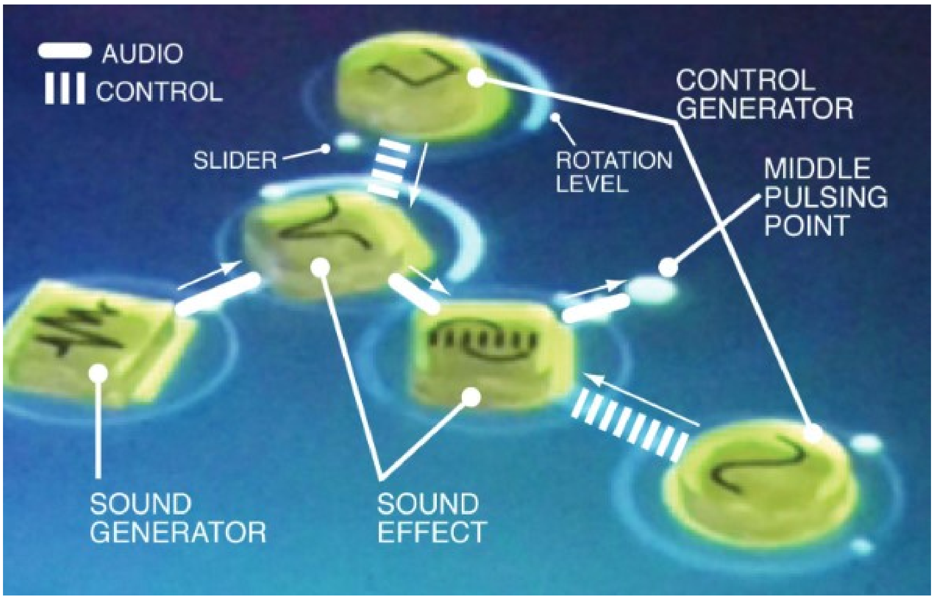

Figure 3.3: Example of a Reactable's thread.

3.6.2 Testing of Reactable in Music Education

To investigate the capabilities of *Reactable* in music learning and improvisation, a study was conducted in 2013 [34] and consisted in testing sessions made by groups of two to four males aged 22 to 54, for a total of twelve testers (see Figure 3.4). Participants were already familiar with *Reactable* before testing and they had a medium to major knowledge in music. Groups were asked to improvise music, similarly to a jam session, by collaboratively using *Reactable* through a series of four sessions, which lasted from 35 to 45 minutes each, over a week period. Participants felt involved and engaged through all sessions, especially who were the most knowledgeable in music. Results were different from group to group, but all of them managed to complete the task as a team.

Figure 3.4: Groups participating in Reactable testing.

Examinations of testing sessions suggested that *Reactable* promotes hands-on, social tinkering in a collaborative environment and fosters development of modular structures from basic to elaborate. The multiuser, simultaneous characteristic of the device led some participants to learn by mimicking another peer through instrumental interaction within the shared environment. Findings also reported that sharing a user interface without predetermined restrictions promotes exploration and creative discovery, thus allowing the system to be able to positively motivate team and peer learning in educational group sessions.

The tangibleness of *Reactable* is another strong advantage of the system when implemented as an interactive environment in a learning setting compared to other systems such as keyboard and mouse. The touch screen and the interactive objects tend to overcome the difference between input methods and how the inputs' information is represented. Indeed, input devices can be distinguished by two categories: those which make a correspondence between behavioural meaning and output, such as a stylus on a touchable surface, and those which are restricted in that regard, such as a mouse. By providing a much closer correlation between the physical and the digital world, DTIs such as *Reactable* are more intuitive than keyboard and mouse pairs, which is a fundamental characteristic to be considered when designing learning environments for children.

3.7 Possible Shortcomings in Large-Scale Interactive Learning Environments

This chapter has presented examples of interactive environments, their study results and potential advantages as learning environments. However, those systems could suffer from some possible limitations if ever intended to be commercialized at a large scale.

The first one is the fact that they rely on relatively expensive or hard-to-find hardware. For example, large-scale, motion-based interactive environments such as the See-Sound Project need a motion sensor as an input tool: as reported above, Kinect is serviceable enough in most cases but it is not fitting when in need of precise tracking. Microsoft also ceased production for it, so it is rarely found in the market, even when looking for preowned units. Other motion sensors can be considered, however the more precise they are the more expensive they get. And even then, if the software (such as a digital serious game) for a full-body interactive environment is intended to be commercialized and brought to schools globally, it has to be designed and developed to work with a specific motion sensor model, which means that compatibility with other motion sensors is not guaranteed and needs to be addressed.

Software development itself for an interactive learning environment can also bring another potential shortcoming. While videogames such the ones designed for *Archimedes* and the See-Sound Project can be relatively simple to develop because of their simplistic nature, other games such as *Pico's Adventure* can be more time-consuming in that regard and may need a greater amount of resources in order to be planned and finalized, because of their greater virtual scale. Some examples of interactive environments above show that they are versatile and adaptable, with hardware ranging from inflatable slides to touch-sensible tables, however their educational goals are generally limited to a single concept, such as "learn and practice how to recycle better" and "learn and practice how buoyancy works", and these mini-games can be played fully and completed in a very short time. Therefore, significant development time and costs for large-scale commercialization may not be worth it.

That is, until sensorial technology (such as touch-sensible surfaces, computer vision and motion trackers) costs become more affordable and until a common, easily accessible hardware infrastructure becomes mainstream for large-scale interactive learning environments: at that point, software houses could potentially develop multiple digital serious games for that platform. Even if they were simple mini-games, they could still serve a purpose as a supporting tool in education by allowing the child to practice some pre-learned concepts or by introducing students to new educational content with an engaging approach.

Conclusions

Large-scale interactive environments have the potential to be an advantageous platform in a learning and education setting, especially when they adopt a game design philosophy, provided that their design choices are careful of balancing between entertainment and educational goals, between software functionalities and user-friendliness. Their best uses include introducing new educational content, learning skills and information through playing, and practicing previous knowledge, all while providing children an engaging and interesting way to approach learning.

Study cases reported in the previous chapter effectively showed how their intuitiveness through interacting via simple to understand input methods, such as a full-body motion sensor or a touch-sensible surface, can be considered a strong asset when educating children, who generally lack deep technological knowledge and practice.

Large-scale interactive learning environments also proved to be flexible and adaptable through implementing options that fit the educational goal and a child's preferences and needs; these systems may include specific accessibility settings designed for children with disabilities and learning disorders, whose engagement can be enhanced compared to traditional education methods.

The social implications of using an interactive learning environment cooperatively with other students or educators are considerably positive: teamwork fosters social initiation between students and offers more opportunities for them to get to know each other and learn how to collaborate with others. Large-scale, motion-based interactive environments are also beneficial in promoting physical activity to children.

Testing results are encouraging overall and promote further research on the possibilities and value estimation of large-scale interactive learning environments. Unfortunately, at the current time there is a not a mainstream global hardware platform to develop interactive learning games for. Kinect could almost have been considered as such in past years, however the ceased production in 2017 and consequent scarcity of models on the market prevent its global distribution in schools nowadays. Hopefully, technology structure for large-scale interactive learning environments will be able to become more affordable and popular in the coming years, at that point software development for those systems could prosper and be meaningful for global releases.

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