Figure 1: Renderings of Magika

Magika, a Multisensory Environment for Play, Education and Inclusion

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ABSTRACT

Magika is an interactive Multisensory Environment that enables new forms of playful interventions for children, especially those with Special Education Needs. Designed in cooperation with more than 30 specialists at local care centers and primary schools, Magika integrates digital worlds projected on the wall and the floor with a gamut of "smart" physical objects (toys, ambient lights, materials, and various connected appliances) to enable tactile, auditory, visual, and olfactory stimuli. The room is connected with an interface for educators that enables them to: control the level of stimuli and their progression; define and share a countless number of game-based learning activities; customize such activities to the evolving needs of each child. This paper describes Magika and discusses its potential benefits for play, education and inclusion.

CCS CONCEPTS

• **Applied computing** → **Interactive learning environments**; • **Human-centered computing** → *Displays and imagers*; *Accessibility systems and tools*; • **Social and professional topics** → *People with disabilities*; *Children*; • **Hardware** → *Tactile and hand-based interfaces*; • **Computer systems organization** → Sensors and actuators.

KEYWORDS

Multisensory Environments, Children, Play, Education, Inclusion, Special Education Needs

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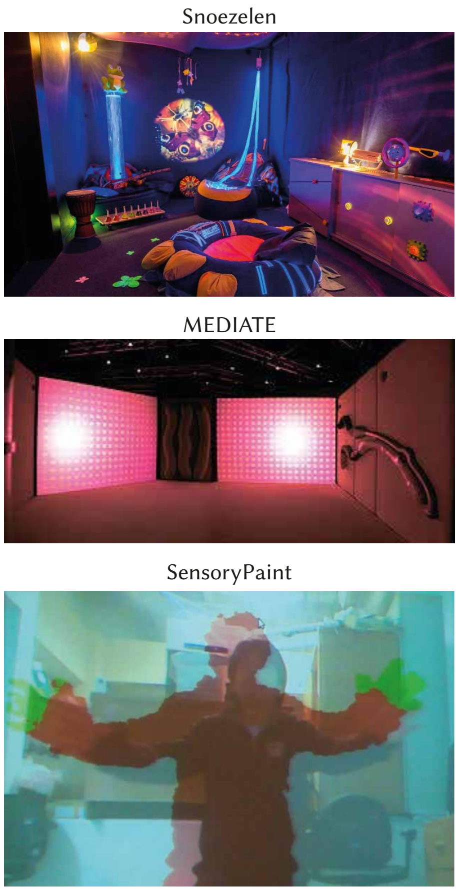

Figure 2: Related Works

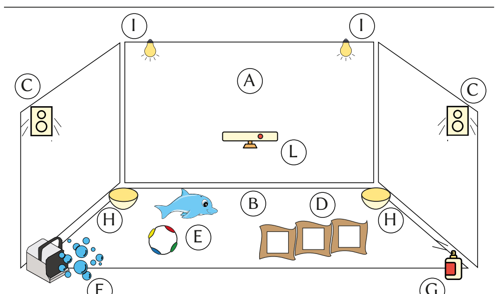

Figure 3: Magika Setup

INTRODUCTION

Advances in Cyber-Physical Systems and Internet of Things (IoT) open up possibilities for a new generation of smart Multisensory Environments (MSEs) where the various sensory affordances are digitally connected, controllable, and interactive. This scenario creates several research challenges:

(1) *Can we build a space that offers a variety of stimuli comparable to the current available products but is interactive, enables the creation and execution of any desired, remotely controllable combination of action-stimuli, and is open to extensions in terms of tangible objects and visual digital contents, eventually at a lower cost?*
(2) *How can we orchestrate interactive behaviors and stimuli in a smart MSE and define meaningful activities for children, especially those with Special Education Needs (SEN)?*

This paper describes the journey undertaken by a multidisciplinary team of software and hardware engineers; UI, UX, and product designers; psychologists; therapists; educators and children to address the above questions. Together, we have designed and implemented a smart multisensory environment called Magika. Magika offers novel opportunities to engage all children in playful learning experiences that conventional MSEs cannot offer. It also empowers educators so that they can autonomously develop new multisensory activities customized to the specific needs of each subject. This technology appropriation process may lead to define new intervention methods in the didactic and therapeutic arena.

RELATED WORKS

Magika's rationale is grounded on the theories of embodied cognition and sensory integration that emphasizes the formative role of embodiment (the way an organism's sensorimotor capacities enable it to successfully interact with the physical environment) in the development of cognitive skills such as mental imagery, working and implicit memory, reasoning and problem solving [10]. Sensory integration theories posit that learning is dependent upon the ability to take, integrate, and process multiple sensory information in order to plan and organize behavior. When this process has deficits, as it is thought to happen in subjects with special needs, an abnormal mental representation of the external world is created, which in turn affects the capability of appropriate behaviors in all aspects of life. Specific interventions for persons with special needs aim at stimulating basic perceptual mechanisms and promoting perceptual learning [10]. They often take place in a dedicated Multi-Sensory Environment (oftentimes referred to as Snoezelen [3]) - a room equipped with physical items and devices that provide gentle multisensory stimulations through sounds, lights, projections, soft fabrics and materials (Figure 2). Prior HCI research indicates that combining the physical and the digital world and offering multisensory stimuli through embodied interaction provides support for persons with disabilities. Some works explored how tangible interaction with smart objects [2] can help children with sensory processing disorders to empower self-reflection, self-directed activity, and language. SensoryPaint [4] allows persons with neuro-developmental disorders to paint on a large display using physical objects, movements and mid-air gestures, and to receive visual-aural stimuli. A field study showed that the use of the system balanced children's attention between their own bodies and sensory stimuli, and promoted socialization. MEDIATE [9] generates sound and visual stimuli in response to gestures and footsteps on the floor in front of a large display, and would stimulate creativity, sense of agency, and self-expression among low-functioning non-verbal children with autism.

Magika combines and extends the features of existing multisensory digital systems in a unique way, proposing a pervasive inter-connected space where all children are involved in new forms of full-body, tangible, playful, multisensory, learning experiences.

Figure 4: Magika Control Interface

MAGIKA

Magika is an unconventional, IoT enabled, physical space designed in close cooperation with 20 teachers from two primary schools in Cornaredo (Milan), where the first rooms have been installed, and 10 psychologists from L'abilitá Onlus and Fraternitá e Amicizia therapeutic centers. All participants signed a consent form.

Goals

Interventions in Magika have four main goals: i) promoting a general feeling of restoration and relaxation; ii) stimulating the vestibular, proprioceptive and tactile sensory systems to improve individuals' ability to process and integrate sensory stimuli in a correct way; iii) learning by doing (which is fundamental to develop cognitive and academic skills [6]) in multimodal learning scenarios with combinations of tailored stimuli from multiple sources; iv) "reverse including" in which special needs children are the main actors in the inclusion process.

Stakeholders

Magika's primary target users are children from 4 to 10 years old, especially those with Special Education Needs (SEN). A SEN child is commonly recognized if she is not able to benefit from schooling made generally available for children of the same age without additional support or adaptations in her study contents and contexts [5]. In Italy, SEN is defined as a child who presents physical, psychological, sensory impairment, permanent or progressive, that causes a learning difficulty and that causes a situation of disadvantage or marginalization [5]. Secondary users are support teachers, teachers, psychologists, therapists and eventually parents and the community overall. We are currently in the process of understanding how Magika can be opened to the public during weekends.

Setting

We developed a technology (Figure 3) that transforms an empty room into a multisensory "magic" room that integrates visual contents projected on the walls (A) and on the floor (B); ambient sound (C), smart physical objects (textured materials (D), stuffed toys (E)), connected appliances (bubbles makers (F) and fragrance emitters (G)), smart lights (wireless portable lamps (H) and bulbs (I)). These elements, controlled using a tablet and automated by a PC, react to children's manipulation (tangible interaction) and body movements (touchless interaction provided by a Microsoft Kinect (L)) to offer visual, auditory, tactile, and olfactory stimuli in any sequence, combination and intensity. The technical details are briefly described in Section "Modularity".

Experience and Flow

We conducted primary and secondary research to define a simple, unique, long-lasting experience for both children and educators. We modeled a design system (i.e. a collection of reusable components, guided by clear standards, that can be assembled together to build any number of applications) based on standard patterns and principles offered in [8] in order to have consistency across all the UX touch-points. We then developed two main entities: Magika Experience Manager (MEM) and Magika Control Interface (MCI), mainly experienced by children and educators respectively. MCI (Figure 4) is divided into three sections: CREATE, PLAY and LIVE. CREATE allows teachers to set new activities and experiences (set of activities) before accessing the room. PLAY, only used inside the room, lets teachers selecting activities and experiences according to what they configured before. LIVE, to control and visualize the flow of the activity in real time. MEM is responsible of managing the entire flow inside the room (Figure 5). The flow is composed by 15 distinct phases, inspired on Campbell's "Hero's Journey" [1, 11].

Figure 5: Magika Interaction Flow

- **Storytelling (0A)**: Before accessing the room, children are told the fabula (inspired by [7]): Magika was a colorful and harmonic planet. The inhabitants belong to 5 species (hereinafter Senzies, as in Figure 8, referred to the 5 main senses): Gus (taste-rs), Olfo (smell-ers), Auri (hear-ers), Tati (touch-ers) and Vis (view-ers) living in 5 different continents (-lands). One day, the awkward Kaos caused a "BigBoom" and made Magika decomposing into millions of colored balls, scattered throughout the universe. Emi ("the sixth sense", emotion), the wise sage of Magika, decided then to send magical spheres around the universe to be helped in the reconstruction of Magika. Everytime a child will experience an activity in the room, she will collect a ball that, after being grouped with other children's experiences, will be sent to the Magika World.
- **Avateering (0B)**: described in Section "Relatability"
- **On-boarding (0C)**: described in Section "Adaptivity"
- **Start (1A)**: the teacher enters the room with children, turns it on by using a PC placed at the entrance, and switches the tablet on. Children take off their shoes in the appropriate area.
- **Warm-up (1B)**: the room automatically starts recalling some video animations and audio/light effects related to the fabula of Magika. Meanwhile the teacher selects the activities and experiences, eventually previously programmed, to play via the PLAY control panel.
- **Idle (1C)**: the room goes in idle mode and waits for the teacher to add players or for children to add their-selves using a badge previously created ("Avateering" section).
- **Identification (1D)**: when children identify themselves, Emi calls their names and shows their avatars.
- **Mission (2A)**: a mission is assigned once the teacher decides the session can start. A random Senzie appears and explains its needs (all characters are gender neutral) of re-building its own continents by using balls created by children's experiences throughout the session.
- **Call (2B)**: After having checked (and eventually changed) the configurations of the coming activity, the teacher will start the activity. Emi will then give activity instructions to children.
- **Zoom in (3A)**: the room zooms in the activity world.
- **Activity (3B)**: as soon as the activity starts, the teacher controls the flow by using her LIVE control panel or a 6-buttons remote controller (Fig. 4) or lets Emi to "Magika-lly" decide how to proceed. Activities are composed by tasks. Everytime a task is accomplished, children are rewarded with sounds and light effects. Activities can end successfully (in this case children win a virtual cup) or erroneously (in this case no rewards are given).
- **Zoom out (3C)**: the room zooms out from the activity world.
- **Result (4A)**: when the ended activity is completed successfully (**Reward (4B)**), the previously random Senzie transforms the cups won in colored balls (depending on the Senzie's colors) and stores them in a white sphere (that digitally shows the number of balls collected for that session). When the ended activity is not completed (**Failure (4C)**), the random Senzie prompts children to continue in their mission. The teacher can always decide to repeat (2B), continue to the next activity or end the session (successfully or incomplete).
- **Goodbye (5A)**: the session can end successfully - in this case the random Senzie shows that it is sending the ball to its Magika continents and thanks all children - or incompletely - in this case the random Senzie congratulates children and asks them to re-try the next time.
- **Magik-ing (5B)**: at the end of each session, children will attach as many colored ball-shaped stickers as they collected during the session on a banner representing the outlined map of Magika. In this way, children will be considered as "Magik-ers".

Figure 6: Magika Avateering Phase

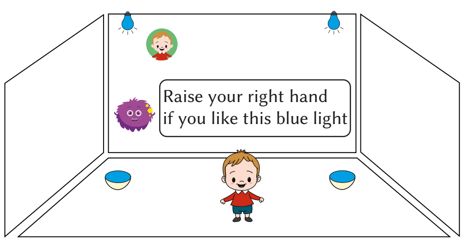

Figure 7: Magika On-Boarding Phase

Figure 8: Magika Senzies

CONTRIBUTIONS

Magika contributes to the current state of art with a complete gamut of features, listed below.

Multisensoriality/Multimodality. Current MSE rarely support learning scenarios that combine stimuli from multiple sources and to multiple destinations. Magika actuates through auditory, visual and olfactory channels and senses through auditory (voice), visual (body movements) and tactile (touches on smart objects and materials) channels (Fig. 9B,I). To add more **tangibility**, we created smart frames (for feet and for hands) to contain more than 30 textured tagged materials (Fig. 3D,9D,9M) that, recognized by the system, enhance the tactile experience.

Configurability. Magika gives educators the possibility to customize their multisensory learning experiences. While in existing smart multisensory systems, all features are "hard-coded" and any UX modification requires operations at programming level, Magika integrates an intuitive responsive interface that directly responds to teachers and children tailoring needs (Figure 9A).

Relatability. Children feel part of Magika in small time. We developed a preliminary phase called "Avateering" in which they create their own avatar through a dedicated interface. They can choose different features as hair, eyes, mouth and labeled t-shirt (Figure 6). This phase ends by giving children a personal Magika badge. Children's avatar and badge will accompany children across all Magika's experiences (Figure 9E).

Immersivity. In Magika children are told a Story (Fig. 9G). It is not be just about solving puzzles, collecting elements or simply watching, reading or writing. Even if all these features are part of the experience, Magika aims at immersing children inside a "tangible", yet concrete, narrative: it contains characters and events that they can be identified with. All players' actions are meaningful to the main story to let them feel relevant and active.

Magicity. Magika, represented by Emi, knows the right moment to call a child to play, to sustain interest, to manage turn-taking and to maintain all players in the story flow (Figure 9H,L).

Relativity. Children are able to recognize their function within the story (agency) and the entire flow is functional to the narrative: in-flow activities are framed to fit and answer with the story and the players' aim is not mastering the activities as a system but rather to be part of an engrossing magika(l) story (Figure 9H).

Automaticity. Children's movements in the space, performances, accomplishment times, face trackings and emotions, audio recordings and feature extractions are automatically collected within Magika. We are working on the integration of machine learning approaches that exploit the progressively increasing amount of gathered data both for diagnostic purposes and to support self-adaptation of the interactive space (Adaptivity)

Autogenerativity. The system exploits a Knowledge-Based Technique (KBT) which aims at capturing the knowledge of human experts to support decision-making during each activity designing and setting. KBT employment validates the definition of "auto-generative" interface: thanks to its rule-based approach, the system automatically extracts contents from the web, elaborates information and reorganizes it to generate plenty of multi-leveled auto-generated adaptable educational activities (Adaptivity).

Adaptivity. We developed an on-boarding phase with the intent of understanding children's sensory preferences and dislikes (Fig. 7 and 9C). From the information gathered from this phase and the data automatically collected (Automaticity), Magika adapts to each child's needs by proposing perfectly tailored tasks and activities (according to personalized education programmes given by psychologists).

Reverse Inclusivity. Magika aims at reducing the marginality in children with Special Education Needs. The environment adapts to each child's needs by giving all the required affordances a child with SEN may need: the multisensory environment is not a plurisensory room at once, yet it precisely calibrates each stimulus and waits for the child to act. In its a cause-effect relationship, it enhances communication, socialization and eventually captivates neuro-typical children to join the experience with SEN mates in a process we call "reverse inclusion".

Mobility. We designed a popup solution called "Merlino" (from the Wizard Merlin) for mass production that is

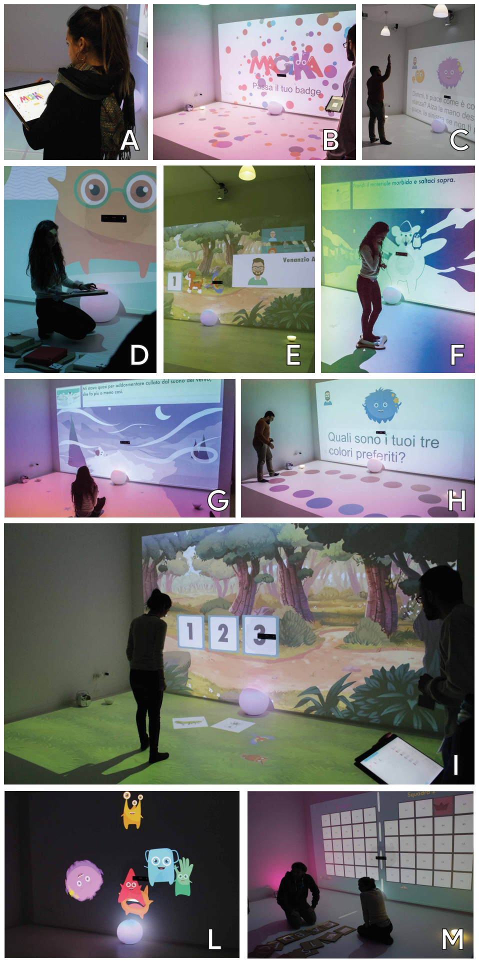

Figure 9: Magika(l) Experiences

Figure 10: Merlino: Magika's Mobile Solution

easily transportable, mountable and disassemblable without any technical knowledge (Figure 10).

SW/HW Modularity. The enabling platform relies on a software and hardware multi-layered and multi-modular architecture. The first layer of the software architecture contains the Experience Manager MEM which manages the experience flow, providing a connection to the Control Interface MCI, orchestrating the succession of activities and updating resources and activities. The Activity layer contains the execution logic of the tasks to be completed during the activity by sensing players' body movements and providing meaningful behavior to Magika; as the base of this layer lies a game engine. The Middleware Layer is composed of an expansible set of independent software packages, each in charge of managing a different technology: smart lightning, smart objects, non-native smart devices, text to speech services, cameras and full-body motion sensors. Each module aggregates different similar products to make the Activity Layer agnostic to the technology changes. Below, in the Physical Layer, physical sensors and actuators are placed according to the specific devices present in the environment. Perpendicularly the Data Analysis Layer and the DB Layer store data, visualize information and grant scalability.

CONCLUSION AND FUTURE WORKS

To our knowledge, Magika is unique: it supports a gamut of stimuli, interaction modes, and learning experiences that are not available all together in existing smart spaces for children, especially those with Special Education Needs. To reply to the initial research questions: Magika could be easily integrated in regular practices at a relatively affordable technological cost (3000$) and shall be regarded as as a configurable and adaptable living lab to enable the exploration of how children behave when exposed to different controlled stimuli and interaction modes and the experimentation of innovative scenarios. Because of these characteristics, Magika may pave the ground towards new didactic and therapeutic interventions for SEN children that we cannot even imagine at the moment. The next step in our research agenda is to perform a rigorous ethically approved empirical study for one year in two schools involving more than 800 children.

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