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MakeNodes: Opening connected-IoT making to people with intellectual disability

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ABSTRACT

Recent developments in accessible electronic-making toolkits have opened up avenues for individuals with intellectual disabilities(ID) to actively participate in creating their own smart objects based on the Internet of Things (IoT) technology. These toolkits present a novel opportunity to foster the inclusion of this often-under-considered community in the development of personalized solutions that can impact their autonomy and well-being. However, understanding IoT encompasses comprehending the inter-object connection paradigm at the core of this technology, an aspect that is not adequately covered by the existing accessible toolkits. To fill this gap, this paper illustrates the design and evaluation of *MakeNodes*, a tangible toolkit to involve people with ID in making smart-thing networks in a guided, collaborative, and engaging way. The toolkit comprises a series of input and output nodes that can be paired to make any object or surface smart. The paper illustrates how MakeNodes empowers people with ID through IoT-making activities that promote collaborative work to address personal needs. Key findings are discussed in the form of lessons learned concerning the importance of physical and visual elements, hands-on exploration, and interaction robustness in improving the accessibility of IoT-making toolkits for people with ID.

1. Introduction

With the proliferation of connected devices, the Internet of Things (IoT) has revolutionized how we think about technology and its role in our lives. IoT drives innovation in every aspect of our daily routines, from smart homes to wearable technology. It has the potential to transform our daily habits and improve our quality of life in countless ways. However, as the number of IoT devices grows, so does the complexity of understanding and managing them. Empowering individuals by involving them in IoT technology design can unlock this potential and pave the way for a more equitable society.

In recent years, advances in design and making toolkits have led Human–Computer interaction (HCI) researchers to an increasing interest in involving fragile communities to engage in technology design and become relevant actors (Ermacora et al., 2021; Hurst and Kane, 2013; Walmsley et al., 2018). Accessible design paradigms can open up electronics and programming to excluded groups, as seen in toolkits supporting the teaching of digital skills to people with diverse disabilities (Barbareschi et al., 2020; Hadwen-Bennett et al., 2018; Darwish et al., 2019). In particular, research has shown that involving people with Intellectual Disability (ID) in design activities can increase technology's usability and significantly impact the lives of these users, allowing them to develop new skills and increase their self-confidence and sense of ownership (Safari et al., 2023; Robb et al., 2021; Safari et al., 2021). Overall, this can lead to a greater sense of purpose and social inclusion as individuals become more involved in the community and can contribute in meaningful ways (Robb et al., 2021; Bennett et al., 2018).

In the last ten years, the maker movement has made significant strides in democratizing electronics knowledge acquisition and participation in electronics making (Meissner et al., 2017; Taylor et al., 2016; Rosa et al., 2018). However, despite the potential benefits of technology for people with ID, many are still excluded from opportunities to engage with technology due to various barriers, including financial constraints, lack of expertise, limited access to resources and accessibility barriers (Motti and Evmenova, 2020; Lussier-Desrochers et al., 2017; Carey et al., 2005; Meissner et al., 2017; Seo and Richard, 2021). ID often comes with concomitant psychiatric, medical, physical, and developmental conditions, such as limited fine-motor skills, hyperactivity disorders, attention deficit disorders, and communication difficulties (American Psychiatric Association et al., 2013). Therefore,

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everyday activities requiring problem-solving, decision-making, and reflection, besides mental and physical abilities like creativity, abstraction, and even manipulating small electronic components, might require extensive assistance. While building physical electronic circuits, individuals with ID may require dedicated support. Despite the efforts to simplify and expand traditional methods of electronic knowledge acquisition, making smart-device prototyping accessible and engaging for ID users still represents a gap in the HCI field also due to the lack of available guidelines for designing accessible IoT-making toolkits for people with ID (Chapko et al., 2020; Motti and Evmenova, 2020). At the same time, existing engagement and maker kits still lack focus on smart-thing connectivity, which is an essential notion for understanding the technological architecture of Internet-of-Things devices and ecosystems.

To truly open the electronic making of connected smart things to people with disabilities, it is therefore essential to consider their unique needs and face the challenges related to the engagement and empowerment of this category of users. Our work investigates how to reach this goal.

1.1. Contribution

To make electronic toolkits accessible to people with ID, researchers have typically adapted off-the-shelf toolkits to make the material more discernable and support handling and manipulation (Gotfrid and Shinohara, 2020; Hollinworth et al., 2014). Although these customized toolkits have reached positive outcomes, accessibility issues still exist related to the design of toolkit components or the interaction paradigm (Hollinworth et al., 2014). Recent works (Senaratne et al., 2022; Ellis et al., 2021) have highlighted the importance of designing accessible toolkits to accommodate the diverse and special needs of the ID population. In line with these approaches, this paper addresses the lack of accessible toolkits and introduces new elements that can facilitate the prototyping of connected smart things. It reports on the results of three workshops involving in total 12 people with ID and their caregivers in creating connected smart things adopting *MakeNodes*, a tangible toolkit designed to involve people with ID in rapidly designing IoT-based, connected smart things.

MakeNodes comprises custom-made 3D printed nodes covering sensors and actuators modules that can be paired through physical manipulation. It was designed and developed based on guidelines from prior work in literature and from authors' previous work with individuals with IDs (Cosentino et al., 2021; Gennari et al., 2023). The aim is to convey easy physical manipulations and provide visual and tactile affordances to assist the comprehension of toolkit components and of the trigger/action paradigm underlying IoT functioning. The three workshops validated the toolkit features through a co-design and embodied exploration approach. Besides helping identify features to improve the accessibility of the toolkit components the results show that MakeNodes reduces cognitive and physical barriers related to the ideation and deployment of connected IoT solutions, and introduces benefits in supporting reflection and empowerment of people with ID. The results also highlight opportunities for adopting this kind of toolkit to design technological solutions that can improve the living conditions of people with ID.

These contributions take one step forward to developing IoT-making toolkits accessible for people living with ID and aim to respond to the following research questions: (i) *Do participants engage in making smart device networks with MakeNodes, and can they achieve it without assistance?*; (ii) *Can a toolkit that focuses on design for real-world scenarios support people with ID in reflecting on daily challenges?*; (iii) *Can a combination of colors and shapes in a toolkit convey a trigger/action temporal structure?*

1.2. Outline

The paper is structured as follows. Section 2 provides an overview of current methods and toolkits available for individuals with ID. Section 3 explains the rationale behind the MakeNodes toolkit and describes its hardware and software components. Section 4 presents the structure and objectives of the user study, along with a detailed explanation of each study phase. Section 5 reports the gathered results and Section 6 discusses the main findings in relation to the study's objectives and the state of the art. Lastly, Section 7 concludes the paper by outlining the toolkit contribution and the next steps.

2. Rationale and background

Intellectual Disability (ID) is a neurodevelopmental disorder leading to limitations in cognitive abilities, including problem-solving, reasoning, abstract thinking, judgment, planning, and learning (American Psychiatric Association et al., 2013). The term is widely used in Human–Computer Interaction (HCI) research and, according to the International Classification of Diseases (ICD-11) (World Health Organization, 2024), it is a disorder that emerges during the developmental stage and results in deficits in intellectual functioning and adaptive behavior. For this reason, individuals with ID may experience a range of challenges, including cognitive, social, communicative, motor, behavioral, and emotional difficulties, which can affect one's ability to carry out daily activities independently (Olesen et al., 2012; American Psychiatric Association et al., 2013; World Health Organization, 2024; Frith and Frith, 1974).

The challenges in using and understanding technology deriving from these conditions have contributed to the growth of the digital divide between people with ID and society (Taylor and Ladner, 2011), which is further accentuated by the lack of access to developmentally appropriate education and training on accessing digital technologies. Engagement in technology or STEM-related activities can provide opportunities for creativity, learning new cognitive skills, and improving social communication and collaboration (Elsayary et al., 2015; Safari et al., 2023, 2021). More importantly, these technologies can provide control and raise a personal sense of agency and autonomy in performing daily activities (Elsayary et al., 2015; Lussier-Desrochers et al., 2017; Safari et al., 2021).

2.1. Co-design and tangible interaction

In recent years, there has been a growing interest in involving individuals with ID in the technology design process. Design activities can provide a supportive environment for individuals with ID, allowing them to take control and make decisions based on their experiences and preferences (Robb et al., 2021; Sanders and Stappers, 2008). Involving individuals with ID in design activities can foster a sense of ownership and recognition (Frauenberger et al., 2012; Benton et al., 2012) and promote the development of creativity, teamwork, and social skills (Robb et al., 2021; Benton et al., 2012). Design activities can offer opportunities to learn and increase competence for young adults and adults with ID (Neidlinger et al., 2021; Bayor et al., 2021; Safari et al., 2023). Design activities can also provide a sense of relatedness, essential for individuals with ID who are often socially excluded (Raman and French, 2022; Safari et al., 2023).

However, when it comes to involving individuals with ID in design activities, there are many challenges (Safari et al., 2023; Dong and Heylighen, 2018), starting with the fact that commonly used methods usually rely on multiple cognitive abilities (Raman and French, 2022; Benton and Johnson, 2015). Numerous studies have investigated using technology to support people with ID to enhance their cognitive, behavioral, social, and sensory–motor capabilities (Kientz et al., 2019). One promising approach is the development of "phygital" interfaces (Gaggioli, 2017), that blend digital experiences with physical ones. This integrated approach recognizes the formative role of embodiment in developing cognitive skills such as mental imagery, memory, reasoning, and problem-solving (Foglia and Wilson, 2013; Wilson, 2002). By combining physical and digital elements, phygital interfaces enhance physical manipulation, physical–digital mappings, and multisensory exploration, providing richer sensory and learning experiences by interweaving computation and physical materials (Antle and Wise, 2013; Falcão, 2017).

While research on phygital interfaces for users with ID is still preliminary (Cosentino et al., 2021), results from the adoption of Tangible User Interface (TUIs) for this target population indicated positive effects on engagement, collaboration, and initiative (Zajc and Istenic Starcic, 2012; Antle, 2007; Gelsomini et al., 2021; Beccaluva et al., 2022). Using TUIs-based tools in technology-making activities for people with ID could enhance participation and inclusion and foster independent exploratory, assistive, and collaborative learning (Marshall, 2007). This approach can serve as a support to professionals in their education activities (Falcão, 2017; Eisenberg et al., 2003; Gelsomini et al., 2017), and this interaction paradigm has been shown to extend the intellectual and emotional potential of interactive artifacts while integrating compelling and expressive aspects of traditional technologies (Eisenberg et al., 2003).

Despite the growing interest in TUIs for individuals with ID, only a few studies have examined their benefits on adults with ID (Gelsomini et al., 2019; Spitale et al., 2019; Falcão and Price, 2012; Tam et al., 2017; Al Mahmud and Soysa, 2020). This work aims to address this gap by exploring the use of TUIs to increase engagement in IoT-making among adults with ID.

2.2. Accessible making toolkits

The field of HCI has increasingly focused on the benefits of making and Do-It-Yourself projects in promoting well-being (Giles and van der Linden, 2015; Taylor et al., 2016; Hurst and Tobias, 2011). In the last few years, the *Maker Movement* has provided opportunities for people with disabilities to engage in making activities, thus experiencing the empowering potential of maker spaces (Bosse and Pelka, 2020; Meissner et al., 2017; Bennett et al., 2019).

Maker skills are relevant in expanding the abilities of participants with disabilities to make personal devices (Meissner et al., 2017). The maker communities have also demonstrated an eagerness to assist other people (Bosse and Pelka, 2020; Taylor et al., 2016; Buehler et al., 2015) and have succeeded with toolkits utilizing accessible microcontrollers, sensors, actuators, and 3-D printing capabilities, enabling users to learn in new ways (Chamberlain et al., 2022). However, the existing work on making toolkits has mainly focused on able-bodied individuals with fine vision and motor skills (Bdeir, 2009; Buechley et al., 2008; Lechelt et al., 2018; Qi et al., 2018). This creates major entry barriers to people with disabilities, especially those with ID, whose conditions often result in limited dexterity (Frith and Frith, 1974).

Accessible spaces and tools are essential to foster making inclusiveness (Annenberg, 2014; Bennett et al., 2019; Seo, 2019; Seo and Richard, 2021; Peppler et al., 2016). A growing body of work in disciplines such as HCI and education technology explores ways to create accessible maker tools, activities, and environments for various communities (Bar-El and Worsley, 2021). Researchers have designed toolkits addressing hearing or vision impairments (Hurst and Tobias, 2011; Hurst and Kane, 2013). Other works have extended guidelines for construction kits addressing diverse abilities, Alper et al. (2012) and Shinohara et al. (2017) also calling for mixed-ability equitable maker spaces (Annenberg, 2014).

However, research on toolkit accessibility has mainly focused on individuals with motor, hearing, or visual impairments (Motti and Evmenova, 2020). Chapko et al. (2020) argue that applications are needed to address the neurodiverse population. For this reason, some works have tried to adapt existing toolkits, making them accessible for ID population (Gotfrid and Shinohara, 2020; Hollinworth et al., 2014; Ellis et al., 2021, 2023; Senaratne et al., 2022). An example is Littlebits (Bdeir, 2009), pre-assembled physical bits for creating tiny circuit boards. Hollinworth et al. (2014) extended Littlebits by adding a large base for manipulating and assembling components. Some proposals have then focused specifically on developing toolkits for people with ID. TapeBlocks (Ellis et al., 2021, 2023) is a low-budget, low-fidelity toolkit based on foam building blocks that use conductive tape rather than wires to form a circuit. The design of TapeBlocks prioritizes materials and assembly mechanisms that are easy to use and engaging for individuals with ID. Authors declare to have followed an iterative process and refined TapeBlocks to be an accessible toolkit thanks to characteristics like low threshold for engagement, simple and intuitive error-tolerant interaction without the need for complex instructions, and the use of elements large enough to be easily physically manipulated.

TronicBoards (Senaratne et al., 2022) is specifically developed to cater to individuals with ID. It comprises easily graspable, manipulable, and understandable modules, offering participants with a diverse range of cognitive abilities the chance to engage in circuit-making with a personal sense of agency. The boards can be connected using various methods, accommodating different motor skills and enabling the integration of circuits into a wide array of materials. TronicBoards presents numerous features to support individuals with IDs, particularly in helping them recognize and interact with tiny controls and module functions. It includes multiple connectors addressing varying motor skills and guide module combinations through visual and tactile cues, such as traffic light colors and high-contrast recognizable symbols.

2.3. Connected-IoT toolkits

While IoT drives innovation in every aspect of our daily routines, the growing of available IoT devices also increases the complexity of understanding and managing them. However, a gap in toolkits focusing on connected smart spaces still exists. We advocate that novel toolkits and design activities should also tackle the interconnected nature of IoT, and design principles should be defined in order to ensure accessibility of these mechanisms to people with disabilities. This is particularly important for people with ID, whose difficulties in concept abstraction are well-documented and can be further compounded by the complexities of wireless trigger/action relationships (Dong and Heylighen, 2018). This represents an opportunity to support people with ID capability to learn and get involved in making meaningful IoT solutions for themselves and others, providing them with tools and knowledge to participate actively in making movement and learning to use IoT technology in a more conscious and independent way, reducing the digital divide. The work presented in this paper tackles this gap by designing and evaluating MakeNodes, a making toolkit to involve people with ID in making connected ioT, focusing both on the trigger-action paradigm and the ideation of smart spaces dealing with multiple interconnected IoT.

3. The MakeNodes toolkit

MakeNodes is a toolkit that aims to involve people with ID in rapidly making smart-things networks, guiding the design through a step-by-step scaffolded process from the initial pairing of a sensor and actuators to deploying the designed solution within an indoor space. The toolkit is composed of 7 devices called “nodes” (Fig. 1): 3 sensor nodes provide a button, an RFID tag reader, and a motion sensor; 4 actuator nodes consist of a single-color LED light emitter, a multiple-color LED light emitter, a buzzer, and a vibration motor. Individual sensor nodes can be paired with up to 4 actuator nodes, creating a wireless sensor network that works following a trigger/action paradigm. Built-in magnets and a series of attachment add-ons permit the nodes’ application to any object or surface, creating smart spaces composed of real things that acquire smart behaviors.

With MakeNodes, participants work in group to complete the design tasks, in an environment where reflection and discussion are encouraged. Users thus collaborate to design node networks to resolve specific problems identified by the group within a room or space. Once the nodes are paired and the network is ready, they can effectively deploy the solution within the designated environment. The typical context in which MakeNodes can be used is illustrated in the following section through a motivating scenario mirroring a real situation observed at the adult day care center where the toolkit experimentation has been conducted.

3.1. Motivating scenario

Chiara and Silvia are two young women living with ID. They both share an apartment with two other peers, living independently. Marco is a caregiver at Fraternità e Amicizia adult day care center, where Chiara and Silvia participate in daily educational and recreational activities. Marco wants to help them address small daily challenges related to their well-being or social life within their shared apartment. Additionally, he aims to introduce them to the potential of IoT making and help them understand the technology behavior behind it. To achieve this, Marco decides to organize an activity using MakeNodes. In a designated area of the care center, Chiara and Silvia are given a collection of nodes with sensors and actuators that can be connected to create an IoT network. At the start of the activity, they are asked to reflect on problems and design opportunities related to daily challenges they encounter while sharing the same apartment. After some discussion, Silvia suggests that one problem they face is the shared bathroom. With only one bathroom for four people, they often experience difficulties in managing its use properly. Based on this, Chiara and Silvia agree with Marco to focus on the mission of *“improving the management of the shared bathroom using IoT”*.

The two young women brainstorm and develop the idea of creating a system that allows someone inside the bathroom to signal people outside not to enter. They decide to use a button as a sensor and a colored light as an actuator. The person in the bathroom would press the button to send a light message to people outside, indicating that the bathroom is occupied. Under Marco’s guidance, they pair the button and the light nodes together. They discuss the best spots to place the nodes for the system to be valuable and practical, agreeing to attach the button to the toilet seat while the light should be placed outside, above the door. Marco then asks them to simulate the setup inside the room, treating it as their apartment’s bathroom. Chiara applies the button to a chair, saying that it represents the toilet seat, and Silvia places the light outside on the room’s door, symbolizing the bathroom door. Once the network is deployed, they test it and agree with Marco that the solution they just ideated could effectively respond to the mission.

3.2. Interaction modalities

The design of MakeNodes interaction tries to address the needs of the different stakeholders highlighted by the scenario illustrated above. The devised usage modalities derive from considerations emerging from literature and authors’ previous works with making toolkits. In literature, works such as Tapeblock (Ellis et al., 2021) guarantee accessibility through low physical-threshold interaction based on pairing through proximity: to form a working circuit, the user is allowed to put blocks on a flat surface and push them together with the back of their hand. At the same time, adopting a third element to perform the pairing, like a scanner, gave positive results in previous studies conducted by the authors with the *IoTgo* toolkit (Gennari et al., 2021, 2023). Considering these results, the research on MakeNodes wanted to investigate further which of the two interaction paradigms would be more accessible to the targeted population. For this reason, as illustrated in Fig. 2, the current MakeNodes version permits the user to pair the nodes following two different interaction modalities: by *contact pairing* and by using a *magic wand*.

Contact pairing. Sensor nodes embed an RFID reader and an RFID tag while output nodes are equipped with RFID tag only. Pairing a sensor with actuator modules requires putting the two nodes closer. To connect more than one actuator node to a single sensor, the user can place actuators closer to the first actuator or to the sensor node. The same action can be performed up to four times, connecting all four available actuator nodes to a single sensor. All the connected actuator nodes activate simultaneously when the associated sensor module is triggered.

To delete a pairing selection associated with a sensor module, a unique “reset” RFID card can be placed close to a sensor node. This is sufficient to reset all the pairing settings associated with a single sensor node.

Magic wand. This alternative pairing modality relies on a device called Magic Wand. It is a plastic rectangular box embedding an RFID reader and presenting a small LED stripe on the outside (See Fig. 3). To define node pairing, the user approaches the side of an initial sensor node with the scanning area of the Magic Wand. The Magic Wand emits sound feedback, and the LED stripe turns blue. Subsequently, the user can select one or more actuator nodes with the same interaction modality. For each output node associated with a sensor, an LED on the stripe turns white, thus providing feedback for the number of actuators connected to the selected sensor.

Like the contact pairing interaction modalities, the user can use the “reset” RFID card to delete a pairing selection associated with a sensor module.

3.3. Accessibility affordances

Each of the seven MakeNodes adopts a color code to guide the interaction with nodes. Each node type is also uniquely shaped to support tangible and visual recognition of its role and functions: Sensor nodes have a blue, square-shaped enclosure, while actuator nodes present a gray enclosure with a rectangle-arrow shape. At the ground of this color and shape choice is the willingness to guide a scaffolding process in which the user chooses an initial sensor node and decides which output nodes have to be connected. The literature provides examples of color-coding schemes that guide the user in scaffolding the interaction. In Tronicboards, authors adopts a traffic-light color-coding scheme, using red, orange, and green to guide the selection of the correct elements’ order (Senaratne et al., 2022). This color coding is helpful in supporting the creation of three-element combinations, but it becomes useless in the case of two-element combinations. More than this, with MakeNodes, the user has to start the interaction by picking a sensor module, so a color-coding scheme should also be able to support the user in understanding the correct order in which to proceed. In this case, the traffic-light color code is again not adequate, as choosing red or green as the first color are both admissible starting points.

The nide shape was designed with the same principles in mind. With MakeNodes, the color coding and the node shapes aim to support the whole scaffolding experience without requiring users to receive too many explanations. The literature does not report on studies on color and shape properties in conveying a precise temporal order for interaction, so the color and the shape for MakeNodes were chosen based on the authors’ previous experience in working with ID. These design choices have then been evaluated and further investigated during the workshop. Results and emerging design guidelines are outlined in Section 5.

In addition to the previously mentioned color and shape coding, all the nodes present two labels on opposite sides, describing each sensor’s function and the actuator’s behavior (See Fig. 4). Labels are designed to facilitate understanding: they show the node behavior through an illustration plus an explanatory text written with a clear and readable font. A label with instructions for pairing is also available on the back of the Magic Wand.

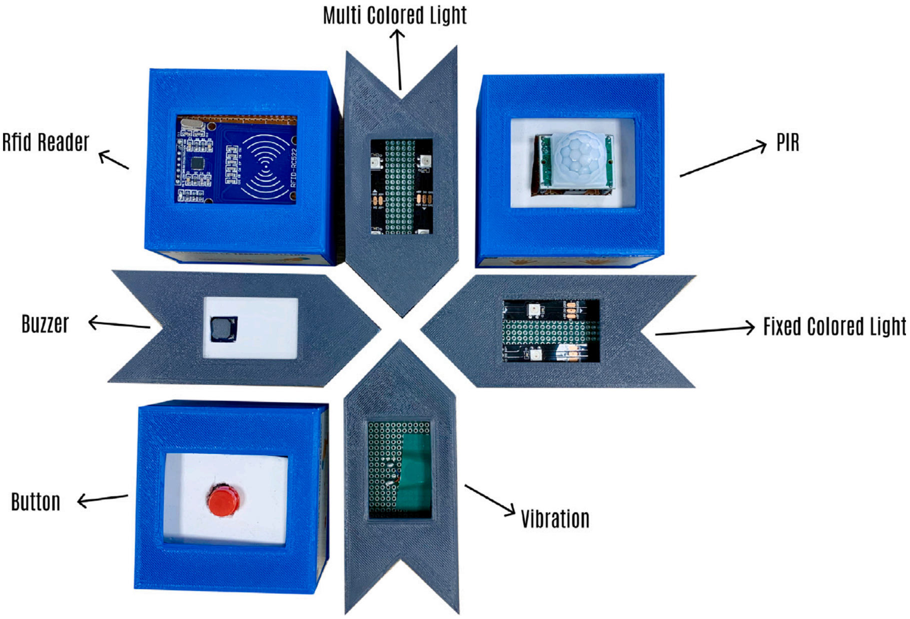


Fig. 1. The MakeNodes toolkit: blue nodes are sensor nodes, while gray nodes are actuator nodes.

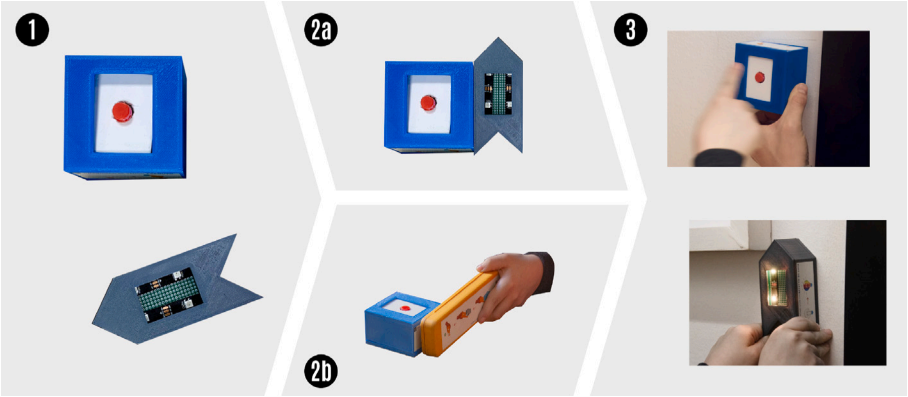


Fig. 2. The two pairing modalities. From left to right: (1) Choose a sensor and actuator node; Pair the two nodes through the proximity pairing (2a) or using the Magic Wand (2b); (3) Place nodes around the room using the magnets or the attachment add-ons.

Fig. 3. The Magic Wand: the “Scanner” symbol provides an intuitive affordance to the user to recognize the active reading area. Instructions are available on the back of the Wand.

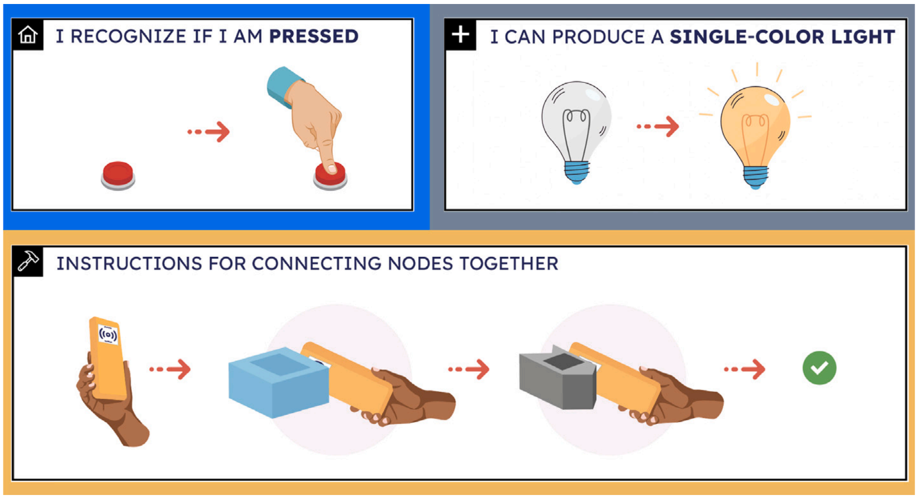
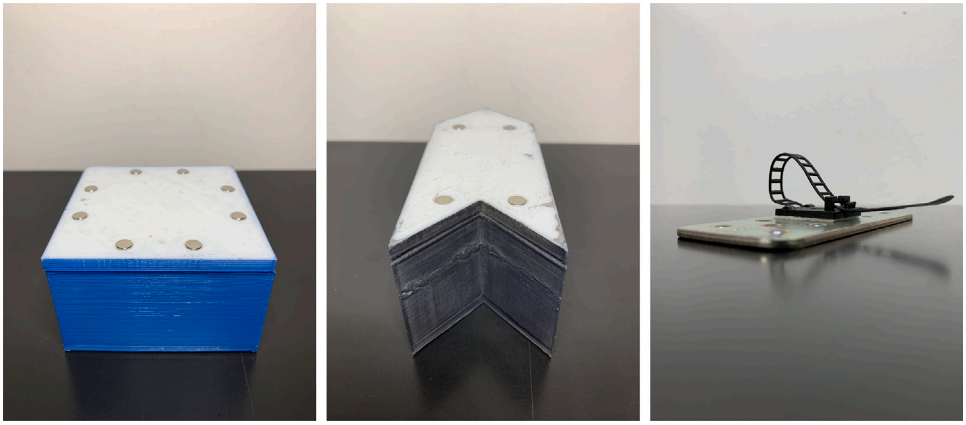


Fig. 4. Example of node's labels: Sensor node label (blue background), actuator node label (gray background) and Magic Wand label (yellow background).



(a) Sensor Node (b) Actuator Node (c) Add-ons Support

Fig. 5. Magnets are placed on the bottom of each sensor (a) and actuator (b) node. Add-on Support (c) can be snapped on the magnets to provide hold for different surfaces and props.

3.4. Technical implementation

Each MakeNodes node comprises a 3D-printed PETG enclosure containing a Lolin D1 mini (ESP8266) board, a charging shield, a Li-Po battery, and a sensor or actuator module. Each node is equipped with an RFID tag, while all the sensor nodes also present an RFID reader. Nodes are connected to the same local network and implement the SSDP protocol and a simple HTTP server. To increase the scalability and flexibility of the tool, a server application, the Hub, takes care of the orchestration of the nodes. The Hub resides on a Raspberry Pi single-board computer, which boots automatically when connected to a power supply and starts the server application without intervention by the user.

Each board contains a USB-A cable, which allows the devices to be recharged using standard smartphone USB chargers, making recharging the batteries more manageable and flexible. The nodes are also designed to leaving the sensor or actuator module in plain sight.

Magnetic support enclosed in the back (Fig. 5) allows nodes to be attached to any ferromagnetic surfaces. In addition, a handful of other attachment add-ons are provided. Snapping one of them on the magnetic interface allows nodes to be placed on different props or smooth surfaces. The toolkit also includes two keychain RFID chips that are used to activate the RFID reader sensor node whenever it was used in a node combination.

4. Design process and methodology

We conducted three workshops over February and March 2023 involving a total of 12 users with ID, 4 for each workshop.

The aim was to gain initial insights from MakeNodes adoption and evaluate the toolkit comprehensibility, participants' engagement and agency when using the toolkit, and the toolkit's capability to support meaningful IoT-based idea generation.

The initial part of each workshop focused on gaining evidence, with the help of participants and in a co-design modality, about the influence of material's color and shape on the scaffolding and comprehension process. As illustrated in Section 2.1, co-design methodologies have established themselves as a powerful way to leverage the real-life experience of end users, particularly when these belong to fragile, underrepresented demographics. However, as some of the caregivers participating in the project stated, individuals with disabilities often get involved in design processes more as informers than as real contributors. We instead wanted to give them a concrete and active role.

The user study thus focused on the following research questions:

(RQ1) Do participants engage in making smart device networks with MakeNodes, and can they achieve it without assistance?

(RQ2) Can a toolkit that focuses on design for real-world scenarios support people with ID in reflecting on daily challenges?

(RQ3) Can a combination of colors and shapes in a toolkit convey a trigger/action temporal structure?

4.1. Participants & context

The study involved a total of 12 users with ID, 5 men and 7 women, aged between 22 and 56. They presented ID ranging from light to severe (see Table 1). All the recruited participants regularly attend a daily center managed by Fraternità e Amicizia, an accredited private non-profit organization that manages social adult day care centers in Milan, Italy. The organization offers numerous services to people with ID, including accommodation, education, and recreational activities. In Fraternità e Amicizia, as well as in most social care institutions in Italy, guests usually work in groups and are engaged in activities promoting integration and well-being.

The recruiting process was managed by one of the caregivers of Fraternità e Amicizia, who also defined groups of four based on the participants' prior knowledge of technology and experience in collaborative environments, such as workshops or other group-based activities. Among the 12 involved users, 4 were also part of a project called *micro-community*, which started in July 2011 and addresses women with mild-medium intellectual disabilities, eager to experience themselves in a context of autonomy. The project provides a sheltered living environment, where the activities in the residential experience related to the daytime and friendship, family, and social sphere are, as far as possible, maintained in continuity with care and education programs. The primary objective is to enhance the guests' quality of life, focusing on their well-being and the preservation of acquired skills, while also fostering greater independence and social engagement.

The participation of the individuals from the micro-community project followed a direct request from the caregivers interested in evaluating the impact of IoT design on improving the living conditions of the micro-community in their private home. These four participants formed a group for the workshop and were asked to focus on IoT networks for their shared apartment.

Before running the workshops, consent was obtained from all participants or their caregivers regarding their participation in the study, as prescribed by the permit released by the ethical board of Politecnico di Milano. The consent encompassed the collection and publication of results, audio recordings, and images, and withdrawal for those who, at any point in the study, would express their willingness to participate no longer.

Table 1
Coded data of study participants. Letters in the first column indicate the workshop attended by the participant.

Identifier	Gender	YoB	Other information
A1	F	1982	
A2	F	1986	
A3	F	1991	
A4	F	1968	
B1	M	2000	Drug-resistant epilepsy, congenital encephalopathy
B2	M	1997	Emotional regulation disorders, psychosis and epilepsy
B3	M	1990	Facial dysmorphism
B4	M	1987	Alternating phases of space–time disorientation.
C1	F	1991	Mixed disorder of conduct and emotions, drug-resistant epilepsy
C2	F	1993	Mental impairment, mild Bipolar Affective Disorder
C3	F	1999	Down Syndrome
C4	M	1996	

4.2. Procedure

Three workshops, each one lasting about one hour and a half, were conducted in a room within Fraternità e Amicizia in use by the participants daily. The first two workshops were held in the Via Giorgio Washington office in Milan, while the last one was in the Via Foppa office, also in Milan. The settings were identical in both offices, with the participants seating around a central table. Four users took part in each workshop.

The study was divided into two phases. In Phase 1, participants were involved in activities investigating the effect of *shapes* and *colors* to convey temporal or reading order, in the attempt to derive design guidelines for accessible toolkits. To the best of our knowledge, the literature has never investigated the impact of colors and shapes on the understandability and usability of trigger/action technologies. For this activity, in addition to the toolkit, the participants were provided with colored polystyrene cubes and cardboard shapes. Phase 2, then, consisted of hands-on activities with the toolkit organized along different tasks.

Table 2 shows the complete structure of the workshops. The activities in each phase and the motivations for handling them are described in the following.

P1T1 - Color task. P1T1 was conducted to assess: (i) how the participants would select two colors freely from a wide range and without any external influence or reference, and (ii) to identify any prevailing color choice or correlation among the selected colors.

Given the absence of guidelines for selecting pairs of colors that can unambiguously represent the concept of "before" and "after", we used principles of the color theory (Agoston, 2013) to identify a set of colors conveying common meanings in everyday experiences (see Table 3).

As illustrated in the left side of Fig. 6, we then gave the participants 20 colored polystyrene cubes and a printed sheet with 6 questions, each one asking them to choose two cubes that best represented a given concept or situation (see Table 4). Each sheet was marked with a unique numerical identifier that identified the user and their position at the table. The researchers explained that the objective of this first task was to involve the participants in studying the use of colors to represent different concepts. They also clarified that answering the questions was a personal experience, and no right or wrong answer existed.

The P1T1 activity lasted about 15 min, during which one researcher facilitated the activity, provided explanations when necessary, and optionally had participants read the questions aloud. A second researcher took notes throughout the task and recorded the session's audio. Two caregivers were always present in the room; one supported and helped participants with difficulties or problems in answering the questions, while the other was available to intervene if needed. 72 answers were collected and analyzed for this first task, and the results are presented in Section 5.

P1T2 - Shape task. This task aimed to collect data on the combinations of shapes that can convey temporal order. Participants were given 30 paperboard cards representing five distinct figures (see Fig. 7) and a sheet with 6 questions (see Table 4). They were then instructed to choose 1 to 3 geometric shapes to answer each question, and place them in the designated space in the sheet (see the right side of Fig. 6).

The shapes given to the participants were selected based on their complexity. Two basic and abstract shapes, namely the square and the rectangle, were chosen along with three complex arrow-like shapes: the thick arrow, the arrow, and the letter L. No identifiers were assigned to the figures to prevent bias during the selection or placement process.

This second phase lasted around 15 min. One researcher continued to oversee the progress while the caregivers attending the session offered assistance in case participants had any doubts or encountered difficulties in placing the figures on the sheet. 72 answers were collected.

Table 2
List of each workshop's tasks divided into phases.

Phase(P)	Task(T)	Task name	Participants	Materials	Duration (min)
1	1	Color task	4	20 cubes	15
	2	Shape task	4	20 cardboard shape	15
2	3	Embodied interaction	4	MakeNodes toolkit	20
	4	Naturalistic observation	4 divided in 2 sub-groups	MakeNodes toolkit	40

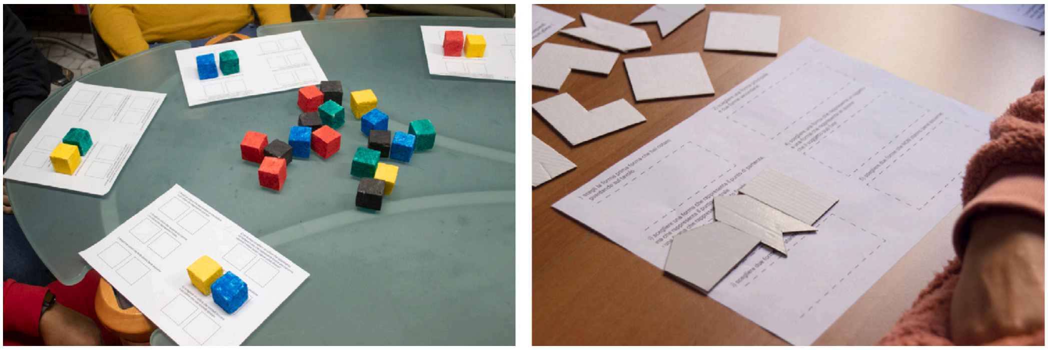


Fig. 6. On the left, participants choose color pairs as a response during the Color Task. On the right, a question sheet and a combination of shapes chosen as a response by one participant.

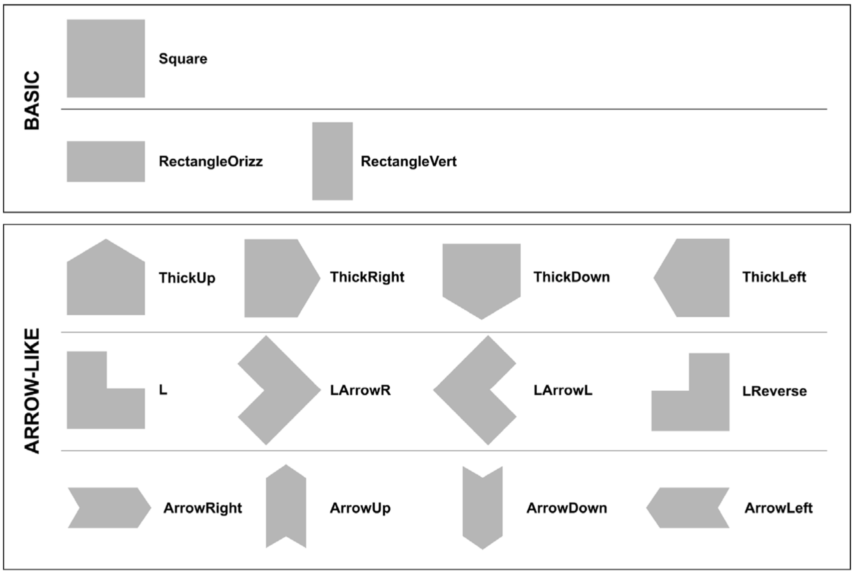


Fig. 7. Shapes adopted in the "shape task". Coded names relate to different orientations.

Table 3
List of color combinations for the color task.

Color combinations	Color 1	Color 2
Traffic light	Red	Green
Hot&Cold	Red/Yellow	Blue/Green
Saturation/Desaturation	Blue/Red/Green/Yellow	Black
Day&Night	Yellow	Blue/Black

P2T1 - Embodied exploration. Phase 2 consisted of hands-on experiences with the toolkit using a learning-by-doing and embodied exploration approach. Participants had access to a complete version of the toolkit presenting colors and shapes previously defined by the researchers (see Section 2.2). These choices were based on design considerations derived from the literature (such as the big size of the nodes or the visibility of the internal components, and from authors' knowledge of product design and color-theory principles (Agoston, 2013).

The first activity lasted approximately 20 min. Participants were encouraged to physically interact with the toolkit without receiving any explanations about its functionality. This approach was chosen to evaluate the toolkit's understandability and assess how effectively its design facilitated the recognition of inputs and outputs. The researchers collected the participants' comments and observed how participants approached the tool without any external influence. It is important to note that, to avoid bias during this second hands-on phase, during Phase 1 the participants were only told that the toolkit was developed to design smart environments without disclosing any specific detail about its functioning and interactions.

Once all the toolkit components (nodes and magnetic attachments) were placed on the table, the researcher allowed the participants complete freedom to interact with the available elements (see Fig. 8). Participants were urged to ask any questions they deemed necessary for better understanding. When participants struggled to generate further questions, the researcher prompted reflective thinking by asking stimulating questions such as: "What do you think this toolkit can be used

Table 4
List of questions administered for P1T1 and P1T2.

Task	Questions
Color task	Choose a color that represents a button and a color that represents a light
	If you had to choose between a color representing a button and another representing a song, would you use the same or different colors?
	Choose a color representing before and another representing after Choose two colors that complement each other Choose two colors that clash with each other Choose a color you would like to touch and another you would not
Shape task	Choose the first shape you noticed on the table Choose a main shape and two secondary shapes
	Choose a shape representing a starting point, one representing an intermediate (central) point, and another for the final point
	Choose a shape representing an object and a shape representing an action that the object can perform
	Choose two shapes that complement each other Choose two shapes that do not complement each other

Fig. 8. Participants' hands-on with the toolkit during the embodied exploration task.

for?". "Why do you think they are different colors? Why do you think they have different lettering?".

P2T2 - Naturalistic observation: task assignment and interaction paradigm evaluation. The final activity of each workshop included a structured, i.e., with a purpose, design experience. Its main objective was to evaluate the usability of the interaction with the toolkit and assess which method for node connection, whether the proximity or the magic wand (see Section 3), was better suited for the participants.

Participants were asked to use the toolkit to control something inside or outside the room. Firstly, the researchers explained to them why the toolkit was developed and the overall objectives of the studio. Then, they illustrated the two modalities for node connection and the role of colors and shapes.

Assisted by the researchers, in each workshop, the four participants were divided into two sub-groups based on their preferences. The researchers clarified that this division would not affect the workshop's outcome and that each group's results would not be evaluated.

Once the two sub-groups were formed, the researchers explained that the activity's objective was to make a room smart using the available nodes. Each sub-group was first asked to identify a situation they could work on within the daily center, the so-called *mission*. For the workshop involving the micro-community, the two sub-groups were asked to focus on their shared apartment by envisioning the workshop room itself as an extension of their shared living space. The researcher and the caregiver supported the mission ideation through examples and suggestions, exclusively in cases where the participants could not determine a mission independently. Once each sub-group identified a mission (see Table 5), they were asked to find solutions using technology. To compare the interaction required by the two node-connection methods, sub-group 1 was asked to connect nodes with the contact pairing method, while sub-group 2 had the magic wand (see Fig. 9).

Sub-group 1 was the first to proceed. The researcher explained they should use proximity to connect the nodes. The participants then selected the nodes to connect, defined the connections, and installed them inside the room to complete their mission (see Fig. 10). Then, the sub-group 2 solved their mission using the magic wand.

After completion, a second round of mission identification was conducted in which the required interactions for node connection were reversed: the group that initially used proximity interaction was now asked to use the magic wand, and vice versa. This task was carried out in the same manner as the first one.

4.3. Data collection

Each workshop was video recorded. One of the researchers also took written notes on the most significant events or user behaviors. At the end of each workshop, two questionnaires were administered to collect data from the participants and the caregivers.[2]

The participants' questionnaire consisted of a variation of the System Usability Scales (SUS) questionnaire with a simplified structure and questions adapted to be accessible to users with ID. To simplify the question comprehension, we followed guidelines and best practices for the definition of surveys with neurodiverse populations and children (Zheng and Genaro Motti, 2018; Motti, 2019; Ellis et al., 2023; Read and MacFarlane, 2006). All the questions provided were kept short, and straightforward language was used. Writing requirement was limited, with only two open questions. For closed questions, ratings were collected through the pictorial Smiley-o-Meter 5-point Likert scales taken from the Fun Toolkit (Read and MacFarlane, 2006), ranging from "Strongly disagree" to "Totally agree" (see Fig. 11). Furthermore, since each neurodiverse individual has unique needs, we asked one of the caregivers to check the questionnaire structure and questions to ensure it was suitable for the participants. The caregiver also administered the questionnaire and ensured all participants completed it after the workshop.

A second questionnaire was used to gather additional feedback and opinions from the caregivers who participated in the trial. The questionnaire included 20 questions addressing different aspects: *toolkit*, *workshop*, *development*, and *future opportunities*.

4.4. Data analysis

Two of the authors analyzed the collected data. First of all, all video recordings were transcripted and analyzed following a deductive process (Braun and Clarke, 2006); significant user comments related to toolkit features and interaction modalities were highlighted and annotated. Cross-checking between the emerged comments and the manual notes was then performed. Specifically, triangulation between the transcript and the researchers' manual notes was performed to identify successes and failures related to node design, interaction, pairing, and troubleshooting.

Subsequently, the responses to the participants' questionnaire were analyzed to assess the system's usability: a qualitative analysis focused on the interpretations of the user's answers combined with the insights extracted from the initial transcript analysis. For the analysis, a value ranging from 1 to 5 was associated to the smile-o-meter likert scale, with "strongly disagree" responses evaluated as 1 and "totally agree" as 5.

The qualitative responses delivered by the 6 caregivers through the questionnaire were also analyzed, looking for insights and emerging themes concerning participant engagement, interaction experience, and the results achieved through the design activity.

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[2] The list of administered questions is available at https://drive.google.com/drive/folders/1MfSqxM4P4VYib2zdoJsIqLgK0SAyQJ7A?usp=sharing.

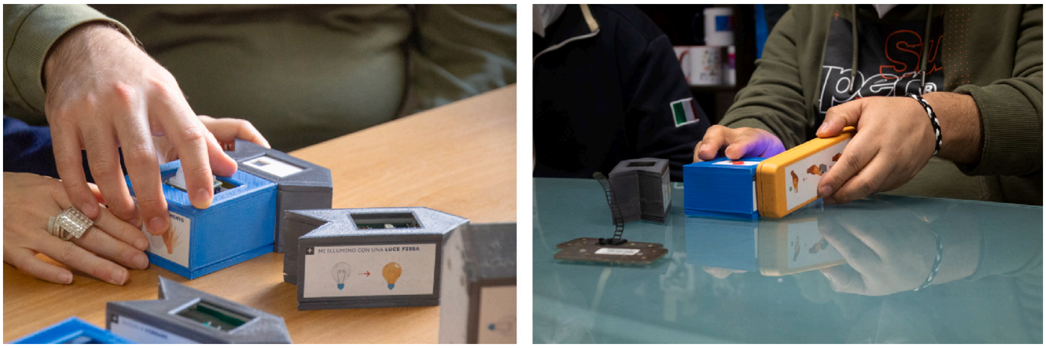

Fig. 9. On the left, participants pair a sensor and an actuator node (PIR and Buzzer). On the right, a participant uses the smart wand to start pairing with a sensor node (button).

Fig. 10. Two examples of sensor nodes deployed by the participants. On the left, the PIR node is applied using the magnets; on the right, the button node is applied using one of the available add-ons.

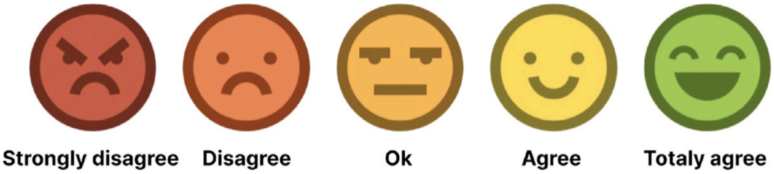

Fig. 11. The Fun Toolkit smiley-o-meter Likert scale adopted in the questionnaire.

5. Findings

5.1. Outcomes

All the participants, within their groups, participated in ideating and designing meaningful node networks. Table 5 reports the generated ideas. While some participants faced more challenges than others, all groups successfully completed the assigned tasks in P2T2 without requiring any intervention from the researcher beyond verbal suggestions. The groups generated 12 unique node networks using the available interaction paradigms. Notably, none of the participants created networks involving multiple actuators.

Regarding the P2T2, which required group collaboration for making the surrounding environment smart, direct observations revealed that defining the “mission” that would guide the design was one of the most challenging aspects. As explained in Section 4, participants were supposed to define the mission themselves by identifying a potential problem experienced at the day care center that could be resolved using the toolkit. However, during Workshops B and C, participants struggled to develop specific aspects to address within the center. One of the researchers thus asked questions to solicit participants’ reflection and ensure that each group had a mission to work on. The researcher asked more specific questions like “Is there anything in the center that could make people feel uncomfortable?” or “Are there any situations that could pose a danger to people?”. While these questions helped some participants generate mission ideas, in most cases, the researcher had to propose a mission himself. Participants were then asked if the mission made sense to them and which group would like to tackle it.

This problem did not occur during Workshop A, which involved four participants from the micro-community project. As explained in Section 4, these four participants were engaged with MakeNodes to design for their shared apartment spaces. The participants could not only reflect together and identify examples of issues or problems they faced in their shared apartment life, but they also engaged in small talks with the researcher and the group, sharing stories and experiences related to the examples they provided.

As a result, four different missions were derived from real issues or problems faced by the four participants. For instance, one sub-group chose to tackle the mission of improving the bathroom management inside the apartment. This mission originated from one participant’s comment about the difficulties of sharing the bathroom among four people. To address this mission, the group proposed a solution pairing a button sensor with a single-color LED light actuator. The light was placed on the door, while the button was positioned on a chair, simulating the toilet seat. The suggested interaction required the person inside the bathroom to press the button when someone tried to access it, triggering a red light outside to indicate that the bathroom was occupied.

Another example of a mission based on a real user experience emerged when one participant shared an incident about recently attempted break-ins in the building where the shared apartment is located. This prompted the participants to propose a mission to make

Table 5
User-defined missions and ideas generated using the toolkit in the 3 workshops.

Workshop	Mission	Sub-group participants	Interac. modality	Sensor node	Actuator node(s)	Idea
A (micro-community users)	Improve visibility in a bad illuminated ambient	A1+A2	Proximity	Button	Single-color led light	Button on the door and single-color light on the table
	Avoiding lost object/Simplify lost-object findings inside a room	A3+A4	Magic Wand	RFID reader	Buzzer	RFID reader on the table and buzzer on the object that does not have to be lost (e.g., on a bag)
	Give alert if someone (thief) enters the house	A3+A4	Proximity	Motion sensor	Buzzer	Motion sensor near the window and buzzer on the bedside table
	Improve bathroom share	A1+A2	Magic Wand	Button	Multiple-color led light	Button attached to the toilet seat and light outside the door, someone using the toilet can press the button to advise people outside the bathroom
B	A solution that helps if the light goes out at night	B1+B3	Magic Wand	Button	Single-color LED light	Button on the door and single-color light on the closet, to prevent people from crashing into it
	Advice/guide everyone if there is a danger	B2+B4	Proximity	Motion sensor	Buzzer	Motion sensor on the door and a buzzer at the center of the table
	Advise if someone is walking in the corridor	B2+B4	Proximity	Motion sensor	Single-color LED light	Motion sensor in the corridor, and a single-color LED light on the table
	Inform if one of the adult day care center's handcrafted art pieces is sold	B1+B3	Magic Wand	Rfid reader	Buzzer	Rfid reader at the adult day care center front desk and a buzzer on the table in the classroom
C	A solution for a too crowed room	C1+C2	Magic Wand	Button	Multiple-color LED light	Button on the wall near the table that can be pressed if the room is too crowded, a multiple-color light on the door to advise people not to enter the room
	Give an alert if someone enters the adult day care center	C3+C4	Proximity	Motion sensor	Buzzer	Motion sensor applied on the front door and a buzzer inside the farthest classroom
	Help people who want to express their opinion in a crowded room	C3+C4	Magic Wand	RFID reader	Vibration motor	Someone who has something important to say can scan an RFID tag on the RFID reader at the center of the table. a vibration motor on each chair would advise anyone to get quiet
	Advice/guide everyone if there is a danger	C1+C2	Proximity	Button	Buzzer	Button on the door and buzzer on the fire extinguisher, to easily find it in case of fire

the apartment more secure from thieves. They combined a PIR sensor module with a buzzer actuator to create a system that emitted an alarm sound when movement was detected. The PIR module was applied to the windows, while the buzzer was positioned in the center of the table. When questioned, the participants confirmed that this solution could work if implemented in their apartment.

One of the questions in the provided participants' questionnaire asked about the place participants would like to make smart using MakeNodes. While some responses indicated an interest in continuing to work with the toolkit within the daily center spaces, others expressed a desire for different environments. For example, participant A2 from Workshop A mentioned the public transportation:

> *A2: In the community, at the adult day care center, on buses to raise respect.*

Participant A4 from Workshop A suggested a specific safety-related application instead of a location-based one:

> *A4: To find lost objects, for smoke detection.*

Additionally, participant C2 from Workshop C proposed another external location where they would like to use the toolkit:

> *C2: To the park, to have fun.*

The last question in the participants' questionnaire asked to provide any comments or suggestions to the research team. Only a few participants actually provided a response to this question.

One participant asked the research team to develop the IoT solution she proposed during the design activity. In Workshop A, one of the outlined missions was to create something that helps prevent the loss or misplacement of items around the house. This mission originated from a user discussing the problem of frequently losing things in their house, such as keys or underground tickets.

Another suggestion was to implement more ways to generate fire alarms in the toolkit. This participant attended workshop B, where one of the missions tackled with the toolkit was to notify people inside a room if a fire or other dangerous events occurred outside the room.

Regarding caregivers' feedback, positive comments were expressed about the participants' ability to reflect on real-life challenges and address them with the toolkit. Some caregivers also mentioned the toolkit's ability to stimulate curiosity about IoT technology while improving the safety of shared spaces. One caregiver specifically stated:

> *In general, the tool is useful for understanding causal links and practical implications in daily life.*

While there was overall optimism about the toolkit, some caregivers also expressed opinions on challenges or areas for improvement. Caregivers indicated that a greater variety of input and output nodes are needed to better support reflection and enhance the capabilities of MakeNodes for ID participants. They suggested that interesting ideas emerged during the workshops, such as smoke or gas detectors to ensure safety inside a house, should be supported by adding such sensors to the toolkit.

5.2. Design and interaction

Data regarding the design of the toolkit and the interaction modalities were primarily obtained through observation and direct feedback from the participants during phase 2 of each workshop. All the collected data were then analyzed and categorized based on the specific aspect of the toolkit the data referred to, i.e., *toolkit comprehensibility* and *pairing modalities*.

From a general perspective, the design of the toolkit demonstrated positive outcomes and highlighted limitations that we discuss in the following.

5.2.1. Toolkit comprehensibility

P2T1 primarily involved participants engaging in free interaction with the nodes to explore their functionality through hands-on exploration. While all the participants showed visible interest when the toolkit was placed on the table and the hands-on session began, none of the participants could autonomously grasp the toolkit's functions fully. We observed two cases where participants could only discern very limited aspects of the toolkit, understanding the function of 3 nodes out of all the 7 available.

> *A3: "[it works] With the current and some special wire around".*
> *Researcher: "And if there were no wires?"*
> *A3: "With magnets!" A1: "With internet".*
>
> *A1: This [PIR node] recognizes if there is movement in the house. It recognizes if a person passes by.*

In other cases, participants understood the behavior of single nodes by deducing it from a possible output they could produce in combination with other nodes:

> *B1: This [node] can turn the light on and off.*
> *It is a switch!*

Despite this, no participant could deduce how to physically connect two nodes together. Even the LED strips visible on light-actuator nodes did not convey the nodes' purpose to the participants. For example, a participant understood that the node's behavior was related to turning on a light only when the "I can turn a light on" label was pointed out by the researcher moderating the workshop.

Another aspect that proved to be complex to grasp was the presence of magnets on the back of each node. Despite the researcher pointing out the magnets under each node, the participants could not determine their purpose, considering them to be a separate element with a function detached from the nodes. In addition, even if a set of add-on attachable modules were available on the table during the task, none of the participants attempted to explore their use. It was also evident that turning the nodes upside down to examine them was not a behavior considered by participants.

Observations on participants' understanding were also collected after the researcher thoroughly explained the toolkit's characteristics and functionality at the beginning of P2T2. An immediate improvement in understanding of the toolkit was observed following the explanation. The color coding appeared to have an impact on user understanding in the P2T2 task. In fact, all participants clearly remembered that input and output nodes were associated with two different colors, and no one attempted to pair two nodes of the same color.

5.2.2. Pairing modalities

All the participants were asked to pair nodes using proximity and the Magic Wand. Furthermore, the participants' questionnaire included a question explicitly addressing these two interaction modalities.

All the participants were able to pair the nodes with both the required interaction modalities. Proximity pairing was observed to be the most intuitive connector for many participants. The Magic Wand interaction instead required more assistance from the researcher even after the experiences in P2T2 and having seen the other participants performing this interaction.

Regarding proximity pairing, participants did not show any issues. Despite the availability of diverse interlocking possibilities, putting together an input and an output node along the longest straight side was the main observed behavior. Very few alternative interlocking solutions were applied, with none of the participants placing one node on top of another. However, the proximity pairing pushed the participants to be more reactive: they sometimes wanted to explore the effect of changing some combinations by employing the available "reset" RFID card.

While the insights collected through observation show advantages for the proximity pairing modalities, the responses collected with the questionnaire show that 8 out of 12 participants preferred the Magic Wand, with a prevalence of female users (7/8). During the workshops, most participants verbally expressed high appreciation for proximity pairing. Participant A4 in Workshop A stated:

> *A4: Bringing objects closer, I believe, is the best solution.*

However, in the questionnaire this same participant, along with two other participants of the Workshop A, actually chose the wand as the preferred pairing modality. The same happened with the participants of Workshop B:

> *B1: Bringing them closer is better because they are activated immediately.*

while in the questionnaire 4 out of 4 Workshop B participants indicated the wand as their preferred pairing modality. These results that contrast the direct feedback gathered during the workshop may be explained by the interest generated by the Wand's interactive features and the visual feedback through color-coded LEDs. Despite the observed lack of usability, the post-activity responses show a curiosity-stimulated potential associated with the Wand and its required interaction. This aspect will be considered and evaluated in future revisions of the toolkit.

5.3. Affordances evaluation

The analysis of responses collected during the color and shape tasks aimed to identify patterns and thus focused on the response's distribution, recurrency, and variation.

5.3.1. Color combinations

A total of 72 responses were collected during the color task. To ensure the correctness of the collected data, all the responses were double-checked by the authors, who triangulated the coded answers with pictures taken during the workshop activities. After this check, 12 of the 72 collected responses were excluded from the analysis. Indeed, the first question of the color task, namely, "Choose a color that represents a switch and a color that represents a light", was considered biased as it resulted in 80% of participants choosing yellow to represent light - the "natural" light color.

After the optimization, the remaining 60 responses were analyzed, looking for emerging patterns in the recurrence of the chosen colors, the picked color combination and the order in which each color appeared in the combination.

The analysis results (Fig. 12) show that the most picked colors as a first choice are blue and red, while the second choice is black, with a

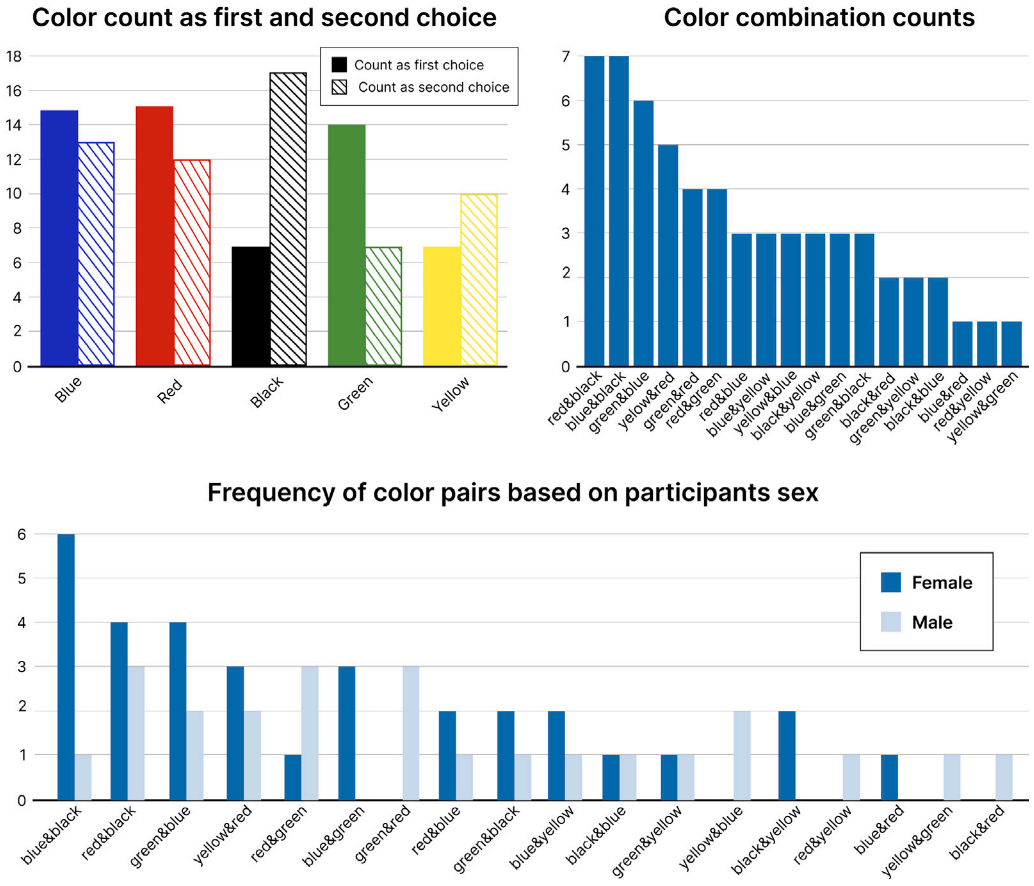

Fig. 12. Color task data.

higher rate than any other color. Regarding the combination of colors, the most picked ones were red&black (7) and blue&black (7). The reverse combinations (black&red and black&blue) were selected only twice, thus it was not considered significant.

During the second workshop day, a male participant declared that he had chosen a red&black combination as it represented the colors of his favorite soccer team. To estimate whether red&black and blue&black responses could be connected to males' common passion for soccer sport in our country,[3] we analyzed differences in the responses obtained from male and female participants. Results show that the two combinations had a higher pick rate for female users, letting us assume that the emerged patterns are not associated with factors different from the participants' color preferences.

Results also show variation in the number of picked colors based on responders' gender. Despite their higher number (7/12), female participants showed less variation in color picking, choosing 13 different color combinations against 15 different combinations from male participants.

5.3.2. Shape combinations

All responses to the shape task were considered for the analysis. As a result, 72 responses were analyzed, consisting of up to 157 shapes. The analysis of the collected responses followed the same validation as the color task, with the researchers performing a double-check by triangulating the coded answers with the pictures taken during the workshop activities. The chosen direction and position of the shape in the response area were also considered. It is worth noting that the researcher gave no specific names or descriptions of the shapes during the activity. Shapes were distributed on the table in random order and direction.

The results (Fig. 13) show that the most picked shape is the "thin arrow", with 40 selections, followed by the thick arrow with 38 selections. The square (23) is the less-picked shape. If we look at the first picking choice (Fig. 13), the thick arrow has the highest rates as a first choice (68%). The rectangle has the lowest picking rate as the first choice (24%). The lowest piked shape as the last combination option is the thick arrow (26%), while the most picked is the thin arrow (48%).

Figures chosen as the middle option can be considered as connectors, i.e., shapes that are suitable to connect other shapes. Results show how the thick arrow is the lowest chosen figure as the middle option (5%). On the other hand, the rectangle has the highest middle-choice pick rate (32%), which is lower than its last-picking percentage (44%) but higher than its first-picking percentage (24%).

By taking into account the orientation of the shapes, the result shows how, out of all the different positions and directions given to each shape, the thick arrow had the highest percentage of recurrence in positioning: 86.6% of the times it was positioned in the up direction. The vertical rectangle (56%) is the other shape with a high percentage of choice. However, this might not represent an emerging pattern if we consider that the percentage of the horizontal rectangle is close to 44%. None of the participants positioned the rectangle in an oblique position.

The most common combination of shapes is ThickArrowup&Ltext, ThinArrowup&Thickup, and RectangleVert&Square (7). If we do not consider the actual orientation of the shape, the most common shapes that appear to be chosen together are ThickArrow&ThinArrow (14), followed by ThickArrow&L (12) and ThinArrow&L (12).

5.4. Engagement & outcomes

Participants appeared engaged, worked collaboratively to combine nodes, and expressed verbal appreciation during and at the end of each workshop:

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[3] These are the colors of famous soccer teams playing in Italy.

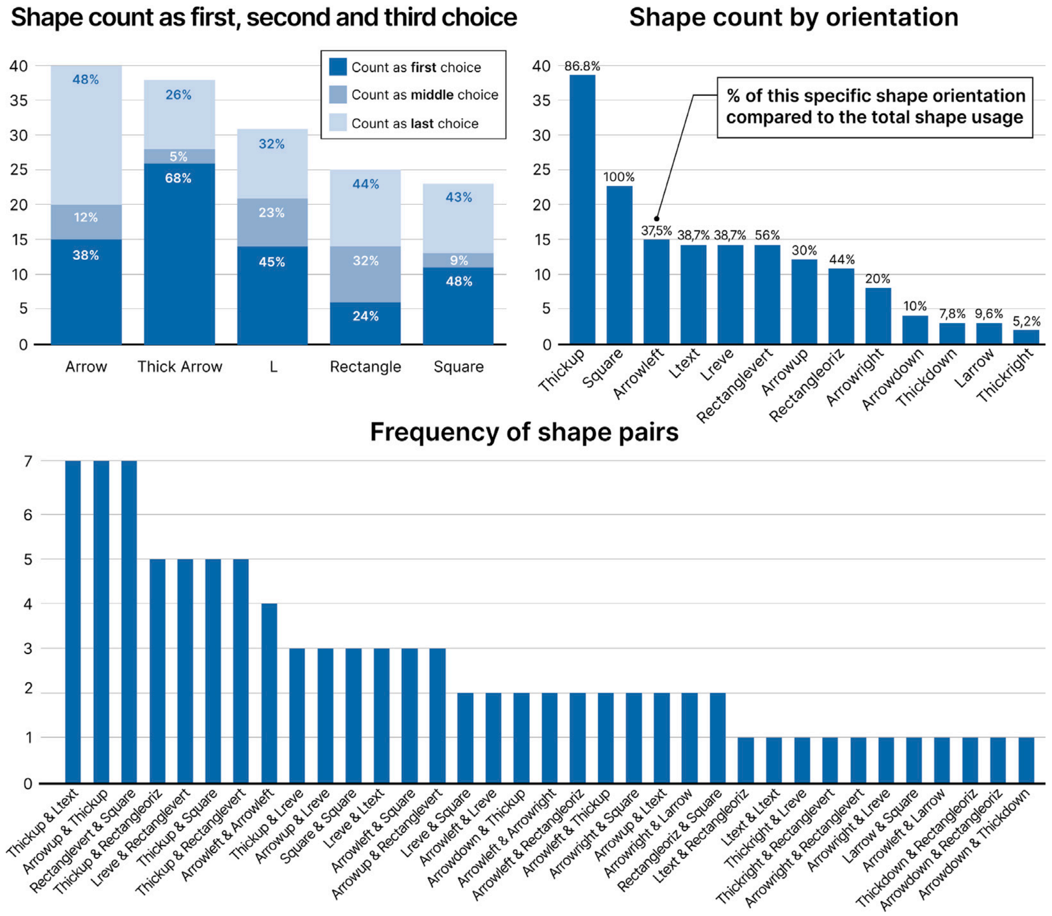

Fig. 13. Shape task data.

> *A3: I like! I like it so much! Thanks!*

> *B1: I like it a lot, it is interesting. I really like it.*

Non-verbal cues, such as smiling and laughing, and small-win celebrations with peers were observed during and between each task, especially during the second phase:

> *A2: Look! It lights up!*

The scheduled break between P2T1 and P2T2 was skipped in accordance with all the participants, who expressed their willingness to keep working with the tool instead of taking another 5-min small break. Only one participant disengaged from the activity and manifested physical and emotional discomfort, leading to the need to stop the activity for a few minutes. The event is not attributable to the toolkit but rather to a feeling of despondency linked to the workshop activity. After a break and having received moral support from the caregivers and the other participants, this participant continued the workshop without showing any difficulties.

The results from the participants' questionnaire confirm the observed positive engagement. 50% of the participants responded to all the questions with the maximum score of 5, corresponding to the "Totally agree" choice in the smile-o-meter likert scale. The questions "Did you like MakeNodes?" and "Are you satisfied with the node combinations that you created with MakeNodes?" received an average rating of 4.75 out of 5 (min 3, max 5, median 5), confirming the positive engagement observed during the activity. In the same way, the question "Would you be happy to recommend MakeNodes to other fellows or friends?" received an average score of 4.75 out of 5 (min 4, max 5, median 5), confirming the user appreciation of the device to the point of being highly motivated in involving their peers in the activity. Only the second question received an average score of 4.66 (min 2, max 5, median 5), which was due to a score of 2 given by the participant who experienced physical discomfort during the activity. The same participant gave a score of 3 when ranking MakeNodes appreciation, giving instead the maximum score to the question related to the satisfaction of the created node connections and a score of 4 to the willingness to recommend the activity to other peers. This let us think that the low score is related to the bad experience with the workshop rather than the toolkit itself.

The caregiver who participated in the workshop also appreciated the toolkit. Just after the end of each workshop, they expressed their satisfaction with how the tool involved the participants and stated they would feel happy to involve them in other future workshops with MakeNodes. Responses from the questionnaire show that all the caregivers agree that the activity with the toolkit was positive for the participants and could bring advantages to people with ID. 5 out of 6 caregivers also expressed their willingness to adopt the toolkit in the structured activity they daily carry out at the care center.

> *It could be used to compensate for participants' spatial abilities, memory difficulties, language difficulties*

> *Surely it brings advantages in the management of local autonomy, e.g., home/school journeys*

When asked, caregivers confirmed that it was a positive and engaging experience for the participants and that some of the involved users expressed positive feedback about the activities:

> *It was funny and useful.*

> *There has been a general appreciation of the activity. Some who did not understand how some parts (the black bands of the magnets) worked reported that they understood, and all would be happy to repeat the workshop.*

Caregivers agreed that the toolkit could represent a more challenging experience for some users than others, especially for understanding the pairing modality and the functioning of some nodes. All agreed that it does not represent a danger or harmful activity. They highlighted several advantages for the participants' social level and well-being, with positive effects on participants' autonomy, life conditions, and interpersonal relationships. In contrast, the aspect that was seen as less impacted by the tool is the technology's critical sense and the ability to conceptualize abstraction.

A very high positive evaluation concerned the capability of the system to improve the co-living conditions of the four participants involved in the micro-community project. With an average score of 4.2/5, all the caregivers agreed that the carried-out activities could positively impact these four participants' lives. All the caregivers also agreed that these four users could use the tool independently to improve their shared apartment spaces.

> *I believe that being actively involved in building useful technology can positively impact girls. Using a tool to help them with daily activities can also impact their mood. Furthermore, the use of a shared tool for the same goal can help them improve social and sharing skills with each other.*

6. Discussion and lessons learnt

Overall, the evaluation of MakeNodes demonstrated the effectiveness of a design activity focusing on IoT objects in engaging adults with ID in ideas generation and technology creation. The results from P2T2 revealed that all participants could utilize the available nodes to quickly design solutions for daily real-life problems (See Table 5). They also collaborated to propose and implement technological solutions to enhance shared spaces within their community. The activities performed with the toolkit addressed challenges and common barriers related to IoT understanding, such as reflecting on trigger/action dependencies and connection paradigms. The questionnaire responses indicated that participants appreciated the toolkit's activities and wanted to continue participating in follow-up activities.

From the collected insights, it is possible to identify factors to be considered to actively involve users with IDs in the design of IoT objects, and explore the role that the focus on device-network definition can play in fostering the understanding of IoT concepts.

6.1. Network-making as a way to understand IoT and engage with design

The data on participants' engagement, which we collected from qualitative observation during task P2T2 and from the questionnaire responses, allow to answer the first part of our research question RQ1: *Do participants engage in making smart device networks with MakeNodes, and can they achieve it without assistance?* The results show that all participants appreciated the toolkit and actively participated. Such enthusiasm suggests that constructing IoT-device networks is not only feasible for users with ID but also holds significant value for them. This positive perception gains further confidence when considering that, despite facing challenges with understanding nodes and pairing procedures, the participants remained engaged for all the duration of P2T1 and P2T2. Their willingness to continue using the toolkit expressed in Question 2, coupled with a demonstrated curiosity about the workings of IoT, highlights their engagement and interest.

The caregivers' questionnaire responses also highlighted that the proposed activity was engaging for the participants and represented an opportunity to increase comprehension of IoT-based technology. They confirmed that working on smart-device networks can improve the participants' ability to reflect on daily problems and become more autonomous in daily tasks. The observed participants' capability to create a working IoT network for their spaces pushes caregivers to think that the tool could represent a way to work on improving user management, autonomy, and social skills.

6.2. Embodied exploration, instructions and immediate feedback

The qualitative data collected during the embodied exploration task (P2T1) provide evidence to address the second part of RQ1: *"Do participants engage in making smart device networks with MakeNodes, and can they achieve it without assistance?"*. To foster independence, agency, and increased engagement among individuals with ID, the literature suggests that toolkits should minimize the need for instructions and reduce reliance on caregiver assistance; if instructions are necessary, they should be kept concise (Ellis et al., 2021). We therefore wanted to assess in which measure different forms of visual cues would enable users to understand the toolkit's functions solely through embodied exploration and without any external assistance from caregivers.

The results from P2T1 demonstrated that the visual cues integrated into nodes did not facilitate the autonomous exploration of the toolkit, and the researchers' intervention was needed. Comprehending the requested interactions was challenging without external help. The printed instructions for the magic wand functioning did not help. Understanding the functioning of single nodes, instead, seemed feasible through embodied exploration, with some participants able to identify the function of some nodes and give concrete examples to explain how they worked. This might be ascribed to the immediate feedback the nodes were able to produce, e.g., a light-actuator node producing light.

These findings indicate that while instructions should be available (Senaratne et al., 2022; Ellis et al., 2021) they might be insufficient for individuals with ID. After a comprehensive explanation of the toolkit, participants indeed exhibited good understanding and interaction abilities during P2T2. The observed behavior might suggest that multiple instructions are effective only when coupled with hands-on guided exploration, such as an initial activity demonstrating how to interact with the toolkit and that could be performed by a caregiver. As also investigated in other studies (Cosentino et al., 2021), equipping toolkits with mechanisms for immediate feedback on components' functioning can be one possible solution to enhance comprehension.

6.3. Design for real-world scenarios with high personal engagement

When involving individuals with ID in technology design, a critical aspect is the connection between what is being designed and the needs of the users (Cosentino et al., 2021). For this reason, MakeNodes solicits reflection on real and familiar contexts to guide the formulation of ideas that tackle the challenges users face daily. The environment in which the toolkit is used, or the one considered for design, becomes a fundamental element of the experience, expanding potential and outcomes. In our study, the potential of designing for a real-world scenario was explored during P2T2 by analyzing participants' engagement, user-generated ideas and questionnaire responses. The results addressed our research question 2: "*Can a toolkit that focuses on design for real-world scenarios support people with ID in reflecting on daily challenges?"*.

Even considering personal or temperamental aspects that may have influenced active participation, it was observed that participants in Workshops B and C, who were asked to reflect on the spaces of the day center, needed help to propose issues or opportunities to design for. This difficulty was not observed during the first workshop, in which the micro-community context triggered participants to express multiple aspects to intervene.

While results suggest that focusing on real-world scenarios can support individuals with ID in reflecting on daily challenges, the improved performance observed in Workshop A may also suggest that the existing relationship between the scenario and the involved users also affects the reflection capacity. Although the adult day care center is frequented daily by the participants, familiarity with a place does not influence their ability to reflect on that environment as much as personal relationships do.

Another aspect that might have led to these different results is a user's sense of responsibility towards a specific environment. In the case of the micro-community project, the participants have a sense of responsibility towards the shared apartment, as they are responsible for managing the spaces and conditions of the house. In contrast, the responsibilities related to the care and respect of the spaces at the day center can be considered limited since these spaces are common to all the community members. Future activities could confirm these preliminary results by involving participants in reflections on additional contexts for which they feel a greater sense of responsibility than the day center.

6.4. Robustness of the interaction paradigm

The observed participants' behavior in P2T2 lets us think that allowing more freedom in the possible interactions could influence the accurate execution of the tasks. The pairing interactions, whether through proximity or through the Magic Wand, emphasized how each user performed the same task differently. The design of nodes, which allowed connection only through two specific faces, led to situations where participants correctly grasped the intended action, such as bringing two nodes close together. However, they sometimes struggled with precise execution, like mistakenly pairing the incorrect sides of the nodes. Similar findings were observed with the magic wand interactions: Some participants positioned the wand on the nodes using the incorrect side of the sensor, or attempted to use it from the opposite side than intended.

The limited robustness of the system in intercepting and interpreting multiple user actions resulted in participants' failures. If the system had allowed for different ways of connecting the nodes, many more attempts would likely have been successful on the first try, enabling participants to pair nodes without external assistance.

These results emphasize how toolkit accessibility for people with ID can be improved by providing multiple modalities to execute a specific task. This approach is crucial for increasing the success rate of complex tasks and reducing the negative impact on user engagement caused by multiple task failures.

6.5. Physical affordances as accessibility factors

Regarding research question 3, *"Can a combination of colors and shapes in a toolkit convey a trigger/action temporal structure?"*, the analysis of the data collected in P1T1 and P1T2 provides evidence of how color and shape could effectively facilitate comprehension.

The analysis of the gathered data, highlighted that the selection of colors and shapes is not merely arbitrary and that these elements can effectively communicate a sense of order and structure within the scaffolding process.

Concerning the results of the color task P1T1, participants showed prevalence in selecting both primary and secondary colors, with the most frequent pairing involving "saturated/unsaturated" color combinations. This outcome also validates the initial design choice made for the toolkit, further confirmed by the fact that, during the making activities, none of the participants required assistance in distinguishing between input and output nodes after the initial explanation.

Regarding the node's shape, the study results from P1T2 provide initial evidence that participants preferred specific figures over others when asked to convey trigger/action relations through shape combination. Results analysis suggests that shape size and complexity could play a role in influencing participants' choices. Smaller shapes, such as the rectangle, seem to be perceived as less attractive as a first or last choice of a combination but result attractive as a connection shape between two figures. This attitude may also be attributed to the shape's simplicity compared to other shapes, which makes it less noticeable and, thus, less attractive as a starting point. However, additional investigation is needed to consolidate this initial hypothesis, especially considering that a big shape, like the square, was frequently chosen as an initial shape despite being also considered a simple shape.

From the point of view of choosing a shape orientation, an interesting observation is that when participants were asked to create a composition of shapes, they predominantly oriented the shapes based on their meaning rather than on the possible interlocking with other shapes. As proof, the thick arrow resembling a house was predominantly utilized as a house (see Fig. 13). This might indicate that users preferentially select forms that resemble objects meaningful to them over abstract shapes, even if the other shapes are suitable for being composed with others. Participants tended to choose a position that agreed with the most familiar use of the object.

The results also highlight an apparent inclination towards shapes with long sides, which can be easily aligned to create united figures, instead of shapes that necessitate complex angles or holes for connection. This was consistently observed during the activity, with participants instinctively connecting nodes by aligning the flat, long sides instead of relying on the excavated parts for connection. These findings, which challenge our initial assumption that an arrow shape would support and guide the combination of figures and are in contrast with the module design choice made by previous studies (Hollinworth et al., 2014), suggest that employing a mix of big and small shapes between the ones that present long sides could help convey a trigger/action temporal structure. While it is important to note that further data is required to validate these hypotheses, these results represent initial evidence for establishing guidelines for the accessibility and comprehensibility of toolkits that involve combining multiple elements through physical affordances. These preliminary guidelines lay the groundwork for defining approaches founded on multimodal guidance, an aspect that is still not exhaustively investigated in the literature and that has, instead, a potential to foster inclusivity among diverse participants by capitalizing on their unique skill sets.

At the same time, while these findings suggest how specific physical affordances could support temporal structure understanding in trigger/action rules for IoT making, observed results related to embodied exploration underline how system accessibility for participants with ID cannot rely only on physical affordances or printed labels. Encompassing a mix of physical affordances, accessibility factors like scaffolding interaction or immediate feedback, and learnability support elements such as dedicated education material could represent a solution to improve technology-making toolkit accessibility and usability.

6.6. Long-term sustainability

Finding ways to sustain outcomes of research projects conducted in situated contexts is a challenge many HCI practitioners face. One approach to facilitate this aspect is the development of toolkits that can be continued to be used by the participants. Most technology design toolkits proposed so far are "standalone" versions that the participants and caregivers can hardly reuse once the study is concluded and researcher support is no longer available, given the significant maintenance they require. This occurs even in cases where the toolkit use would lead to additional positive effects related to the continuation of the experience or further possible outcomes.

For this reason, the design of MakeNodes was, as suggested by other research in the field (Scheepmaker et al., 2021), conceived from the very beginning to simplify its use in case caregivers had decided to continue using it even after the project's completion. This was achieved from a design perspective, by adopting elements such as easily rechargeable batteries or cost-effective 3D-printed modules, as well as from the perspective of skills required to use the toolkit. The operation of the technology underlying MakeNodes only requires a control hub to function. To activate the system, it is only necessary for this hub to be connected to power and connected to a Wi-Fi or mobile network. This aspect contributes to making the system usable by caregivers, only requiring minimal training and even in contexts not considered during the workshop.

6.7. Adaptability to new contexts of use

MakeNodes's design involves real environments and objects, shifting the interaction focus halfway between the toolkit and the environment in which the toolkit is used. By its nature, the toolkit adapts to different contexts, as the interaction and connections between nodes are independent of the environment in which the networks of nodes have to be placed. This approach circumvents the constraints associated with creating new components whenever there is a change in the usage context, a limitation often encountered in toolkits that utilize physical cards (Cosentino et al., 2021; Gennari et al., 2021). While these cards incur minimal production costs, they necessitate adaptation every time there is a shift in context or in the elements to which the design is to be applied. Designing a toolkit that can adapt more easily to new contexts and users without requiring additional efforts further extends the scope of a project. In this way, positive experiences could also be sustained and made available to new users and caregivers not involved in the research project.

7. Conclusions

This paper has presented MakeNodes, a tangible making toolkit designed to involve individuals with ID in IoT network-making in an engaging and accessible way. We conducted the evaluation of the toolkit through three co-design sessions involving 12 adults with ID. The collected data were analyzed using an inductive approach, and the results highlight that participants could actively engage and collaborate in making meaningful node networks, which they then deployed within their daily-center spaces.

Through our analysis, we identified themes related to the engagement and comprehensibility of the toolkit when working with individuals with ID. We also gained insights into the effectiveness of our approach, which involved designing for real-world scenarios. The findings of our study contribute to addressing a gap in the literature concerning ID people's access to IoT network-making. Additionally, our research highlights the importance of incorporating real-world scenarios as design material and outlines affordance elements that could improve the accessibility of scaffolded interaction tasks.

7.1. Limitations

Although the research yielded positive findings, some participants experienced difficulty interacting in a group settlement during the workshops. This factor may have affected their level of engagement and hindered their ability to participate in the workshops exhaustively. The caregiver initially attempted to involve more diverse individuals and organize groups based on individual capabilities and requirements. However, it was observed that some groups worked together more fluently than others.

Despite the efforts devoted to including a diverse group of participants, the number of participants involved could be considered small. For this reason, this study's findings may not fully represent larger populations or different contexts. This situation often occurs with studies with a neurodiverse population (Motti, 2019). Additionally, when the study was conducted, there were still limitations related to the COVID-19 pandemic in Italy. These limitations impacted the organization of the participative study within daily center spaces, where, for example, protective masks were still required. This inevitably caused delays in the study's organization and limited the number of involved participants.

Furthermore, it is crucial to acknowledge that individuals with ID may possess varying degrees of autonomy and interpersonal skills despite exhibiting similar IQ levels. It becomes challenging to generalize the observed outcomes to a broader population. Nevertheless, our study did demonstrate the potential for a selected group to collaborate towards solutions that could benefit their peers in the day center, by taking into account the needs and capabilities offered by the center.

Another limiting aspect is that the employed toolkit is still in its first stages of deployment and comprises a limited number of nodes and sensors. The toolkit's full potential may not have been fully realized in this iteration, and some of the limitations that emerged during the study could be addressed by adopting a broader range of sensors and ad-hoc 3D-printed add-on attachment modules.

7.2. Relevance for future research

The novel contribution of this paper lies within a broader research focusing on methods to enhance the inclusion of people with ID in technology design, while also addressing their well-being. The results and themes outlined in this study can serve as a resource for future researchers aiming to adapt or design toolkits that involve people with ID in technology making and facilitate STEM learning Future developments could provide the opportunity to craft new elements and to create complex combinations by considering additional ways to pair nodes. Also, node personalization could be extended allowing individuals to modify node characteristics like the color of the light or the definition of triggers based on sensed data. This would increase the range of making possibilities covered by the toolkit.

Further work is needed to evaluate the real impact of the node networks designed by the study participants on improving their living conditions. However, the study results are promising. In addition to the participants' engagement and appreciation, the positive feedback from caregivers confirms that the work done can positively impact the involved individuals, and especially the ones belonging to the micro-community. Future work will further involve micro-communities in designing effectively within their shared environments, and long-term evaluation will be conducted to determine the effectiveness of the implemented solutions in improving the users' quality of life. However, the obtained results are an initial confirmation that involving people with ID in technology design and making is feasible and can have positive concrete effects.

CRediT authorship contribution statement

Diego Morra: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Giacomo Caslini:** Writing – review & editing, Writing – original draft, Software, Resources, Conceptualization. **Marco Mores:** Writing – review & editing, Methodology, Formal analysis. **Franca Garzotto:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Maristella Matera:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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