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A rapid-prototyping toolkit for people with intellectual disabilities

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ABSTRACT

Micro-electronics tools, coupled with card-based tools, are employed for prototyping smart devices with non-experts. Lately, researchers have started investigating what tools can actively engage people with intellectual disabilities (ID) in their prototyping. This paper posits itself in this line of work. It presents a toolkit for ID people to rapidly prototype together their own ideas of smart things, for their own shared environment. It analyses and discusses engaging or disengaging features of the toolkit in light of the results of two workshops with eight ID participants. Lessons of broad interest for the design of similar toolkits are drawn from the literature and study findings.

1. Introduction

There is increasing attention to empower people with intellectual disability (ID) to become relevant actors in the design of technology for their well-being and independent living (Walmsley et al., 2017). On the one hand, their inclusion has been mainly sought during ideation and validation in Human Computer Interaction (HCI) (Vega et al., 2020). On the other hand, the Maker movement has enabled the inclusion of diverse users in the prototyping of their smart devices (Taylor et al., 2016; Ermacora et al., 2020; Meissner et al., 2017), but limited efforts have been undertaken to involve ID people in the prototyping of their own smart devices (Chapko et al., 2020).

In general, ID people are among the most marginalised and underserved groups in society in terms of access to education and training (Lussier-Desrochers et al., 2017; Senaratne et al., 2022). This paper posits that smart-device prototyping with ID people is an empowerment opportunity for them and, as such, it should primarily consider non-tangible benefits that the experience can bring them (Hurst and Tobias, 2011; Meissner et al., 2017; Lechelt et al., 2018; Ellis et al., 2021): it should actively engage them, and promote a sense of agency and independence. Several research findings, however, highlight that it is challenging to foster their engagement in designing together, with minimal or no assistance (Ellis et al., 2021). ID often comes with concomitant psychiatric, medical, physical and developmental conditions (e.g., limited fine-motor skills, hyperactivity disorders, attention deficit disorders, communication difficulties). Thereby, common design activities, like problem-solving, decision-making and reflecting, besides abilities like creativity and abstraction, and even the manipulation of small electronic components might require extensive assistance (Dong and Heylighen, 2018). Works that tackle the challenge are mainly exploratory (Bdeir and Ullrich, 2010; Buechley et al., 2008; Qi et al., 2018).

How to make smart-device prototyping accessible and engaging for ID users is thus a gap that needs covering (Senaratne et al., 2022): this paper tackles it. It reports on two smart-thing prototyping workshops with 8 ID people, their caregiver and a researcher. The workshops used the novel gameful IoTgoID toolkit. As illustrated in Fig. 1, IoTgoID consists of a card-based game-board with rules for stirring ID people, together, across design with prototyping, a scanner for reading cards, and 3D-printed things with embedded microelectronics that give immediate feedback on design choices. ID people can combine cards and specify the behaviours of their smart things. Its scanner reads cards and automatically materialises the desired behaviours in the smart-thing prototypes. This physical and digital (a.k.a., *phygital*) interaction offers benefits to ID people, since it leverages the advantages and the formative role of embodied interaction (Gaggioli, 2017; Lechelt et al., 2018).

Using the toolkit, the ID participants in the workshops prototyped feasible ideas for smart things. This paper analyses aspects of the toolkit

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Fig. 1. Various elements of IoTgoID, from left to right: game board, laboratory, scanner and a 3D printed thing to be made smart.

that affected their engagement in the experience. In other words, the analysis does not focus on the quality of the prototypes by ID people, rather on non-tangible outcomes for them. To assess whether the workshops enabled for independence and agency, the paper inspects when ID people required assistance, and when instead they were independent agents of their design choices. General lessons for future prototyping toolkits are drawn from the literature and study findings: the conclusive lessons of the paper offer guidelines for other HCI researchers or practitioners working in the field of design with ID people.

2. Related work

A considerable amount of research has focused on the design of smart things and their prototyping with different end users but ID people (Frauenberger et al., 2017, 2016). Very few works engage them in design with prototyping: there is a need for research on such toolkits for them, which address their needs and desiderata, e.g., Gotfrid and Shinohara (2020). The next sections analyse related work and distill recommendations, which are the main references for the smart-thing design toolkit and research of this paper.

2.1. Smart-thing design toolkits for ID people

There are many simplified electronic toolkits for making, which can help democratise the design of smart things (Martin, 2015). However, these toolkits are generally inaccessible to people living with ID (Senaratne et al., 2022). Very few proposals try to lower physical and cognitive barriers by extending or adapting existing toolkits to make them accessible to people with ID. An example is Magic Cube, a physical interactive cube equipped with sensors and actuators (Lechelt et al., 2018). It facilitates hands-on exploration of electronic components, while enabling the programming of interactive behaviours. The results of a study with Magic Cube suggest that an interactive toolkit for making can engage and enhance the comprehension of abstract computational concepts. A similar experience was conducted with Littlebits (Bdeir and Ullrich, 2010), pre-assembled physical bits for creating tiny circuits. In Hollinworth et al. (2014) the authors extended Littlebits by adding a large base for the manipulation and assembling of components. A study with six users with ID evaluated their usability and users' enjoyment; the overall experience was reported easier and to require less assistance for the manipulation of bits. Moreover,in Gotfrid and Shinohara (2020) the authors investigated the effectiveness of embedding Littlebits components into puzzle pieces. This solution helped identify and recognise each component, and understand how to integrate the different components of a circuit.

Very few works have instead focused on developing toolkits specifically for ID people. An example is TapeBlocks (Ellis et al., 2021), a low-budget, low-fidelity toolkit based on foam-building components and conductive tapes to connect different types of blocks, e.g., buttons, light sensors, LED lights. The peculiarity of this toolkit in comparison to the others is that its design tries to privilege materials and assembly mechanisms which, according to the reported user studies, were perceived easy to use and actively engaging for ID people. Another example of a toolkit for ID people is TronicBoards (Senaratne et al., 2022). It comprises a curated set of modules coded into an easy-to-recognise traffic-light scheme. The modules can be connected in multiple modalities and integrated into different materials, e.g., conductive tapes and conductive threads. TronicBoards was evaluated with ten participants who could create electronic circuits with it. However, the study could not determine which physical features, among the ones included in the toolkit, were relevant to accommodate the diverse characteristics of participants.

The variability of the characteristics of ID people is indeed a crucial factor in creating toolkits for them: as described by the two main classification systems, i.e., ICD 11 and DSM.V, intellectual disability exhibits interpersonal variability within some common traits, i.e., difficulties in problem-solving, abstract reasoning, communication, social participation, and personal autonomy in social contexts (World Health Organization, 2021; American Psychiatric Association, 2013).

A more recent work, dubbed as an electronic and programming package for people with intellectual disabilities, consists of tools such as the prototyping toolkit TapeBlocks along with programming robots like Blue-Bot and Sphero (Ellis et al., 2023). This package was used as a STEAM course with 11 people with intellectual disability, with the help of 4 coaches. The one-year-long study highlighted that the physical aspect of the toolkit supported diverse group interactions. They also highlighted that fostering relationships and alignment with the host organisation are vital elements needed to successfully engage people with ID in such activities. They also identified key qualities needed for building skills and sustaining the interests of people with ID. This includes support for repetitive but diverse activities, simple interoperability, low threshold for manual dexterity, support for both individual and group activities, allowing describing ideas with physicality and embodiedness instead of just verbally, and support for making for personal goals of the people with ID. Another study focused on investigating the potential of maker technology to empower disabled children in a school setting (Vandenberghe et al., 2022). This work lists features like being completely open to configuration and being structure-less. Furthermore, the technology should accommodate interdependence within the existing social structure, i.e., caretakers or educators and peers. However, a balance should be maintained to avoid introducing interdependence needs that cannot be met, especially from already overburdened support staff.

Besides making or other prototyping tools, research has also investigated design toolkits with game cards for engaging end users in design, mainly in the ideation stage (Mora et al., 2017; Gennari et al., 2020b). Design toolkits with cards often address younger generations, e.g., children and teenagers (Gennari et al., 2020a; Dibitonto et al., 2018). In addition to cards representing things that can be augmented with smart behaviours, sensors and actuators, these toolkits usually present motivational cards establishing the goals of the design activity (Mora et al., 2017; Gennari et al., 2020a). They might also guide the users to reflect on ethical or technical implications of the smart thing design process (Dibitonto et al., 2018; Brito and Houghton, 2017). Some toolkits, like SNaP and IoTgo, provide users with digital and making tools across all design phases, so that they can acquire programming skills by building programs starting from the initially conceived ideas (Gennari et al., 2020b, 2022b).

Given the capability of these toolkits to enhance non-experts' engagement, a few works have investigated their adoption in design or co-design activities with ID people. In particular, COBO (Cosentino et al., 2021) is a card-based toolkit that aims to involve ID people in the design of smart things. The toolkit, inspired by SNaP, has cards for three components of smart things: physical things, sensors, and actuators. An interactive board reads and interprets card combinations and automatically generates code that simulates the ideated smart behaviour on an embedded tablet screen and with the selected sensors and actuators. According to the results of a study with 4 adults with ID, COBO seems to enhance participants' self-achievement by empowering them to ideate solutions to realistic problems, e.g., designing for an inclusive urban park. However, differently than IoTgoID, COBO targets the ideation stage, and it is not meant to support the prototyping of smart things with reflections.

2.2. The design space

The analysis of the reported literature yields recommendations for the design of prototyping toolkits for ID people. The most relevant ones for this paper are organised along three main dimensions as follows.

2.2.1. Physical attributes and interactions

Users with ID might have limited motor control or manual dexterity (Ellis et al., 2021; Senaratne et al., 2022; Hollinworth et al., 2014). To ease manipulation, one of the main recommendations from the literature is to provide large surfaces and materials without sharp edges. Also, user-friendly material and visual aspect must be preferred. For example, Tapeblocks (Ellis et al., 2021) uses colourful EVA to make the toolkit seem familiar, friendly, soft and yet robust. Researchers investigating usages of Tapeblocks highlight the benefits of holding multiple sessions, as an opportunity for consistent reinforcement of new skills and concepts. It is also recommended to minimise opportunities for incorrect usages of material, for instance, by preventing electronic components from being connected the wrong way round. Hollinworth et al. reported how difficult it was for participants to distinguish input and output in LittleBits toolkits (Hollinworth et al., 2014) . The internal components must be kept visible to encourage exploration and discovery (Ellis et al., 2021; Senaratne et al., 2022). For example, TapeBlocks' internal visibility and lack of hidden components facilitated participants in discovering by doing.

Another crucial recommendation is to use concrete representations for abstract concepts to foster reflective practices. For instance, (Lechelt et al., 2018) provide a concrete way of exploring abstract concepts through embodied interaction, where the tasks could only be successfully completed by shaking, tilting, and blowing into the Magic Cubes. Similarly, COBO was designed so as to read combinations of cards, representing behaviours of smart things, and simulate the effects of their combinations by activating matching sensors and actuators mounted on its interactive board and display on a screen as well (Cosentino et al., 2021). Moreover, Lechelt et al. (2018) suggest to keep actions with the toolkit short and scaffolded, so that users can reach fast "small wins" that can promote a sense of achievement.

2.2.2. Social interactions

Design with prototyping toolkits should promote social connections and leave room for discussion. For example, in the study by Ellis et al. (2021), users were involved in making as a group, in an environment where reflection and language were practised and names were given to new ideas and concepts. It is also argued that sharing tangibles can foster collaboration and dialogue; Lechelt et al. (2018) report how the physical nature of the Magic Cube toolkit pushed users to share their successes with their peers after completing a task, by waving the cube in the air and tilting it towards the others. A clear interplay between the facilitator, caregiver and the ID participants is also important. In the study by Ellis et al. (2021), coaches were adept at encouraging participants: they constantly motivated participants, giving a sense of pride when completing a challenging task.

2.2.3. Instructions and guidance

Toolkits for ID people should minimise the need of instructions, so as to "lower the engagement threshold". In the experience reported by Ellis et al. (2021) concerning the Tapeblocks toolkit, participants seemed to have incrementally built an understanding of how to operate the toolkit "in 15 min in the first workshop without instructions". However, if instructions are needed, they should be kept simple and intuitive: for example, the only instructions provided for Tapeblocks explain that for creating a circuit all that is required is to push a power block and an LED block together. Moreover, it is important to provide multi-modal guidance, such as verbal, visual and written instructions, to foster the inclusion of diverse participants and leverage different skills. For example, the Tapeblocks toolkit includes multiple indicators to ease the comprehension of the polarity of board modules (Ellis et al., 2021). At the same time, to avoid confusion, it is recommended not to add multiple competing information or stimuli to the toolkit. For TronicBoards, this was referred to as "reaching a trade-off in foregrounding and backgrounding" (Senaratne et al., 2022): the technical circuit symbols on the back of each board turned out to be confusing and not needed in the introduction, hence they were suggested to be "backgrounded". How to achieve this trade-off was left for future investigations.

3. The IoTgoID toolkit

IoTgoID is a gameful phygital toolkit, with a modular game board and decks of cards, as well as electronic and physical components. The aim of IoTgoID is to engage ID people in the design of their own smart things for their context, in the form of working prototypes with embedded electronics. Its design is inspired by the IoTgo toolkit. This was adopted in various field studies and evolved according to the needs of different users (Gennari et al., 2024; Gennari and Rizvi, 2021; Gennari et al., 2021; Bonani et al., 2022). In particular, in November 2021, IoTgo was used in a high school class (Gennari et al., 2022b). IoTgo enabled all participants to collaboratively design their smart things for a social well-being goal, independently of their prior programming expertise. This study involved a learner with ID, who successfully completed his smart-thing design with his support teacher. This learner exploited the automated generation of programs offered by IoTgo to explore different available physical input and output devices (e.g., buttons and motors). His participation in the creation activities and his outcomes led us to consider that individuals with ID could use the toolkit. However, it also highlighted the necessity for customisation. This inspired the IoTgoID tool presented in this paper.

The IoTgoID phygital toolkit was conceived for design workshops with attendees of Fraternitá & Amicizia, a non-profit organisation based in Milan, Italy, which operates in the field of psycho-social and intellectual disability. Starting from IoTgo, the literature analysis reported above, besides rounds of inquiries with the caregiver of Fraternitá & Amicizia, IoTgoID was designed as follows: the IoTgo toolkit was used as a probe with the caregiver, and iteratively revised prototypes of IoTgoID were used with the caregiver to inform its design.

The novel IoTgoID phygital toolkit for ID people considerably differs from IoTgo for its physical attributes and interactions, rules and roles for social interactions, and instructions and guidance. The remainder explains these aspects and what they are based on, highlighting what results from the rounds of inquiries with the caregiver and literature analyses. Furthermore, Tables 1 and 2 recap, at a bird's eye view, the main differences between IoTgo and IoTgoID due to those rounds.

Table 1
Comparison of the main physical attributes and interactions differentiating IoTgo for teens and IoTgoID for ID people.

Physical attributes and interactions	
IoTgo	IoTgoID
One board per design level: story co-creation; context analysis; laboratory; reflections, revisions	One single board for all levels: context exploration; laboratory; reflections and revisions
Branching between levels	A linear progression between levels, except in the last level from which branching is possible for revising decisions
Level 1: context exploration	
Story co-created by teens	Story by caregiver for ID people
Persona cards to empathise with and design for	ID people design for themselves
Many locations to design for, co-created by teens	One location, Fraternitá & Amicizia, with which all ID people are equally familiar
Level 2: the laboratory	
Many individual input- and output-device cards, leading to 100+ possible combinations (briefly, combos)	36 combos, each for one input- and one output-device, combined together as combo cards as if they represented physical devices (C1) are easy to use in combination, (C2) are useable by people with reduced manual dexterity, (C3) their states are immediately perceivable
Card based representation of physical things to make smart	3D-printed small-scale versions of physical things to make smart, with visible and easy-to-explore microelectronics
Web app for generating and customising programs from combos of input and output cards	A scanner for reading combos and materialising immediately their effect on physical things with microelectronics
Level 3: reflections and revisions	
Multiple reflection cards	Few reflection cards
Reflection questions require elaborated written answers	Reflection questions require yes or no answers

Table 2
Comparison of the differences in rules and roles for social interactions, instructions and guidance between IoTgofor teens and IoTgoIDfor ID people.

Rules and roles for social interactions	
IoTgo	IoTgoID
Teens work on their own, alone or in small groups	ID people work with a caregiver
Teens work across levels with similar roles	ID people change and exchange roles across levels
Sharing rules are not given	How to share material is indicated by visual cues on the board
Instructions and guidance	
IoTgo	IoTgoID
Instructions are written on boards or in separate booklets, visuals are adequate for teens	Instructions are printed on the board and represented with visual cues, kept at a minimum level to avoid confusion
Text is written for teens of high-schools	Text is revised by the caregiver

3.1. Physical attributes and interactions

3.1.1. Game board and play

IoTgo design. The game board and play of IoTgo are divided into progressive levels, with pebbles and cards concretely representing design parts. The board initially guides players to explore a design context with a problematic situation (the need to encourage social interactions), conveyed through a story co-created by players. Then the board challenges players to tackle the situation with new smart things: they have to choose physical thing cards (e.g., two benches) to make smart with microcontrollers, physical devices represented on cards and wireless communication (e.g., the smart benches play a happy tune if people sit on them, so as to make people socialise). All levels include multiple reflection cards, requiring elaborated answers, and written stimuli (e.g., on data sharing).

Results and IoTgoID design choices. The caregiver appreciated the progressive game-play, i.e., levels in IoTgo, are revealed one at a time, by unfolding boards. According to the caregiver, this can "guide clearly through design, taking one short step after the other" linearly. Similarly, it was appreciated the overall aesthetics for progressing through design (e.g., arrows) and concluding a level (e.g., start and end spots), but the number of choices was recommended to be reduced.

In line with the rounds of inquiries with the caregiver, the final game board and play of IoTgoID maintains such aspects of progression, but other physical attributes and interactions are designed anew for ID people, which detailed as follows. In line with recommendations from the literature, IoTgoID contains a single game board, printed on a large surface, without sharp edges and with soft colours. Levels of IoTgoID are short and balanced, represented on the single board, each with a goal and short tasks to achieve, besides a "small win" to celebrate:

Level 1, for exploring the context of use,

Level 2, the laboratory, for prototyping a smart-thing idea for the context,

Level 3, for reflecting and revising the choices made.

The progression within and across levels is mainly linear, as recommended by the caregiver. However, to enable multiple sessions and encourage reflections, in Level 3 players can end the IoTgoID game, or move back to Level 1 or 2 and revise choices therein (see Fig. 2). The physical attributes and interactions of each level are explained next.

3.1.2. Level 1: context exploration

IoTgo design. IoTgo asks players to co-create a story, to empathise with the people they are asked to design for. Then IoTgo asks players to choose one among many missions and consider their relevance for the story, besides to consider relevant locations for their design.

Results and IoTgoID design choices. Starting with a story was considered important by the caregiver and hence this choice was incorporated in IoTgoID. However, the story was written by the caregiver for ID people, and not co-created by them. The caregiver deemed too complex the request of taking the viewpoint of other personas, in different locations, and designing for them, as IoTgo does. Instead, IoTgoID asks its players, the ID people, to design for themselves and the Fraternitá & Amicizia location, with which they are all equally familiar. Missions of IoTgoID were revised with the caregiver so as to be meaningful for Fraternitá & Amicizia attendees. Examples are as follow: to make new friends; to improve the safety of people; to make people more respectful. Level 1 of IoTgoID ends with a first reflection card, related to the relevance of the picked-up mission for the given story and location.

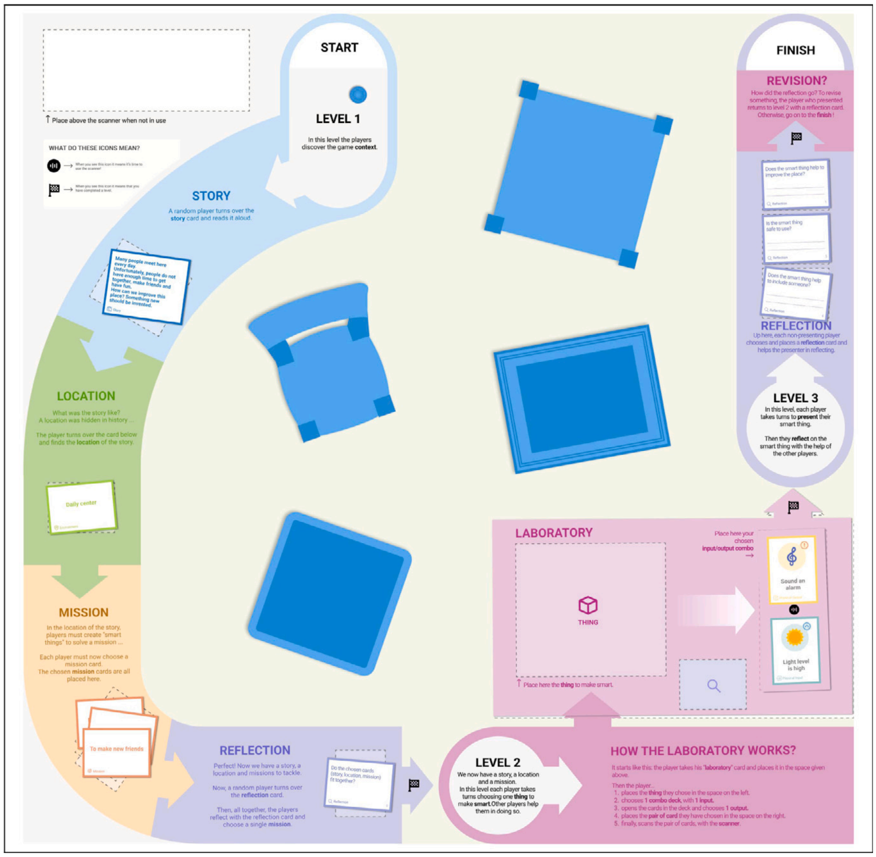

Fig. 2. The IoTgoID board for ID people, divided into three levels.

3.1.3. Level 2: laboratory

IoTgo. IoTgo decomposes technological choices for smart things in terms of input and output cards, representing diverse input and output devices for smart things, e.g., a button input card, and an LED matrix output card. Each card comes with a state the device can be in, e.g., a button can be pressed or not, an LED matrix can show a happy icon, a sad icon or be switched off. This open space gives players the freedom of choosing among more than 100 combinations of input and output devices via cards (briefly, combos). Things to make smart are also represented in an abstract form with cards in IoTgo. Also, IoTgo comes with a web app. This automatically generates a simple code for testing how a thing becomes smart. It also enables players to further customise it by means of input and output cards, and by modifying the code.

Results and IoTgoID design choices. Level 2 of IoTgoID, for rapidly prototyping a smart thing, was completely redesigned for ID people. Like IoTgo, Level 2 of IoTgoID uses input cards for input devices, and output cards for output devices. In IoTgo, choosing a combination of input and output cards, plus the states they can be in, means reflecting on more than 100 possible combinations, which was considered too demanding by the caregiver. Therefore, 36 new combo cards (briefly, combos) were created for IoTgoID, each with one input card with a state and one output card with a state. Two such combinations are in Fig. 3. The combos were selected for IoTgoID if the represented physical devices for input and output (C1) are easy to use in combination, (C2) useable by people with reduced manual dexterity, and in case (C3) the states they can be in is immediately perceivable. For instance, the combination of a light sensor and an LED matrix was discarded because difficult to use together reliably (C1). The dimmer and accelerometer were discarded because they were deemed difficult to manipulate or their functioning difficult to understand (C2, C3).

Moreover, similarly to SNaP and COBO (Gennari et al., 2022a; Cosentino et al., 2021), for each combination of input and output cards,

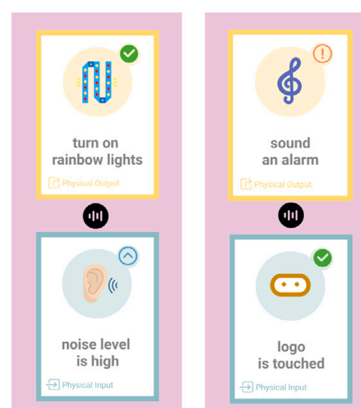

Fig. 3. Two examples of combos of input–output cards with the states, the represented physical devices can be in, when combined.

IoTgo contained a web app that enabled to generate automatically the code controlling the behaviours of the matching physical devices. However, notice that the player had to edit on a computer screen the code that was generated by IoTgo for the chosen combination. Moreover, the player had then to learn how upload it onto a micro:bit board to see the behaviour in action. The caregiver deemed this part would make the activity too long and fragmented, and therefore frustrating for ID people. Furthermore, the presence of other mediating devices might hamper ID people's understanding of the consequences of their choices. The absence of delays and detours from the reading of combos and making things smart was recommended to help participants perceive "cause–effect relations between the cards they choose", with abstract representations of a smart-things' components, "and the effect of their

Fig. 4. (1) A 3D-printed thing embeds a micro:bit, to connect to the IoTgoID scanner embedding a Raspberry Pi. (2,3) The scanner reads the NFC tag of a combo card, generates a program and (4) uploads it on the micro:bit in the thing, thus making it smart.

choices on physical things", thereby helping bridge the gap between abstraction and concreteness. Therefore it was decided to leave it out in IoTgoID and to show the effects of the choice of combos directly and only on the physical things.

In fact, whereas IoTgoID had cards representing things to make smart in abstract form, a choice which was considered too abstract for ID people by their caregivers, IoTgoID contains 3D-printed things which are small-scale versions of actual physical things in the Fraternitá & Amicizia environment: a chair, a table, a painting, a dustbin, a folder. Each contains a micro:bit micro-controller, with all the physical devices represented on combos. The scanner of IoTgoID embeds a Raspberry Pi mini-computer, with an NFC card-reader, and each combo has an NFC tag. After attaching the scanner to a 3D-printed thing and scanning a combo, a program is automatically generated for the combo and uploaded on the micro:bit in the 3D-printed thing. The 3D-printed thing becomes immediately interactive and hence "smart". See Fig. 4.

Moreover, as recommended in the literature, 3D-printed things were left partially open, so as to make the electronic components visible, enabling their exploration, and yet avoiding incorrect connections.

3.1.4. Level 3: reflections and revisions

IoTgo. Level 3 of IoTgo contained multiple reflection cards, each requiring elaborated answers.

Results and IoTgoID design choices. These were adapted for IoTgoID with the caregiver's help into 8 reflection cards, with yes–no answers. Level 3 is unstructured and less scaffolded in IoTgoID, in the hope of promoting open, free dialogues around reflection cards: it contains three place-holders for the cards, without any visual cue on which reflection should be first. Reflection cards are to be picked randomly from players and placed face-up on the place-holders to aid in reflecting on smart things.

3.2. Rules and roles for social interactions

IoTgo. The board of IoTgo can be independently used by single players or different players, who have similar roles. Rules for sharing and social interactions are not organised by the toolkit itself.

Results and IoTgoID design choices. The board of IoTgoID is placed on a table surface, and used by four players. The rules and roles for promoting and organising social interactions during the game-play were designed ad-hoc for people living with ID, as explained in the following. The master, e.g., a role taken up by the caregiver, is in charge of initially explaining the game rules and giving players a pebble to move along the board, besides providing hints or scaffolding on a need-to-have basis to make the game progress. Roles of players different than the master depend on the level.

In Level 1, players are to take turns with the pebble on the board, listen to or read what is written on the board or cards, and choose and reflect on missions. Level 2 asks each player to choose their 3D-printed thing and place it in the centre of their laboratory. Then the player has to choose one combo for one physical input device and one physical output device, and use the scanner for reading it. Meanwhile, the others are invited to help out discover the matching devices in the 3D-printed thing and how to interact with them.

Level 3 asks a player to pitch their smart thing, and place it in the centre of the board. The others are to randomly pick up one reflection card, read, in turn, what is printed on it, and help the speaker reflect, with the aid of the card, on the smart thing. Last but not least, some cards or other physical materials are on purpose shared so as to promote social interactions around the board, as recommended in the literature. How to share materials is mostly indicated via visual cues, differently than in IoTgo.

In Level 2, for instance, the smart thing under design by a player is placed in the centre of the laboratory, to enable players to share their work in progress with others, gain feedback and socially connect with them. There are also shared decisions to take concerning the material during the gameplay, to promote discussions. For instance, at the end of Level 1, players have each chosen a mission and are to negotiate a single one to carry ahead, as indicated on the board.

3.3. Instructions and guidance

IoTgo. Instructions in IoTgo are written on the board for guiding players while using the materials, or in separate companion booklets, with visuals and text adequate in complexity for the intended players.

Results and IoTgoID design choices. In view of language difficulties, written instructions are given when necessary and kept at a minimum level in IoTgoID. To keep also the number of different materials to use at a manageable level for ID players, differently than in IoTgo, instructions are not kept in separate booklets. Rather, they are printed on the board and represented with visual cues as well. For instance, arrows are used to indicate how to move from one level to the other, and instructions are printed on the board to clarify what to do in each level. Visual representations are also kept at a minimum level to avoid giving multiple confusing stimuli.

Cards have iconic representations and companion text information, meaningful for Fraternitá & Amicizia attendees. In particular, the text of the starting story was created with the help of the caregiver, e.g., to balance its length and make it easy to relate to for Fraternitá & Amicizia attendees. The text on reflection cards is written with simple sentences and questions, e.g., compound phrases with disjunctions were avoided. Whereas in IoTgo reflection cards trigger elaborated answers and demand abstract reasoning, reflection cards of IoTgoID require yes–no answers. Moreover, they are related to mission cards. Example reflection questions of IoTgoID are as follows: Does the smart thing help make friends? Is the smart thing safe to use? Does the smart thing reduce waste?

4. Study design

4.1. Research motivations and question

The study reported in this paper revolves around IoTgoID design workshops, which aimed at engaging ID people to collaborate in designing smart things for their own context. The design workshops were two, each one conducted with four ID people, a researcher and a support coach (caregiver). As explained in the introductory section, the engagement of ID people in working collaboratively together in design is per se a benefit, which potentially stimulates their cognitive capabilities, and impacts their knowledge of technology (Senaratne et al., 2022; Ellis et al., 2021). Moreover, as emerging from the literature analysed above, an ideal toolkit for them should also minimise the need for assistance on the side of the caregiver, giving them a sense of agency (Ellis et al., 2021). The study thus focused on the following **research question**:

> Do participants engage in designing with IoTgoID collaboratively, and what (dis)engages them, with or without assistance?

4.2. Participants and context

Two workshops with IoTgoID were conducted in two different mornings in May 2022. Eight participants were recruited for the workshops: 4 males and 4 females, mean age 30.57 years old, Standard Deviation (SD) equal to 5.59. Inclusion criteria were as follows: regular attendance to the daycare centre, similar IQ. Participants were divided into two different groups, each of four members, and each participated in a workshop. Both groups comprised two males and two females with slight differences in mean ages. More specifically, the mean age for group 1 was 33.9 years old ($SD = 3.06$) whereas it was 27.5 for group 2 ($SD = 6.01$). Each workshop lasted approximately 2 hours, with ID participants working with IoTgoID. The Table 3 reports demographic information and the ID type of each participant. Each workshop was conducted by the same caregiver and researcher, acting as a technical facilitator.

Before running the workshops, all participants and their caregivers signed informed consents, as prescribed by the permit released for the study by the ethical board of the Politecnico di Milano, Italy. These forms included information about the study itself, procedures, goals, data treatment and withdrawal for those who, at any point in the study, would express their willingness to no longer participate in it. All informed consent forms are stored in a safe cabinet.

The workshops were conducted in spaces at Fraternitá & Amicizia that participants attend on a daily basis. Therefore, the participants were already familiar and at ease with the location, thus allowing them to design for themselves, their own smart things for their own context, in situ.

4.2.1. Survey

A post-study survey was created by considering the literature on surveys for ID people and children, besides consulting with the caregiver, e.g., Read (2008). The caregiver suggested that questions should be as direct as possible, and explained verbally by the caregiver himself/herself during the administration of the survey. This contained closed-format questions and an open-format question. Each closed-format question was for a specific level of IoTgoID, that is, a stage in the design process. The closed-format questions investigated participants' engagement, like the Fun Toolkit (Read, 2008), respectively in

(**Question** 1) reading the story, location description and mission for the context exploration in Level 1,

(**Question** 2) using the laboratory for prototyping smart things in Level 2,

(**Question** 3) reflecting and revising them in Level 3.

Table 3
Participants in the workshop.

Code	Group	Gender	Age (y)	ID type
1F_bluestripes	1	F	30–34	mild intellectual disability
2M_orange	1	M	30–34	mild intellectual disability, facial dismoriphisms
3M_red	1	M	35–39	intellectual disability with space–time disorientation
4F_white	1	F	35–39	affective/cognitive developmental disorder in organic personality disorder; moderate pulmonary insufficiency and right ventricular dilatation in Fallot tetralgia
1_black_M	2	M	20–24	mild intellectual disability, congenital encephalopathy, drug-resistant epilepsy
2_orange_M	2	M	25–29	mild intellectual disability
3F_hat_F	2	F	25–29	Struge–Weber syndrome, right hemiplegia
4F_blu_F	2	F	35–39	mild intellectual disability

Each question was accompanied by a visual representation of the level, and explained verbally by the caregiver. For answering, there were five smileys in a row, corresponding to five increasing levels of engagement to choose among, labelled by a verbal caption, from "strongly disagree" to "strongly agree". Such dual-code representation, verbal and pictorial, enables a direct access to the semantic network in which emotional information is stored (Gennari et al., 2017). See a snapshot of part of the filled in survey in Fig. 5. T The survey ended with an open-ended question, probing participants to share their opinion about IoTgoID.

The participants' choices of smileys for the closed-format questions of the survey were coded as follows. The smileys corresponding to "strongly agree" and "agree" were mapped to 1, indicating engagement. All others were mapped to 0, standing for lack of engagement.

4.2.2. Observations and interviews

Systematic quantitative observations were conducted and based on the Baker Rodrigo Ocumpaugh Monitoring Protocol (BROMP) 2.0 (Ocumpaugh, 2015). Specifically, participants' play with IoTgoID was video-recorded. Videos were then analysed to systematically transcribe in notes and code participants' engagement by means of the BROMP protocol, which offers several behavioural indicators of engagement, and related coding schemes; if two indicators occur simultaneously, the most prominent is coded (Ocumpaugh, 2015). Moreover, utterances were considered to disambiguate unclear behaviour indicators, a situation also reported in (Senaratne et al., 2022).

Transcriptions by researchers highlighted when participants needed assistance or scaffolding. Coding of engagement and disengagement was done as follows. For each participant and level, two researchers independently coded engagement/disengagement indicators with the following coding scheme from BROMP:

- 1 for engagement, e.g., in case a participant reads the story on the behalf of all others in Level 1, a participant interacts eagerly with her smart thing in Level 2, a participant answers reflection questions in Level 3;

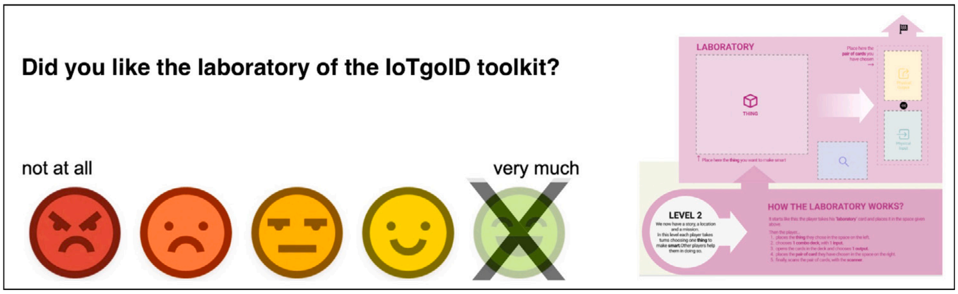

Fig. 5. A snapshot of the questionnaire for participants.

- 0 for lack of engagement, e.g., in case a participant moves away from the game table in Level 1, a participant does not interact with smart things in Level 2, a participant yawns when reflections are carried on in Level 3.

Initially, researchers worked independently one of the other, and afterwards they compared their codes iteratively.

After the workshops, interviews with the caregiver were run and hence used to triangulate engagement data, so as to minimise biases and gain a holistic view over the study results, as explained in the following.

5. Study results

5.1. Engagement

Coded choices from the survey filled in by participants, coding and notes by researchers of videos, and interviews to the caregiver were triangulated and processed to gain a holistic perspective on the engagement of participants in design with the others, framed along the IoTgoID levels, and hence to answer the research question. Specifically, for each level, the two researchers cross-checked their engagement coding and notes, obtained from videos, against the coded choices of participants, obtained from the surveys, thus marking any difference. The caregiver had thus the final word on whether a participant was engaged in a level (1) or not (0). The reason for this choice was that the caregiver knows each participant, and hence the caregiver could expertly assess whether the chosen smiley by a participant was reliable and whether certain behaviours or utterances, transcribed by the researchers in notes, reliably indicated the participant's engagement or lack of engagement. For instance, while other participants were choosing their input and output combination in Level 2, 3F_hat moved and looked away from the table, and hence seemed mainly disengaged to researchers, although she answered, and to the point, when she was asked about her choice. In the survey, this participant stated to like this level "very much". The engagement of this participant in Level 2 was thus re-considered with the caregiver who ruled out the reported behaviours as indicators of disengagement for her, e.g., because this participant "has the same behaviours in other activities which she enjoys very much". This was used to code her as engaged (1) in Level 2.

The final results are as follows. In Level 1, the behaviours of 50% participants (4 out of 8) were coded as 1, denoting engagement. In Level 2, the percentage raised to 100%. In Level 3, the percentage dropped to 25%.

5.2. What engages them with or without assistance

The transcribed notes and hence again videos were analysed, firstly by the researchers and then by the caregiver to tackle the research question as follows. They looked for IoTgoID features which engaged participants, giving them a sense of agency, or which required assistance from the technical facilitator or the caregiver. The main results of the analysis with relevant notes are reported in the following, thematically divided per level of IoTgoID and group of participants.

5.2.1. Level 1: context exploration

This level asked participants to understand how to interact with the IoTgoID board, read and listen to instructions and cards in turn for exploring the context. Results are reported per group as follows.

First group. In the first group, when the IoTgoID board was unfolded, participants commented: "*it is a bit like the goose game... cool... I like its colours*". When the facilitator explained what IoTgoID is made of, all followed what the facilitator said and voiced their appreciation. For instance, when the facilitator said "*there are cards which we will be discovering step by step''*, they all exclaimed "*that's beautiful*". Text on the board, related to instructions, or on cards seemed adequate except for the reflection area: longer sentences, long words or words with harsh sounds seemed to be most difficult and should be revised (e.g., "to *r*esolve"). However, all participants volunteered to take turns in reading the text aloud, in spite of reading difficulties. When one read all others listened carefully or pointed out what to do next with their fingers on the board. All participants from the first group managed to choose a mission on their own, which they seemed to enjoy and elaborate on, e.g., 1F_bluestripes stated "*[this] is useful to understand what others think*". Moreover, they all collaborated on choosing and relating to a single shared mission card to carry over in the game, at the end of Level 1, without the need of scaffolding from the caregiver or facilitator: "to make new friends". 1F_bluestripes reflected as follows on the importance of being friendly with all:

> All of us have our own preferences, however, it is important that we try to be friendly to all: what I have learned coming here is that each of us has their own difficulties [...] but we cannot exclude people based on that. The smart thing can help us in making friends with all.

Second group. In the second group, similar behaviours occurred. They agreed to read instructions on the board one by one. See Fig. 6 for a participant volunteering to read what she is pointing at with her finger. All listened, without talking but very focused on the game. A difference with the first group emerged in the mission area, when mission cards were unveiled and briefly explained. Each participant in turn was to choose their mission. Unlike in the first group, only one participant in the second group (3_hat_F) chose a mission and elaborated on reasons for choosing it. The others seemed to have chosen a mission card randomly or anyhow without elaborating on their choices. In general, it was unclear for them how to place all their mission cards on the board, and the facilitator had to assist them in this task. When it was time to choose a single shared mission, they wanted more than one mission to tackle and not to have a single mission to agree on. In the end, the facilitator and caregiver intervened, participants agreed to have one shared mission but also to add a further one. 1_black_M said: "*I would like to have the mission to make people more respectful*", the one that was picked up randomly. 4_blu_F agreed, whereas 3_hat_F would have liked to have "to make new friends". Then 4_blu_F stated "*ok, let's start with making people more respectful*".

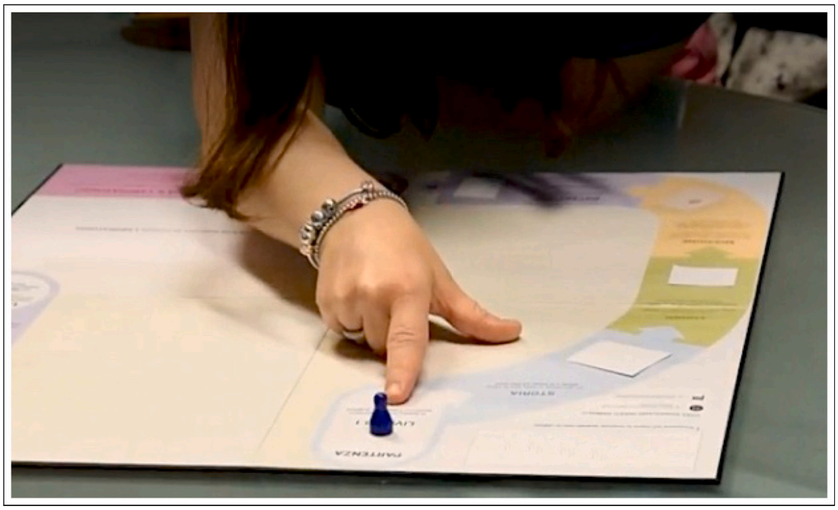

Fig. 6. A participant volunteers to read during Level 1.

5.2.2. Level 2: laboratory

In this level, each participant in turn used his or her own laboratory to rapidly prototype a smart thing with a combo of input and output, read by a scanner and translated into a working program for the embedded micro:bit with physical input and output devices.

First group. In the first group, when 3D-printed things were positioned on the board, all participants moved close to them and commented on them happily "*how beautiful*!" (1F_bluestripes). They made jokes (4F_white said "*we can drink coffee on the table*", and they all laughed), which suggested that using IoTgoID up to Level 2 put them at their ease. They all followed the instructions for choosing their combos, but they were confused on where to place the 3D-printed things to be made smart. However, when probed about the input or output cards, all participants engaged in sharing their understanding and reflections on their choices. When probed on what they expected inputs or outputs to be, one of them answered "*the thing you have to say*" (1F_bluestripes), a comment probably stirred by the conversation-agent example of a smart thing explained at the start of IoTgoID. The caregiver then intervened and added what follows: *input is what comes in, output is what comes out*. Then participants elaborated on it further together, e.g., 4F_white commented that "*the input is like giving the 'start' signal*", and 1F_bluestripes continued the reasoning by stating that then "*the output reacts*". Usually, the choice of the input was done individually with possible feedback from others, and the choice of the output was instead taken together with all others, assisting each other. For instance, 1F_bluestripes chose her input card ("touch") on her own, without any doubt. Then, when output cards were unveiled one by one, a joint decision was taken for her output, and others commented that they also had ideas for their own combinations, e.g., 4F_white stated to *have already chosen mine [her combinations]*, thereby showing to be engaged and reflect on her own while the game progressed.

Initially, they were all confused about how to interact with the scanner, e.g., 4F_white wondered whether the scanner should read the LED matrix of her smart thing, and she did not think that it could read the combination of input and output cards. The facilitator explained that once and then they picked it up immediately. Moreover, it was not always clear where some input devices were positioned on the 3D-printed thing (e.g., logo to press), probably due also to the size of the thing which was fitting tightly the embedded electronics components. Meanwhile, the facilitator and caregiver connected the scanner and thing, participants continued discussing what inputs and outputs are, besides their choices among themselves, further showing their engagement in this level and the sense of agency it gave them. When asked to connect the scanner to the thing, at the start, they were hesitant. However, they seem to have understood its working quickly. For instance, once the facilitator forgot to connect the scanner to the 3D-printed thing, and 3M_red noted that because the yellow light did not light up as usual on the embedded micro:bit.

In general, the gameplay of Level 2 seemed clear to all after three rounds with IoTgoID: when the choice of input and output was in charge of the last player, she repeated what she had to do on her own (4F_white), without any need of scaffolding probes or assistance. When this level was over, all participants kept on looking at their smart things. They seemed eager to keep watching or interacting with their own smart things. See Fig. 7.

Second group. Behaviours in the second group were generally similar. For instance, when the facilitator unveiled the 3D-printed things, all focused their attention on them. 2_orange_M was highly engaged in Level 2, e.g., he exclaimed "*yeah!*" or "*boo!*" depending on the thing the facilitator was showing. When it was 2_orange_M's turn to select a combination of cards for his thing, he showed to be very happy and eager to interact with the board and touch the thing, as so were all the others, e.g., 3_hat_F chose the input even if it was not her turn to do so. They all wanted to eagerly try out their 3D-printed things after scanning their combination of input and output.

5.2.3. Level 3: reflections and revisions

This level asked each participant, in turn, to present their smart thing and the others to help the speaker reflect on it with three reflection cards. In case reflections pointed out areas for improvements, the speaker was asked to revise his or her smart thing, and choose a different input and output combination.

First group. In the first group, when reflections were conducted, three players were rather awaiting for instructions: if not probed, they would not intervene. Although the reflections they conducted were meaningful, e.g., *to make friendship the voice tune matters*, they were often unrelated to their smart things, except in one case, namely 4F_white. In general, all participants were lost and frequently required assistance, e.g., when it was her turn to read out the reflection card for the player presenting his smart thing, 4F_white asked *and now what shall I do [with all this stuff I have in front of me]*, and, while stating it, she gestured with her hand towards her own smart thing, close to her, and the given reflection card, as if expecting to have to do something with them together. When the revision time came, three out of four were not willing to revise their smart things, e.g., 3M_red was not willing to revise the happy outcome when there was noise in spite of reflection probes to the contrary by others in relation to the reflection lens "finding new friends". In the end, only 4F_white revised her thing,

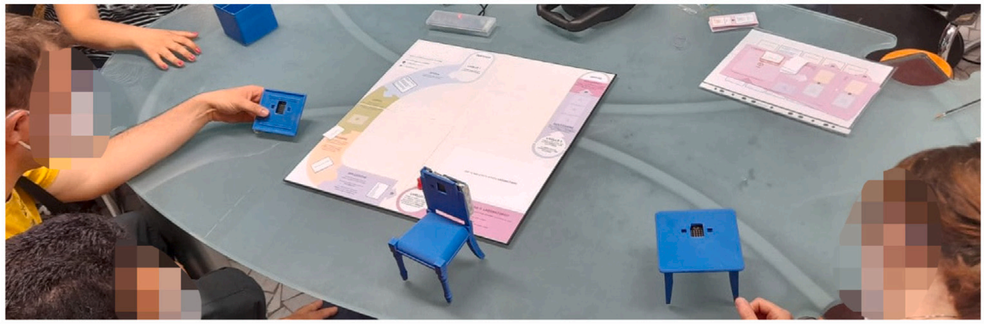

Fig. 7. Participants continue watching or interacting with their smart things at the end of Level 2.

making her table light up with colours and stating that she revised her table so, "*in order for it to appeal to people around and hence make new friends*".

Second group. In the second group, most participants were in trouble when asked to reflect on their choices. Often 3_hat_F answered on behalf of the other players or tried doing so. The caregiver crucially intervened and referred to their physical environment and shared experience, so as to connect their elaboration to something which they had experienced. For instance, he said what follows:

> *Think of the painting in the hall, and imagine if it had a sensor that detects shaking and then makes the light switch on. Do we want it to be shaken to fulfil the mission of making people more respectful?*

His intervention enabled participants to reflect on the need to revise the chosen combinations of input (shaking gesture), mission (making people more respectful) and thing (painting). In an interview, when probed about this, the caregiver explained that all participants were especially careful about that painting, which is fragile, and so he knew that they would immediately pick up his cue and understand that it is generally better to avoid that paintings are shaken. In general, long discussions during revisions seemed to bore all participants, and, very frequently, the caregiver had to refocus their attention. 3_hat_F was also visibly tired and generally disengaged, e.g., she stayed bent, eyes away from the speakers and at times individually touching her smart thing while others were talking.

However, when they could albeit briefly interact with input and output cards, and carry on their own revisions, they were visibly happy. When 4_blu_F had to present her smart thing, she exclaimed "*yes, finally!*", and she then became very active again, advancing many ideas. 1_orange_M and 4_blu_F wanted to try different input and output combos; when they scanned the new combos, also the others (especially 3_hat_F got again engaged, e.g., they wanted to interact again with the others' smart things and see "*what happens*".

6. Discussion and lessons learnt

The study invited 8 ID people and their caregiver to rapidly prototype, with the novel IoTgoID toolkit, their ideas of smart things for their own environment, collaboratively. The study tackled the following research question: whether participants engaged in working together through each level of IoTgoID and what (dis)engaged them, with or without assistance. Data were collected with three main instruments and processed within a holistic perspective to answer the question. Findings, reported in Section 5, are discussed in the following. These and relevant literature are reflected over to distill lessons for engaging toolkits for ID people, that minimise assistance.

6.1. Discussion about engagement results

The analyses of the coded engagement helped answer the research question as follows. They highlight that all participants were engaged in Level 2, partly in Level 1 and mainly disengaged in Level 3. Qualitative data helped identify possible reasons behind the different engagement results in each level, in relation to the physical aspects of IoTgoID rules and roles for social interactions, besides the way instructions and guidance were proposed.

Level 1. Participants were to take turns for reading and listening to instructions on the board, and exploring the context with cards. They seemed partly engaged and the need of assistance by the facilitator or caregiver were minimal or restricted to specific features of IoTgoID, especially for the second group. They appreciated the physical aspects of the board, e.g., the soft colours and the shape, features also recommended in other studies concerning toolkits for ID people (Ellis et al., 2021), and immediately recognised it as a board game (e.g., one participant commented that "*it is like the goose game*"). Rules for socially interacting in the game and reading were followed in spite of language difficulties. Pain-points were mostly related to missions, in the second group. In particular, they wished to choose their own mission to carry ahead in the game and were reluctant to negotiate it with the others.

Level 2. Participants seemed to be generally engaged with IoTgoID and, in turn, to interact with its laboratory for rapidly prototyping and testing smart-thing ideas expressed with card combos. The need for assistance on the side of the facilitator seems to have been minimal for both groups, or needed for operating the scanner the first time of usage—it seemed surprising and unexpected that the scanner would interact with paper combos and not the 3D-printed things with electronics. Scaffolding was also needed to explain once what input and output cards stand for—what comes in, and what comes out. Then, participants started elaborating collaboratively on what input and output meant (e.g., one started commenting that "*the input is like giving the 'start' signal*", and another continued by stating that "*the output reacts*"). In both groups, participants took turns in choosing and scanning their combo, and helped each other with the choices and the electronic material, in line with the rules of the game. During breaks, they continued interacting with their smart things or discussing their choices. A major pain-point was the size of the 3D-printed things, which tightly fitted the microelectronics, and thus required exceeding manual dexterity.

Level 3. A participant had to act as speaker and pitch his or her smart thing. The others would take each a reflection card, randomly, to assist the speaker in reflecting and revising the shared smart thing. As for the physical aspects, Level 3 was less visually structured than the other two levels, it minimised instructions and left ample room for discussions, as recommended in other work in the analysed literature, e.g., Ellis et al. (2021). However, according to the results of the reported work, discussions for reflecting together need to be clearly guided, kept concrete and short. Not presenting participants were confused about their roles and the lack of tangible directions. At this point in the gameplay, they had in front of them a number of objects, and they did not know what to focus their attention on, and how to interact in the game-play with others (e.g., '*and now what shall I do?*"). This reading of their source of confusion aligns with past findings, according to which multiple choices can confuse ID people (Senaratne et al., 2022). Similarly, although reflection cards reported simple questions, they lacked in concreteness, and were not immediate to relate to the smart things players had conceived and prototyped in the previous levels. The caregiver or facilitator needed to assist participants frequently, and to re-direct participants' reflections or revisions in relation to their smart things. This happened across the first and second group, with small differences. In particular, the caregiver intervened so as to better connect the reflection question on the card with a physical smart thing at Fraternitá & Amicizia all participants had directly experienced: connecting the question to the small-scale 3D-printed thing was not equally easy. Moreover, long discussions around revisions bored the second group, who lost attention for regaining it when they could again touch smart things and test out revisions (e.g., one uttered "*yes, finally!*").

6.2. Lessons learnt for the design of engaging toolkits

The literature analysis and the results of the study reported in this paper offer lessons for revisiting the design dimensions considered for IoTgoID, related to physical aspects and interactions with its game board, rules and roles for socially interacting in the game-play, besides instructions and guidance (see Section 2.2). The distilled lessons are written as guidelines for HCI researchers or practitioners who study how to create prototyping toolkits and methods for engaging ID people in smart-thing design.

6.2.1. Physical aspects and interactions

Different physical aspects and interaction possibilities offered by toolkits can affect the engagement of people with ID. Related lessons are recapped in Table 4.

6.2.2. Social interactions

The literature recommends to design tasks that promote social interactions. IoTgoID was designed to promote and organise social interactions, by setting specific game rules and roles, besides sharing material with decisions to take jointly. See Table 5.

6.2.3. Independence and agency

To promote a sense of independence and agency, and to increase engagement, the literature recommends that toolkits for ID people should minimise the need for intuitive instructions as well as the need for assistance on the side of the caregiver (Ellis et al., 2021; Lee et al., 2020). Related recommendations are unravelled in Table 6.

7. Conclusions

While methodologies for the design of inclusive and accessible technologies are gaining momentum (Anon, 2018), few approaches enable ID people to engage with smart-device prototyping (Ellis et al., 2021). This paper presented the novel IoTgoID toolkit for engaging ID people, collaboratively, in smart-thing prototyping, and two workshops with 8 ID people using the toolkit to ideate and rapidly prototype smart things together, for their own environment. The study presented in this paper assessed what features of the toolkit engaged or not participants in designing collaboratively, besides when assistance was required. Their engagement with minimal assistance was highest during laboratory activities, in which the interaction paradigm of IoTgoID enabled them to experience, tangibly, the effects of their design choices. Lessons of general interest were also derived from the study and literature. Further studies are planned to generalise what promotes engagement, focusing on what enhances user independence and reduces or eliminates the need for caregiver assistance. For example, while in the reported study,

Table 4
Recommendations for physical aspects and interactions.

Linearity	Toolkits should maintain a linear progression across levels. In the study of this paper, levels and a linear progression helped participants reach small wins and gain a sense of competence—two relevant goals from the literature (Lechelt et al., 2018).
The right type and number	In line with recommendations from the literature, there needs to be room for free choices and exploration. This turned out to be insufficient in the case of mission cards of IoTgoID; due to their limited availability, participants were at point limited in their choices. At the same time, the number of choices should be carefully balanced, and adequate to the decision-making capabilities of participants. This seems to have been the case for the chosen 36 combos (out of more than 100), each with one input card with a state and one output card with a state. They were generally easy to understand, and so their matching with physical devices. Criteria for selecting them were whether they (C1) were easy to use in combination, (C2) useable by people with reduced manual dexterity, and in case (C3) the states they can be in would be understandable through immediate feedback on the 3D smart things. Instead, in Level 3, the amount and abstract nature of objects that players had to handle confused them (see also lessons for social interactions below).
Tangible abstraction	Abstract concepts should be materialised (Lechelt et al., 2018; Cosentino et al., 2021). Levels 2 and 3 of IoTgoID managed to make abstract concepts and design accessible, e.g., by using: arrows for clearly stirring ID people along prototyping tasks; cards for representing the main components of any smart thing and design choices to take; combo cards for making concrete abstract concepts like states of input and output devices, and how to combine them together feasibly.
Reflections and revisions	In line with Lechelt et al. (2018), the space for reflection and revisions in IoTgoIDwas left open but this choice made it unclear what to use and how to play. Future toolkits should enforce the immediate connection between reflection stimuli and required revisions. Moreover, discussions should be kept short to allow for "small wins" in dialogues, besides in the general game play (Lechelt et al., 2018).
Prototypes vs real things	3D-printed things engaged ID participants in Level 2 of IoTgoID, but they did not aid participants to reflect on smart things in Level 3; reflections became easier when reported back to real physical things participants had experienced with. This is recommended for future toolkits.
Easy-to-manipulate	In line with other findings, also this study stressed that toolkits should provide large surfaces, easily manipulable materials and connectors for ID people (Ellis et al., 2021; Senaratne et al., 2022; Hollinworth et al., 2014).

Table 5
Recommendations for social interactions.

Structured and with stimuli	The social interaction rules were generally clear, except in Level 3 iof IoTgoID. The amount of objects participants had accumulated at that level made it unclear not only how to interact with the game objects but also how to interact with other players. In the future IoTgoID-like toolkits may consider separating clearly the objects that pertain to each level and player, according to the role played in the game, e.g., as game master, speaker or in charge of stimulating reflections.
Balanced roles	Crucially, roles need to be balanced with the competencies of participants. In particular, they should take account of the individual competencies and preferences, leveraging them to promote engagement (Bayor et al., 2021). Furthermore, the caregiver participating in the study of this paper deemed it too complex to require participants to take up the role of designing for others and for unfamiliar environments. Future toolkits, like IoTgoID, may be similarly designed so that players with similar difficulties design for themselves and for their shared facility.

Table 6
Recommendations for independence and agency.

Chatbot	In line with the literature, conversational assistants could be used to further support ID people together with a caregiver (Catania et al., 2019; Xu et al., 2021; Cosentino et al., 2021).
Self exploration	Self-exploration of toolkits and its technology can help in promoting independence and agency. This self-exploration can build on participants' own sense of curiosity (Ellis et al., 2021). Future toolkits could include combo cards that, when scanned, can be explained by a conversational assistant, without the need of a moderator. Furthermore, if inspiration is needed, the conversational assistant can also narrate examples of smart things created by others.
Screenless multi-modal guidance	The literature recommends providing multi-modal guidance to foster the inclusion of diverse participants and leverage different skills (Lee et al., 2020; Senaratne et al., 2022). A conversational assistant, could be a way to accomplish this need without introducing a screen which would generate additional stimuli, creating distractions that could hamper social interactions, as also reported by the caregiver participating in the study, reported in this paper.

the toolkit's instructions were read by caregivers, future versions could provide these instructions through audio recordings or through a conversational agent able to provide explanations when needed (Cosentino et al., 2021). This feature would improve the toolkit's accessibility to individuals with diverse reading proficiency levels, thus further addressing the ID population's variability (World Health Organization, 2021).

CRediT authorship contribution statement

Rosella Gennari: Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Maristella Matera:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization. **Alessandra Melonio:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Marco Mores:** Methodology, Conceptualization. **Diego Morra:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Mehdi Rizvi:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Maristella Matera reports financial support was provided by The Italian Ministry for Universities and Research (MUR). If there are other authors, they 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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