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Design for social digital well-being with young generations: Engage them and make them reflect

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ABSTRACT

Digital well-being traditionally means limiting the effects on individuals of technology abuses. However, in a broader perspective, it can be crucial to consider the pervasiveness of technology, and the effect it can have not only on individuals but also on their peers in the context of diverse everyday-life situations. Within this view, which emphasises the social side of digital well-being, the paper argues the need of educating young generations to participate in the making of technology for a social goal and have a reflective attitude towards technology and its impact on society. It, therefore, presents a design toolkit as a means to (i) engage young generations to become active in design for social digital well-being and, thanks to the exposure to how technology works, (ii) reflect deeply on the pros and cons of technology in use in their everyday life. By presenting the results of a study with 24 high-school pupils and their teachers, the paper discusses how a phygital toolkit, which structures the design process, engages them in the rapid prototyping of their own smart things, and how it acts as a proxy for soliciting their own reflections around technology and social digital well-being.

1. Introduction

People live in an increasingly connected society, and technology plays a vital part in it. Almost everyone uses a smartphone or another smart device (e.g., smartwatch), usually on a daily basis and sometimes simultaneously. This social transformation affects many aspects of everyday life, including how people relate to others and the social environment, besides the way in which people perceive themselves, their needs, and emotions (Sarwar and Soomro, 2013; Gowthami and Kumar, 2016). Such a situation led to concerns related to the so-called digital well-being, namely, related to the influence that technology has on an individual's well-being.

So far, the literature on digital well-being has focused on the effect of technology on individuals, trying to identify digital-life abuses that could create real-life distortions. Recent works (e.g., Vanden Abeele 2020, Büchi 2021) have started reflecting on a broader perspective and describe digital well-being as concerning not only "individuals' effects (e.g., positive emotions), but also domain satisfaction (e.g., one's relationships or job), and overall life satisfaction in a social environment characterised by the constant abundance of digital media use options" (Büchi, 2021). Following this line, this paper suggests that the notion of digital well-being take a step forward, and pose greater emphasis on the impact that technology can have also on society and the diverse everyday situations in which technology can have a role. Digital well-being can be thus considered as an aspect of a broader domain related to the role of technology for social well-being: given the pervasiveness of digital media and mobile connectivity, the responsible usage of technology by individuals can have an impact also on their peers and on different facets of their everyday life.

The attitude towards such a responsible use of technology can be developed if the pros and cons of technology are deeply understood. The role of education can in particular be crucial to instil in the youngest generations the awareness of technology's impact, as well as sensitivity to the responsibility for technology use or misuse. In this respect, it can be beneficial to engage young generations in technology design and promote their reflections through it. To reach this goal, this paper proposes a design toolkit that guides the youngest generations to actively take part in technology design, and to reflect deeply on the pros and cons of technology in use in their everyday life.

Considering the role of education in responsible design, this paper hypothesises that the use of adequate design toolkits can engage young generations in understanding technology and can foster their critical reflections. So far, promoting critical reflections on technology in the

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youngest has been addressed in a very limited manner (Kanafi et al., 2021; Iversen et al., 2018). This is instead a fundamental aspect to consider in education: due to the unprecedented penetration of ICT in every aspect of everyday life, a primary responsibility when teaching Computer Science is to educate the citizens of tomorrow (Di Cosmo, 2006).

To emphasise the technology pervasiveness and the impact that technology can have on the many aspects of everyday life, the focus of the proposed toolkit is on the design of smart things enhanced with the Internet of Things (IoT). This is a novel contribution as the majority of works proposed so far in the digital well-being space have addressed mobile devices, e.g., smartphones. The focus on IoT entails reflections on a wide range of additional challenges, including ubiquitous and connected devices, collection of data about human behaviours in a variety of ways, direct interaction between people and technology in social situations, all aspects that could play a crucial role in generating positive or negative effects on social and individual digital well-being.

1.1. Contribution

In order to promote education to responsible design as a key for pursuing digital social well-being, this paper introduces IoTgo, a phygital toolkit and a related method for designing with end-users, which guides people who are not expert designers, and in particular young generations, to ideate, conceptualise, program, test and reflect on IoT-enhanced smart things.

In line with the phygital concept (Gaggioli, 2017), defined as the use of technology to bridge the physical and the digital domains, the IoTgo toolkit presented in this paper aims at blending digital experiences with physical ones, so as to provide an engaging, reflective experience for young generations. The original IoTgo toolkit was used by different researchers with diverse people: being it modular and open, IoTgo was adapted to cater to varying needs, desiderata and expertise (Gennari et al., 2021b; Gennari and Rizvi, 2021). In particular, for the study reported in this paper, the IoTgo toolkit was significantly changed for enabling high-school students to design for social digital well-being, and to reflect critically along the process on the impact of technology on it. For the first time, this paper illustrates this novel version of the toolkit, which introduces new components for guiding design for social digital well-being and reflections on the ubiquity and connectivity of smart things, besides on social aspects.

By illustrating the results of a study conducted with a class of 24 pupils in their second-last year at their high-school, designing for social digital well-being with IoTgo, the paper assesses whether and how the toolkit engaged pupils in the design technology for social digital well-being, and whether and how it guided them in reflecting on related aspects. The main outcome is that design with the toolkit engaged and solicited critical reflections through design, geared towards social digital well-being. Starting from these results, we discuss how an active role in design can develop pupils' attitudes towards an extended view of digital well-being that also includes their social sphere.

1.2. Outline

The paper is organised as follows. Section 2 discusses the rationale behind research and introduces a novel perspective on the relationship between digital and social well-being. Section 3 introduces the toolkit for the design of IoT-based smart things, with emphasis on components that are relevant for digital social well-being. Sections 4 and 5 describe the study at school and Section 6 discusses its main outcomes. Finally, Section 7 reflects on limitations and lessons for future research work.

2. Rationale and background

In recent years, researchers have started investigating the negative effects that the excessive use of technology can have on people's mental health, especially the negative effects that the usage of smart devices and social networks can have on people's well-being and social relations. Different studies showed how these media can negatively impact attention (Harmon and Mazmanian, 2013; David et al., 2015; Kushlev et al., 2016), mental health (Demirci et al., 2015; Matar Boumosleh and Jaalouk, 2017; Alhassan et al., 2018), and even the sense of connection with others or the surrounding social environment where digital media are omnipresent (Elhai et al., 2016; Dwyer et al., 2018; Richardson et al., 2018).

These and other reflections prompted people to rethink the role technology plays in their everyday lives to the point that even large companies, such as Google and Apple, started taking a stance in favour of well-being (Google, 2022; Apple, 2022). A new concept of well-being emerged, often referred to as *digital well-being*, which refers to the idea of *well-being of the human being within an information society* or, more generally, to the *influence that technologies have on the level of mental and social well-being of the individual* (Burr et al., 2020).

Researchers in academia and industry have studied and developed solutions for promoting this conception of well-being, with special attention on apps or app functions to make users aware of the amount of time spent with smart devices, e.g., accessing social networks. The idea is to support users in regaining control over their time, often suggesting digital-detox programs. For example, the Google Well-being initiative (Google, 2022) is based on the assumption that *getting a better, more detailed understanding of your technology use is the first step towards improving your overall digital well-being*. Some research works then led to the design of a multitude of Digital Self-Control Tools (DSCTs) (Lyngs et al., 2019; Monge Roffarello and De Russis, 2019), conceived to simplify the users' self-monitoring process, by tracking their behaviour and providing feedback for mitigating harmful practices. However, there is yet no definitive evidence that DSCTs are the most effective solutions for the improvement of people's digital well-being. For instance, despite the clear negative health and social aspects related to incorrect use of technologies, there was no clear evidence of the effectiveness in the long run of screen-time apps to correct wrong phone-checking habits (Loid et al., 2020). Similar results were reached in other studies concerning digital-detox interventions (Wilcockson et al., 2019).

It is also important to consider that the proposed DSCTs often focus on the use a specific device, i.e., the smartphone in the majority of cases. Although this could be reasonable due to the significant, ever-increasing diffusion of this device (Poushter et al., 2016), recent research solicited reflections on multi-device usage scenarios, stating that this more articulated dimension is crucial to (i) truly understand what digital well-being is, and (ii) extend its scope, to make it a key concept in the development and usage of future digital technologies.

Other aspects have to be considered. There are studies highlighting that digital devices also affect the social environment (Elhai et al., 2016; Dwyer et al., 2018; Richardson et al., 2018). In Robinson et al. (2015) the authors claim that digital media use is individually beneficial, but socially problematic because its spread tends to intensify social inequalities. Although different facets of digital media seem to affect well-being, Büchi suggests that digital media should be integrated into everyday life in such a way that they enable and support rather than detract from the achievement of personally valued goals (Büchi, 2021).

This debate highlights that DSCTs are not enough, especially because these tools and their underlying approaches totally neglect the advantages that technology might bring in some scenarios, e.g., those involving fragile people for whom technology is an essential element for their own social development (Devito et al., 2019). In these situations, limiting the time spent with smart devices or apps can marginalise people further.

Among the studies that underline the need of rethinking the initial definition of digital well-being (Monge Roffarello and De Russis, 2021; Cecchinato et al., 2019), the proposal by Mariek MP Vanden Abeele discusses factors like balancing positive and negative connectivity effects or the improper medicalisation of digital addicting situations (Vanden Abeele, 2020). Similar to Vanden Abeele, other definitions have been developed putting greater emphasis on the pervasiveness of digital media and mobile connectivity in everyday life. Büchi (2021, p. 4), for instance, describes digital well-being as concerning "individuals' effect (e.g. positive emotions), domain satisfaction (e.g. one's relationships or job), and overall life satisfaction in a social environment characterised by the constant abundance of digital media use options" (Büchi, 2021). According to this view, digital well-being is considered to be a multi-faceted construct not limited to its effects on individuals. It takes on an extended meaning, which goes beyond limiting the adoption of digital media, and moves towards increasing users' awareness of not only the cons of technology but also of the multiple pros that adequate and responsible technology use can bring, e.g., inclusiveness. Digital tools for social inclusion have an enormous potential to address the challenges of the contemporary young generation, but also in this case their use must be guided by the awareness of both their potential and the risks for the well-being of young people (Şerban et al., 2020).

As reported in Şerban et al. (2020) adopting digital technologies to address social inequality is not immediate to achieve, it needs the right mindset that can be shaped starting far before the development of specific tools, as well as more reflection regarding the accessibility of technology and how digital approaches can be made inclusive for young people from all backgrounds. As also argued by De Russis et als (Monge Roffarello and De Russis, 2021), it requires educating people, starting from the youngest, bringing the notion of digital well-being into schools. Designing technology with the younger generation, in particular, and reflecting through design with them can help promote such a critical stance (INTERACT Research Unit of Oulu University, 2021).

However, one aspect to consider in such design activities is engagement so as to motivate young people to learn successfully and empathise with the set design goal. To favour learning success and engagement for all participants, it is necessary to address different senses and to include physical activity, as well as multi-sensory learning (European Union, 2010).

A number of investigations highlight the gains in social and emotional well-being that can be attained through pupils' more active and engaged involvement in school activities, with benefits in areas like improved learning outcomes and experiences, higher satisfaction, as well as stronger relationships and engagement levels (Kuurme and Carlsson, 2011; Coombes et al., 2013).

In line with these assumptions, the work reported in this paper has the ultimate goal of educating younger generations to digital well being, and specifically to social aspects of digital well-being, i.e., to *digital social well-being*. Giving adequate design toolkits to schools is a key factor in achieving the goal of educating the youngest. In recent years, several works proposed toolkits for helping even inexperienced designers conceive smart technologies, and reflect not only on their own needs and on the technology itself but also on ethical, emotional and social aspects related to the development of smart technologies, e.g., (Gennari et al., 2017b, 2021a, 2022b). In the following, the relevant IoT toolkits are described.

2.1. IoT toolkits for design with Young end users

Designing IoT-based smart things with the end users is not simple, especially when the younger generations are involved, e.g., children and teenagers. Many aspects have to be considered, such as understanding how a smart thing interacts or communicates with other smart things.

With the aim of adding physical interactivity to the design of smart things, toolkits usually provide physical-computing cards, usually organised into input and output decks. By using these cards, users can specify interactive behaviours of smart things, and in parallel understand the input/output, event-driven pattern governing such a physical interaction. Focusing on interactivity also enables younger generations to reflect on the use of smart things in realistic situations, and this in turn can promote their role of critical users of technology. To strengthen this aspect, toolkits such as Tiles IoT Inventor toolkit also provide human-action cards representing the way final users can trigger the smart-thing outputs represented by feedback cards (Mora et al., 2017). Likewise, SNaP and COBO also have specific physical-device cards, divided into inputs and outputs, chosen according to the environment and mission (Gennari et al., 2019; Cosentino et al., 2021).

It is also interesting to note that, whereas several toolkits have generic physical-device cards, a few separate them into physical-computing and communication cards, under various names. For example, Tiles IoT Inventor toolkit contains separate cloud cards for data services, such as maps or news information (Mora et al., 2017). The IoT Service Kit has cards for smart-city-related services, e.g., parking data (Brito and Houghton, 2017). In IoT Design Deck, the cloud-computing services are not differentiated from the physical components of smart things, but rather merged with inputs and outputs (Dibitonto et al., 2018).

Toolkits rarely focus on interconnecting different smart things, in a peer-to-peer communication fashion. Instead, they tend to enable specific cloud services (Gennari et al., 2021b). Such communication features, be it cloud computing or peer-to-peer communication, could instead be important to pursue education on social digital well-being. It can help younger designers focus on scenarios that involve multiple devices and, as such, (i) they are more realistic with respect to current digital well-being habits, and (ii) they can stimulate reflections on the privacy and security risks that networking brings (Vigano and Magazzeni, 2020).

Furthermore, although young generations tend to feel confident with smart things, few education initiatives make teens reflect on them critically: promoting reflections on technology in the youngest has been scarcely addressed in the literature (Kanafi et al., 2021; Iversen et al., 2018). Moreover, meaningful reflections turn out to be difficult to elicit from children or teens (Gennari et al., 2021a; Kinnula et al., 2020). To establish an education process for social digital well-being, it is important to foster critical reflections, and provide young users with tools focusing on responsibility in design (Schaber, 2010). This is instead a fundamental aspect to consider in Computer Science education, as it can have an impact on the citizens of tomorrow (Di Cosmo, 2006).

In the literature, there are proposals of playful card-based toolkits for IoT-based smart things with tools for reflection. They usually include motivation cards specifying design goals or objectives. Toolkits such as Tiles IoT toolkit (Mora et al., 2017) use criteria cards to focus on a goal to meet and assess (e.g., sustainability), and mission cards (e.g., "Create a smart thing that motivates people to recycle garbage") to guide users in ideating for a specific objective. IoT Design Deck (Dibitonto et al., 2017) and IoT Design Kit (De Roeck et al., 2019) both include specific cards that ask to reflect on technical or ethical aspects. The goal is to raise designers' awareness of the potential negative consequences of some design choices.

Toolkits, such as SNaP (Gennari et al., 2019) and COBO (Cosentino et al., 2021), provide users with missions related to specific environments, e.g., a park, that help reflect on the ideation of technologies within such environments. They also guide users with digital tools across design, by generating programs from simple ideas of smart things, with two different aims: for relieving them of programming tasks in the case of COBO; for enabling them to start learning programming in the case of SNaP. Despite their attempt to structure the design process also soliciting reflections in design, these toolkits

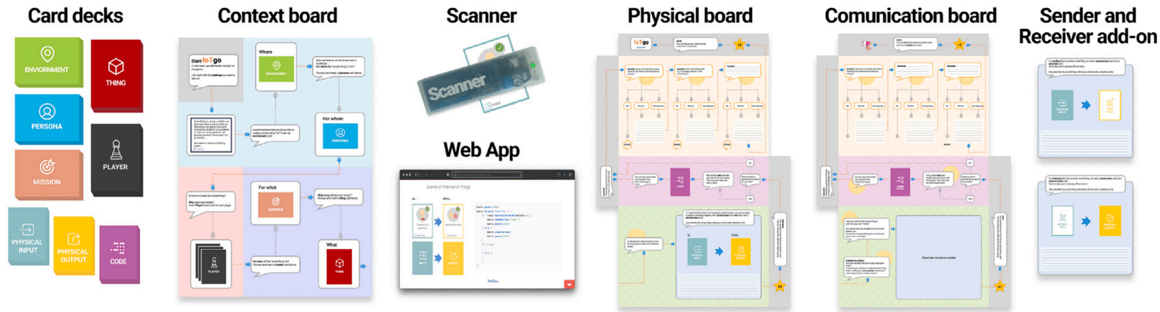


Fig. 1. An overview of the IoTgo toolkit.

do not propose materials and activities for systematically guiding the reflection process.

The study reported in this paper is based on the adoption of the IoTgo toolkit for guiding high-school pupils in the design of IoT-based smart things. As illustrated in the following section, IoTgo covers the entire design process, from the ideation and conceptualisation of the smart thing, to programming the ideas into a working prototype. To engage young people, it blends digital experiences with physical ones and takes a *phygital* form that bridges the physical (e.g., paper-based cards and boards) and the digital (e.g., a digital app guiding smart-thing programming) dimensions (Gaggioli, 2017). The main novelty of IoTgo is the proposal of materials and structured activities for enabling participants' critical reflections. The next section in particular illustrates how the IoTgo toolkit promotes engagement and reflections in design for social digital well-being.

3. The IoTgo Toolkit

IoTgo is a phygital toolkit for people who are not seasoned designers or programmers. Its card-based tools help them explore what smart things are meant for, that is, a context with a challenging situation, persona and goals they have, translated into missions. Moreover, the card-based tools guide them to make things smart by means of physical inputs (e.g., touch sensors, buttons) and outputs (e.g., LEDs, speakers), and by interconnecting them via peer-to-peer IoT communication (*communication* henceforth). The IoTgo toolkit includes ad-hoc hardware and software, namely, a scanner and a web app for reading cards and automatically generating programs for smart things.

Over time, IoTgo evolved through usages by diverse researchers with different people, such as pupils of different school levels, teachers, university students of art and design and of applied linguistics, besides professional artists (Gennari et al., 2021b; Gennari and Rizvi, 2021). In particular, for the study of this paper, the IoTgo toolkit was significantly changed and adapted for engaging high-school pupils in design for social digital well-being, and enabling them to reflect on the technology under design and how it can affect society.

The tools of the current version of IoTgo toolkit, relevant for the study of this paper, are described in the following sub-sections in more details, also highlighting their relevance to social digital well-being. Fig. 1 offers a bird's eye view of the complete IoTgo toolkit.

3.1. Paper-based tools: Boards with cards and reflection lenses

The IoTgo toolkit has boards with reflection lenses and cards to play. The study reported in the paper used the following three boards: the *context board*, *physical board* and the *communication board*. They are illustrated in Figs. 3, 4, 6, 7, 9 and 10. Table 1 recaps them and which task of the design process they are meant for. Boards are modularised into distinct levels, which are gradually revealed by unfolding the boards themselves, so as to guide users seamlessly through empathising with the design context, ideating and conceptualising a smart thing along given patterns, and reflecting on it with playing cards, as explained below.

Table 1
IoTgo boards, the matching design tasks and cards.

Board	Design task	Cards
Context	Empathising with the context, starting ideating and conceptualising	Challenge, environment, persona, player, mission, thing
Physical	Ideating and conceptualising a smart thing with physical inputs/outputs, programming and testing it, reflecting on it	Input and output
Communication	Ideating and conceptualising the communication between smart things, programming and testing it, reflecting on it	Input or output, with the sender/receiver communication add-on

Table 2
Mission cards used for the study, concerning social digital well-being.

Mission cards:		
to include to create relationships	to trigger emotions to empower	to behave responsibly to understand each other

3.1.1. Context board

The context board of the IoTgo toolkit focuses on understanding, empathising with and specifying the context in which the smart thing is being designed. It comes with placeholders for the challenge, environment, player, persona, mission, and thing cards, described in the following.

Challenge. A challenge card narrates a story concerning a context and it ends with an open challenge, which sets the design goal. Fig. 2 illustrates the challenge card used for the study described in this paper. The story related to social digital well-being and how technology can increase pupils' quality of life in the specific school context and in relation to aspects such as social inclusion and reducing existing social gaps. It was about teens who do not socially interact at school and the challenge asked to tackle the goal of using technology for remedying it:

> *Something's wrong: we quarrel, we do not say 'hello', we feel lonely and spend more and more time withdrawn or with our noses glued to our mobile phones. And we do not have much fun together at school. Something has to be done. We need to create something smart*!...

This card should also help create empathy (Dam and Siang, 2020), in relation to persona and mission cards described below.

Persona. Persona cards represent types of people for whom smart things are meant. Examples are an international student, a teacher, a student, a person with special needs, a parent. See Fig. 2 for an example persona card (i.e., international student).

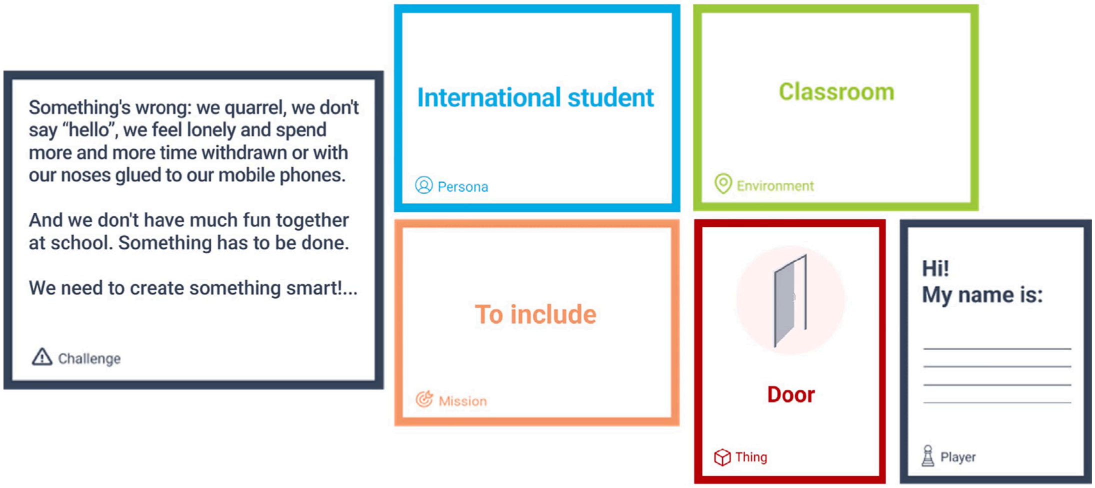


Fig. 2. Examples of challenge, environment, persona, mission, thing, and player cards for the context board of IoTgo (translated in English from Italian).

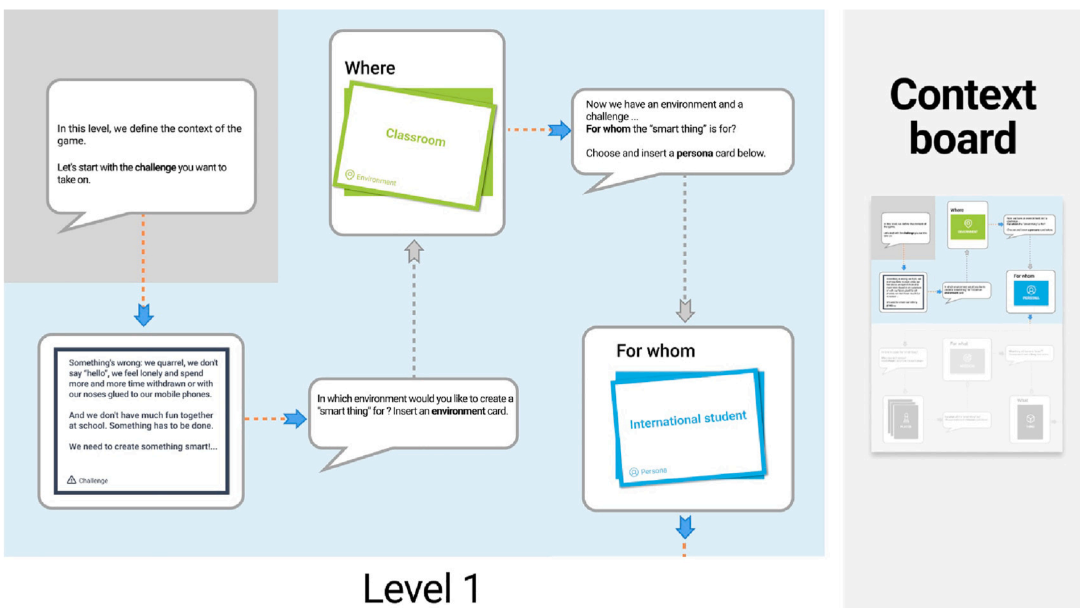


Fig. 3. A filled-in context board of the IoTgo toolkit. In focus: the first level of the board (upper part) showing the chosen challenge, environment and persona cards.

Mission. The deck of mission cards crucially changes according to the context and goal set by the challenge card. Missions for this study are listed in Table 2. They all target the social digital well-being design goal of the challenge card (e.g., using technology for improving social interaction and inclusion). See Fig. 2 for an example mission card (i.e., to include).

Player. Player cards represent the users of the IoTgo toolkit.

Environment. Environment cards represent locations where a smart thing is to be located. Examples for this paper are the classroom, school library, garden. See Fig. 2 for an example environment card (i.e., classroom).

Thing. Thing cards represent actual things, present within the environment, which are to be made smart. Examples are a door, a chair, a backpack. See Fig. 2 for an example of a thing card (i.e., door).

Levels. Arrows and text on the board guide towards empathising with the design context and starting to ideate and conceptualise the thing to be made smart for it with the aforementioned cards. The board is modularised into two levels, illustrated in Figs. 3 and 4.

The first level introduces the story and the design goal (challenge), besides where design takes place (environment) and for whom (persona).

The second level asks the player to identify themselves (player) and specify further the design context, deciding on a mission for the design goal (mission), and the thing to be made smart in the chosen environment (thing).

3.1.2. Physical board

The physical board is divided into three levels which use the following cards.

Input and output. Two decks represent the physical components for making things smart. These are divided into input and output cards. Each such card represents an input or an output, with a state it can be in. The majority of states are simplified as Boolean, e.g., "on" or "off", "up" or "down". For example for a input device such as a button, there are two input cards, one per state: the "button is pressed", and the "button is not pressed". In case a card represents an analogue input or output device, then a threshold is set according to the chosen context

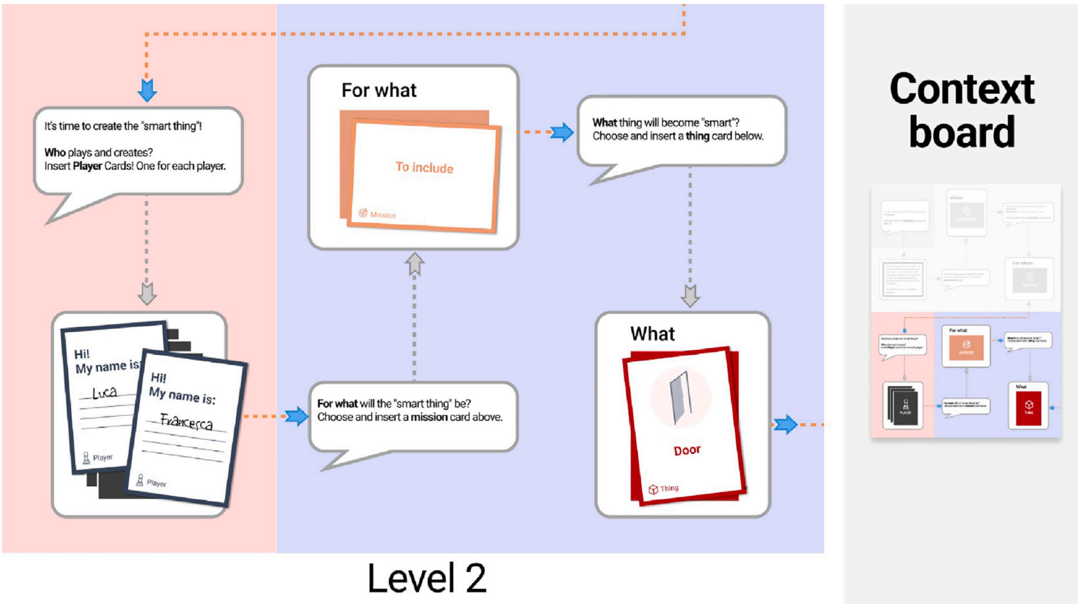


Fig. 4. A filled-in context board of the IoTgo toolkit. In focus: the second level of the board (lower part) showing the player, mission and thing cards.

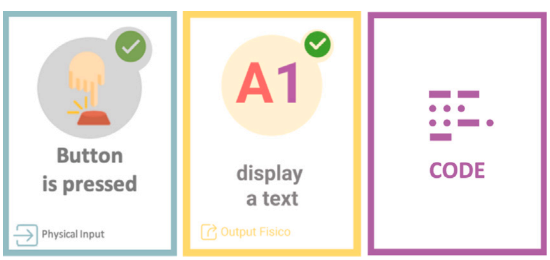


Fig. 5. Example of input, output and code cards for the physical and communication boards of IoTgo.

(e.g., high or low) and two states are created accordingly. For instance, for an analogue input device such as a temperature sensor, there are two cards for two states: the temperature is higher than 20 degrees Celsius, the temperature is not higher than this threshold. An example of an output card is for displaying text, with two states: "display a text", "stop displaying text". See Fig. 5 for examples of input (i.e., button is pressed) and output cards (i.e., display a text).

Code. Code cards are used for triggering the automated generation of programs, according to a given pattern. See Fig. 5 for an example of a code card.

Levels. The first level of the physical board asks to decompose and conceptualise a smart-thing idea by means of input and output cards. A box asks to describe with words the idea, in a specific format, which reminds of an infinite loop and a conditional: whenever something is detected (input) then there is a reaction (output). See Fig. 6(b).

The second level of the physical board guides towards the automated generation of a JavaScript program by means of software and hardware tools of IoTgo, described below. The generated programs all follow a similar pattern: what changes depends on the chosen cards in the board, especially input and output cards. The generation is activated by playing the code card. Such an automated generation of ready-to-use programs is meant to scaffold a recurring pattern for smart-thing design, to abstract away low-level programming choices and frees time for reflecting on such smart things at a higher level. See Fig. 6(a).

Table 3
Reflection lenses and questions printed on the physical board.

Lens	Question
Relevance:	Does the description of your idea make sense for the selected mission and persona?
Safety:	Is your idea safe or could it physically harm anyone/anything?

The third level of the physical board has two printed reflection lenses, with scaffolding questions about the physical nature of smart things, described in Table 3. This level of the board also contains an open reflection lens, with the option to add a reflection question and answer. See Fig. 7. If needed, pupils can refer to cookbooks, which contain hints for scaffolding reflections.

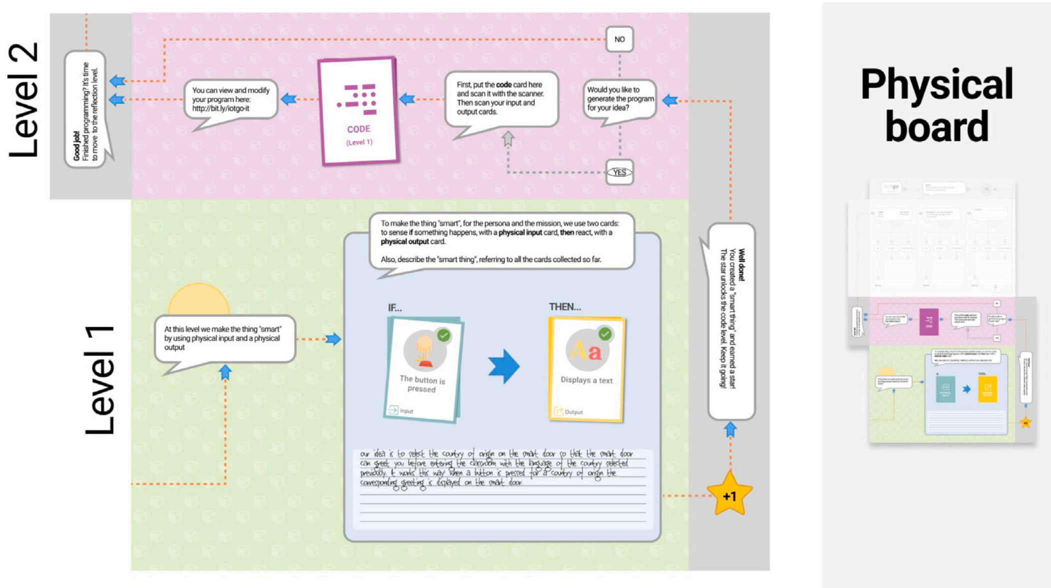
3.1.3. Communication board

The communication board can be added next to the physical board. It helps understand and conceptualise an idea concerning IoT peer-to-peer communication between two smart things. See Fig. 9.

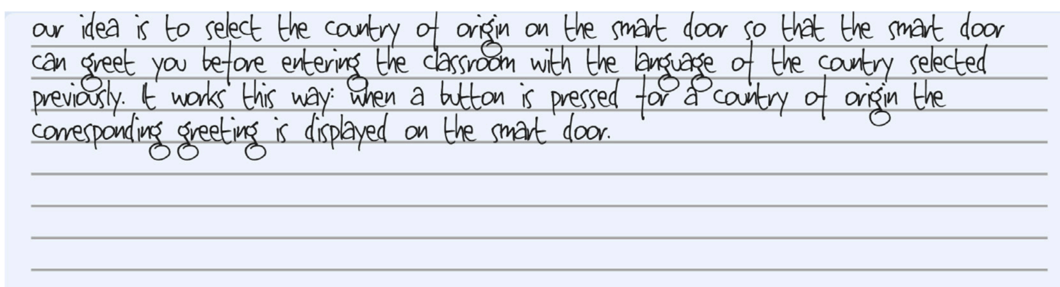
In the first level, depending on whether a smart thing is a sender or receiver, a corresponding communication add-on is added to the board. See Fig. 8 for examples of these communication add-ons. An add-on asks the sender to add an input card and the receiver to add an output card. Again, it invites to describe the communication in words in a specific format, which reminds of an infinite loop and a conditional: for sender, whenever something is detected (input) then data is sent (communication); for receiver, whenever data is received (communication) then there is a reaction (output).

The second level of the communication board guides towards the automated generation of a JavaScript program by means of software and hardware tools of IoTgo, described below. Again, the automated generation is triggered by means of the code card and is meant to scaffold a recurring pattern for the communication among smart-things, abstract away low-level programming details and free time for reflections.

Similar to the physical board, the third level of the communication board also contains lenses for reflecting on the smart things, in relation to data they exchange. The reflection lens and question printed on the board is in Table 4.



(a) A filled-in physical board of the IoTgo toolkit. In focus: the first and second level of the board (lower part) for ideating and conceptualising a smart thing with physical inputs and outputs and for programming it.



(b) The zoomed-in description of the idea reported by a pupil, from a filled-in physical board (translated in English from Italian).

Fig. 6. (a) the first and second level of the physical board; (b) zoomed-in description of the idea.

Table 4
Reflection lens and question printed on the communication board.

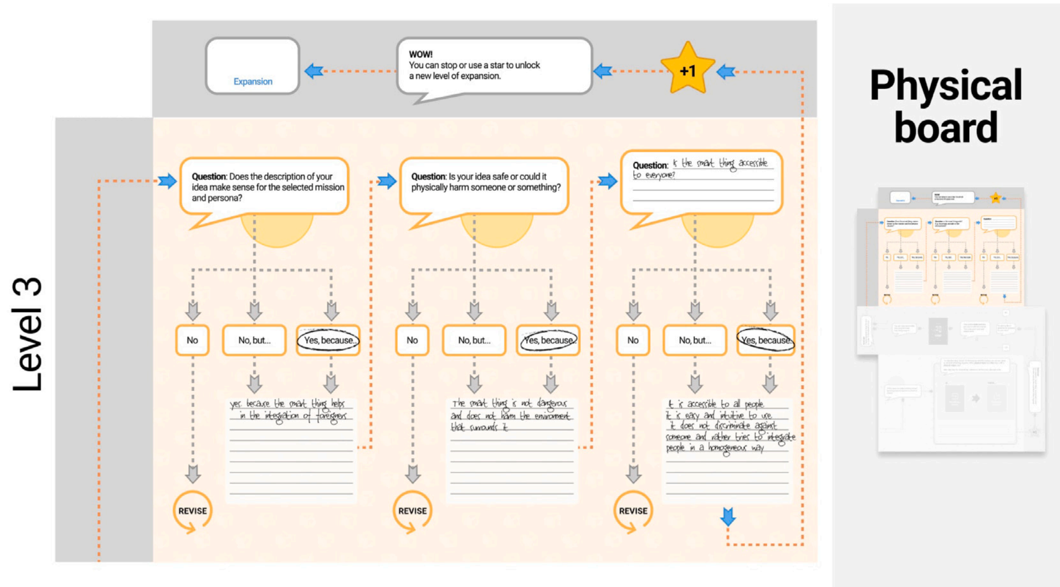
Lens	Question
Relevance:	does your smart thing idea, once augmented with communication abilities, make sense for the chosen mission and persona?

The board also contains two open reflection lenses, where questions and answers can be added. Also in this case, pupils have cookbooks, with relevant hints for scaffolding reflections.

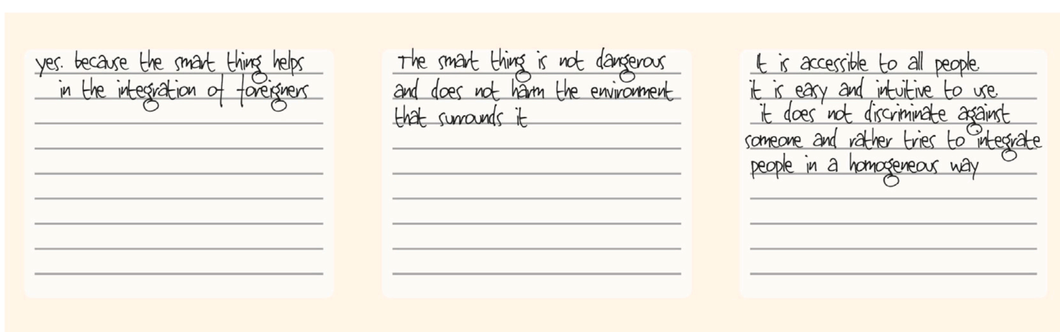
3.2. Hardware and software tools

The IoTgo toolkit is meant for non-seasoned programmers. Therefore, it also includes tools for supporting the programming of smart-thing ideas geared towards a specific design challenge and with recurring, good programming patterns, in line with the approach to purpose-based programming, recently advocated by Cunningham (Cunningham, 2020). Therein she argues that programming for a purpose is relevant for such users, and that programming patterns with a goal (termed “programming plans”) are adequate for them. Whereas the physical tools of IoTgo help conceptualise an idea with such patterns, the digital tools of IoTgo automatically generate and help evolve programs, with patterns for making a smart thing interact through physical devices and communicate with another. Such an approach reduces the burden of creating working, bug-free programs, freeing time for reflection on the design of such smart things for the goal at hand.

The tools are of two types: a physical scanner for IoTgo cards and a companion web app. See Fig. 11. They automatically generate JavaScript programs from the cards placed on the IoTgo boards, especially for input and output. In fact, each input and output card represents a chunk of code which can be directly used to construct a working program for the smart thing. The generated programs are in JavaScript for the study reported in this paper, embedded in Makecode and for Micro:bit micro-controllers. As the IoTgo toolkit aims to cater for varying needs and expertise in other languages than JavaScript, the Makecode’s block based program as well as Python version of the program are also available. Furthermore, there is also an online version of the IoTgo toolkit, its companion web-app, which enables its users to rapidly select different input and output combinations and generate matching programs, even without a physical scanner.



(a) A filled-in level 3 of the physical board of the IoTgo toolkit for reflecting through lenses and questions related to physical aspects.



(b) Answers to the reflection lenses, zoomed-in (translated in English from Italian).

Fig. 7. (a) The third level of the physical board for reflecting; (b) the answers to the reflections lenses, zoomed-in.

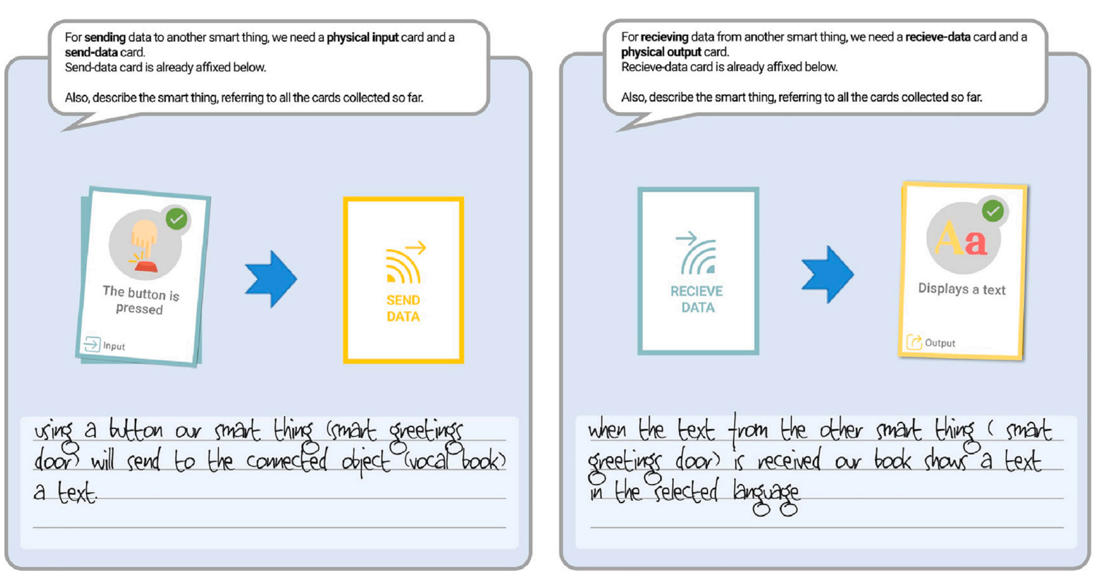


Fig. 8. Examples of the sender (left) and receiver (right) communication add-ons for the communication board of the IoTgo toolkit (translated in English from Italian).

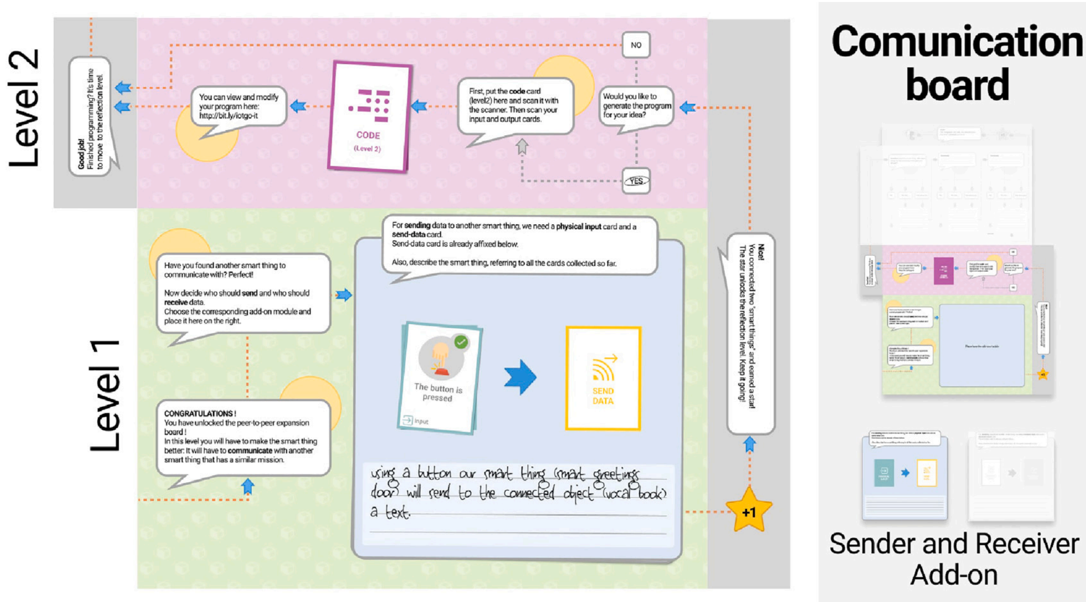


Fig. 9. A filled-in communication board of the IoTgo toolkit. In focus: the first level of the board for ideating and conceptualising the communication between smart things (lower part) by using the sender and receiver add-on, and the second level for programming it (upper part).

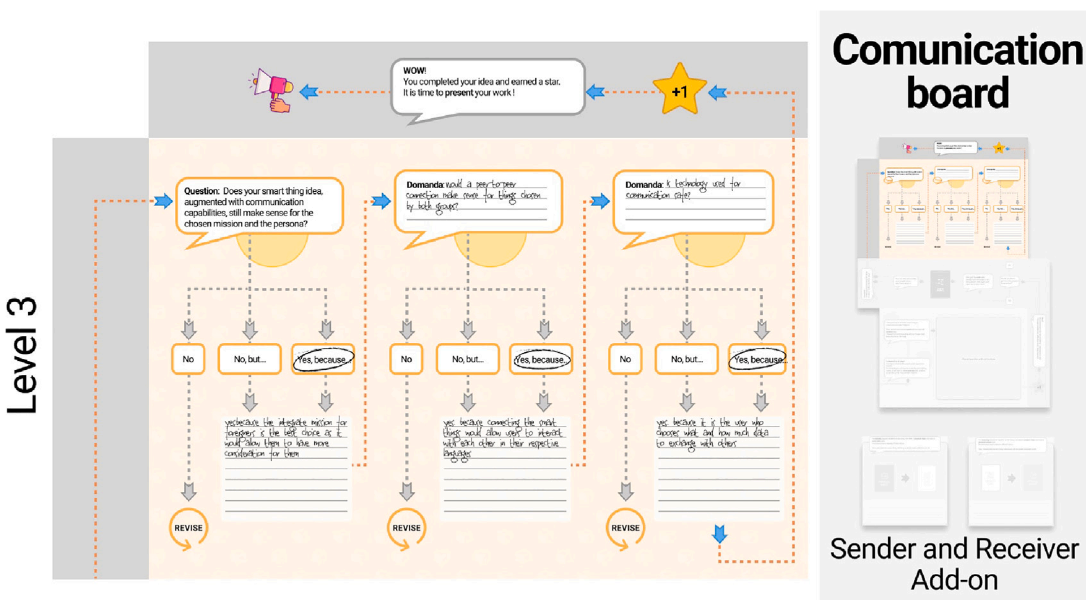


Fig. 10. A filled-in communication board of the IoTgo toolkit. In focus: the upper part of the board for reflecting through lenses and questions related to data exchanged during communication.

4. Study design

In November 2021, an activity based on the use of the IoTgo toolkit for designing smart things was organised with a class at a technical high-school. This was one of a series of initiatives that the school intended to undertake to engage and get the younger generation reflecting about social responsibility through the design of computing artefacts. The activity focused on the design of smart things, in relation to social digital well-being. This goal was conceived through brainstorming sessions held with a pool of school teachers, which led to identifying social inclusion as the main theme of the activity, given the relevance of this factor for increasing pupils' quality of life at school (European Union, 2010; Panesi et al., 2020). The discussion with the teachers revolved around the impact that digital technologies can have on reducing existing social gaps and promoting social inclusion (e.g., in relation to disability, immigrant background, and socio-economic disadvantages), and the resulting benefits on pupils' quality of life. Often, the discussion touched on recurrent situations occurring daily at school and concerning obstacles to physical presence, active participation, and attainment for all. In line with recent findings presented in the literature (e.g., Panesi et al. (2020)), the teachers thus identified the study as an opportunity to challenge their pupils to conceive technology with an impact on social inclusion at school—and more specifically, within their class—which could, in turn, make them recognise and reflect on the effect that the proper use of technology can have on social well-being in general (Şerban et al., 2020).

Based on the emerged insights, we, therefore, planned a design activity for investigating whether and how a toolkit, structuring both the design process and reflections on pervasive smart things, engages pupils in the *design of technology for social digital well-being*, and fosters

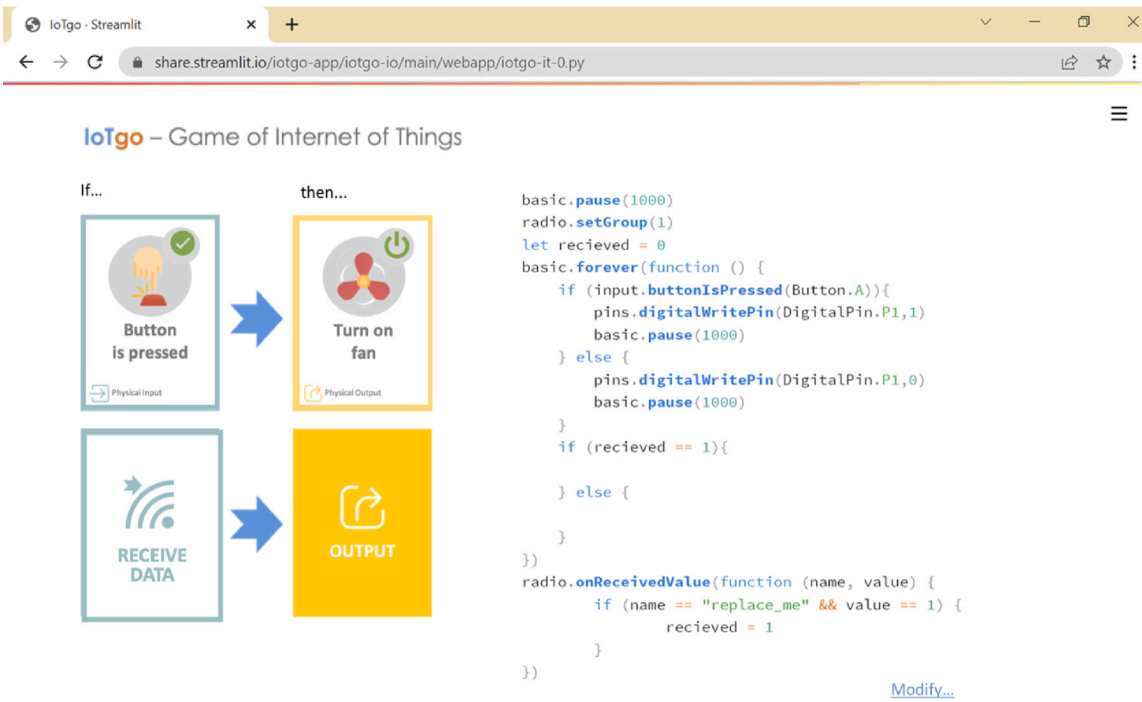


Fig. 11. The IoTgo companion web-app, with selected input and output cards on the left, and the generated JavaScript code on the right.

their *critical stance on the impact* that technological devices can have on society. The research questions are based on literature findings, which show how engagement correlates to learning of technology design (Gennari et al., 2017a; Melonio et al., 2020), and how a structure can help reflect on technology, but that meaningful reflections are difficult to elicit from children or teens (Gennari et al., 2021a; Kinnula et al., 2020).

The purpose of the research led to two sets of research questions. The first set is related to *engagement in design for social digital well-being*:

R1a. Do pupils engage in design for social digital well-being?
R1b. What engages or disengages them?

The second set is related to *reflections in design for social digital well-being*:

R2a. Do pupils reflect in design for social digital well-being?
R2b. What do they reflect on, across design?

4.1. Participants, setting, and ethics

Pupils. The study involved a class of 24, 17–18 year-olds of the second-last year of a technical high-school. They had already intermediate knowledge of Computer Science, as well as programming languages. Specifically, they had already studied JavaScript (the programming language used in the study) for one year and a half at school, within their Computer Science classes, but not with any focus on IoT or smart things. All of the pupils and their parents provided informed consent prior to their participation. Moreover, the Politecnico di Milano data-protection office granted researchers approval concerning the study protocol. Post-study data processing was undertaken anonymously to meet data protection requirements and regulations of Politecnico di Milano and Free University of Bozen-Bolzano.

Researchers. Three university researchers were present during the entire study: one acted as a moderator and a technical facilitator, available for the pupils when they needed help, especially in relation to technical aspects (e.g., hardware issues); the two others acted as observers, managing the protocol and data collection.

Teachers. During the study, the Computer Science teacher and one teaching assistant, whose role in the school is also to support pupils with learning disabilities, also participated in the activity but kept themselves in the background and mainly acted as facilitators for the communication between pupils and researchers. This setup gave space for the researchers to observe the activities and take notes during the entire duration of the study.

Settings. The study was organised over three days in November 2021 and was held in the computer room of the school, during the school class schedule. Pupils worked in pairs and then in 4-member groups. Each pair was provided with an IoTgo toolkit, a laptop computer, and a micro:bit board.

4.2. Procedure and material

The study started from an exploration stage (Day 0) and continued with stages for ideation, programming, and reflection for designing smart things (Day 1), and for making smart things communicate (Day 2). All the tasks the students worked on in the three days are outlined in Table 5. The tasks relevant to the data collection are the ones tackled on Day 1 and Day 2.

4.2.1. Day 0: Exploration

Day 0 focused on preparatory activities to deepen the design theme, learn how to use the IoTgo toolkit, and customise it by co-designing new material.

D0Task1: Exploring. In the morning, pupils explored and became familiar with the goal and the material of their design for social digital well-being. Besides giving a short introduction of the activities planned for the three days, a researcher, supported by the class teachers, introduced to pupils the topics and concepts related to digital well-being. The researcher illustrated what Digital Self-Control Tools (DSCTs) can help with, and reported examples of the use of such tools, as well as their pros and cons in different contexts. The researchers then expanded the discussion on the relationship between technology and well-being, to highlight the importance of not only controlling technology use but also understanding how properly-designed technology can encourage

Table 5
The organisation of the study per day (D0, D1, D2): date and duration, the aims, the code of the tasks, and the outcomes.

Day 0 (D0): Exploration	Day 1 (D1): Smart-thing design	Day 2 (D2): Communication
15 November 11:15–14:30	17 November 8:00–14:00	18 November 8:00–15:00
D0 Aim	D1 Aim	D2 Aim
Familiarise with the goal of the study and explore the material	Design a smart thing (one per pair)	Design the communication between two smart things already designed in D1 (in groups of two pairs)
D0 Tasks	D1 Tasks	D2 Tasks
D0Task1: Exploring D0Task2: Co-designing	D1Task1: Ideating D1Task2: Programming D1Task3: Reflecting D1Task4: Revising	D2Task1: Ideating D2Task2: Programming D2Task3: Reflecting D2Task4: Revising
D0 Outcome	D1 Outcome	D2 Outcome
Customised cards for the context board: environment, thing, and persona cards	Filled context and physical boards and a running smart thing per pair	Filled communication boards and connected smart things per group.

and support other dimensions of life quality, in particular social inclusion. By means of several concrete examples, the researcher presented stories and related challenges that can be solved with smart things. The focus on social inclusion thus shifted the attention to the social aspects of digital well-being.

Next, pupils were divided into pairs and invited to explore the design material, under the guidance of a researcher, who was moderating the task: IoTgo cards and boards, micro:bit input and output devices, and the JavaScript programming environment for micro:bit. Finally, pupils were challenged to recognise input and output cards and to match them to micro:bit input or output devices and to JavaScript programming constructs.

D0Task2: Co-designing. In the afternoon, the pupils worked on the co-design task to customise the toolkit material, which was mainly moderated by the teachers assisted by a researcher. The teachers presented the school as the setting in which to contextualise the design and reflect on aspects of digital well-being and social inclusion. Therefore, they asked pupils to identify different environments in their school where social inclusion could be improved. Teachers wrote them on the interactive whiteboard and, with the help of the pupils, clustered similar ones. Next, teachers asked pupils to imagine different things that are present in the chosen environments and that had the potential to become smart. Researchers made sure the things would not be already smart, such as a smart lamp or a watch. Teachers wrote things identified by pupils on the whiteboard and then clustered similar ones. The same process was repeated for personas: pupils listed the types of people who are typically in the school and might interact with and benefit from the chosen things.

At the end of the day, the researchers created the environment, thing, and persona cards that had emerged from the toolkit customisation activities.

4.2.2. Day 1: Ideating, programming and reflecting for a smart thing

On Day 1, pupils mainly worked in pairs to design a smart thing (one per pair) by using cards and boards of the IoTgo toolkit.

D1Task0: Empathising. As a starting point of the design process, pupils read the challenge card reporting the story setting the design goal. See Fig. 2. The story aimed at immersing pupils in the design context by reminding them of the concepts of social digital well-being introduced on Day 0. Afterwards, six related missions, chosen by the teachers with researchers, were introduced to pupils: *"to include"*; *"to trigger emotions"*; *"to behave responsibly"*; make responsible *"to create relationships"*; *"to empower"*; *"to understand each other"*. See Table 2.

Pupils were then split into 12 pairs (as in Day 0) and introduced to smart-thing design with the IoTgo toolkit by the researcher acting as moderator. Researchers assigned randomly the 6 missions to the pairs so that two pairs shared the same mission. The two pairs with the same mission would have formed a group for working together during the following activities. In total, there were 12 pairs and 6 groups.

D1Task1: Ideating. Pupils, in pairs, used the IoTgo toolkit to choose their location, persona, and thing to make smart.

D1Task2: Programming. Pupils chose the input and output cards, then they used the IoTgo toolkit to generate a program for their smart-thing idea and thus were able to test it.

D1Task3: Reflecting. The pairs sharing the same mission joined into one single group to reflect on their smart things: one pair presented the conceived idea and the program, and the other commented on it by using the reflection clues of the IoTgo toolkit; then the pairs swapped the roles.

D1Task4: Revising. Pupils elaborated in pairs on their ideas and programs, according to the reflections of the previous task and what teachers and researchers had explained in relation to smart-thing programming and social digital well-being.

At the end of Day 1, each pair designed a smart thing with IoTgo. Fig. 12 shows the outcomes, task by task, of a smart thing designed by a pair of pupils.

The final idea transcribed on the IoTgo board was:

> *In the school yard there is a smart bench that offers/shows quizzes to students sitting on it. Depending on the quiz answer, the bench alerts the students of another bench where they can find other students with similar interests to socialise with.*

This idea came out through the different steps outlined above that revolved around the selection, in D1Task1, of *"schoolyard"* as a location card, *"student"* as a persona card, *"to include"* as a mission card, and *"the bench"* as the thing to be made smart. In D1Task2 the pair had then chosen the *"button"* as the physical-input card and *"show a text"* as the physical-output card. For the reflection stage, the pupils used two reflection lenses proposed by IoTgo but were also able to add one reflection on their own, related to energy consumption: *"Does the smart thing need to be recharged?"*

Interviews. At the end of Day 1 researchers interviewed the teachers in relation to the engagement of pupils during the day's activities as well as the reflections pupils conducted.

4.2.3. Day 2: Ideating, reflecting and programming for communication between smart things

On Day 2 pupils worked in groups formed by the two pairs sharing the same mission. The aim of joining the pairs was to design the communication between the two smart things ideated and generated on Day 1. Therefore, at the start of Day 2, pupils were introduced to peer-to-peer communication and how to enable it between their smart things with IoTgo. Besides introducing technical concepts, this activity was proposed as a means to pursue interesting effects on reflection. On one side, it helped pupils focus on realistic scenarios, similar to current digital-enhanced habits and situations, where teens are surrounded by multiple interconnected devices. On the other side, the smart-thing connectivity could stimulate reflections on aspects generated by data processing and sharing, like privacy and security risks. Hence this activity would allow pupils to extend their initial ideas into more complex and complete artefacts, which could trigger interesting reflections while designing for social digital well-being.

Afterwards, the pupils worked on 4 tasks focusing that followed the same steps as Day 1.

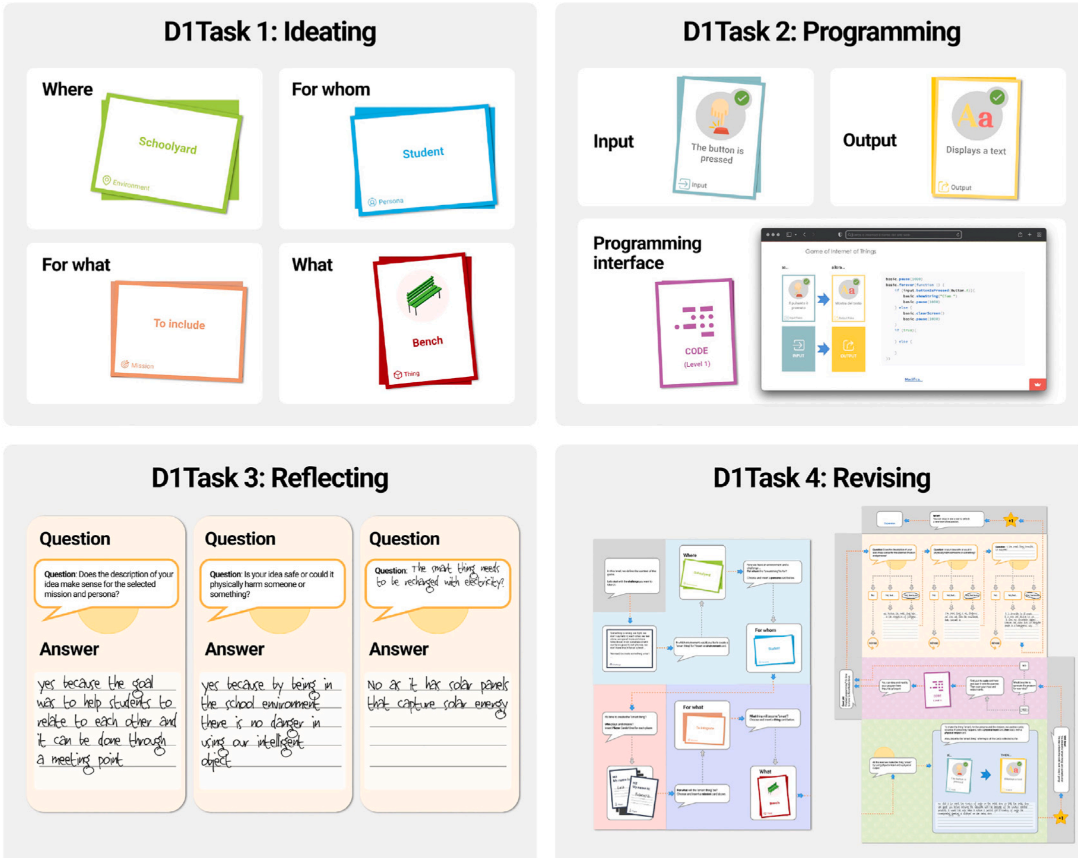


Fig. 12. The outcomes, task by task, of a smart thing designed with the IoTgo toolkit during Day 1 by one pair of pupils.

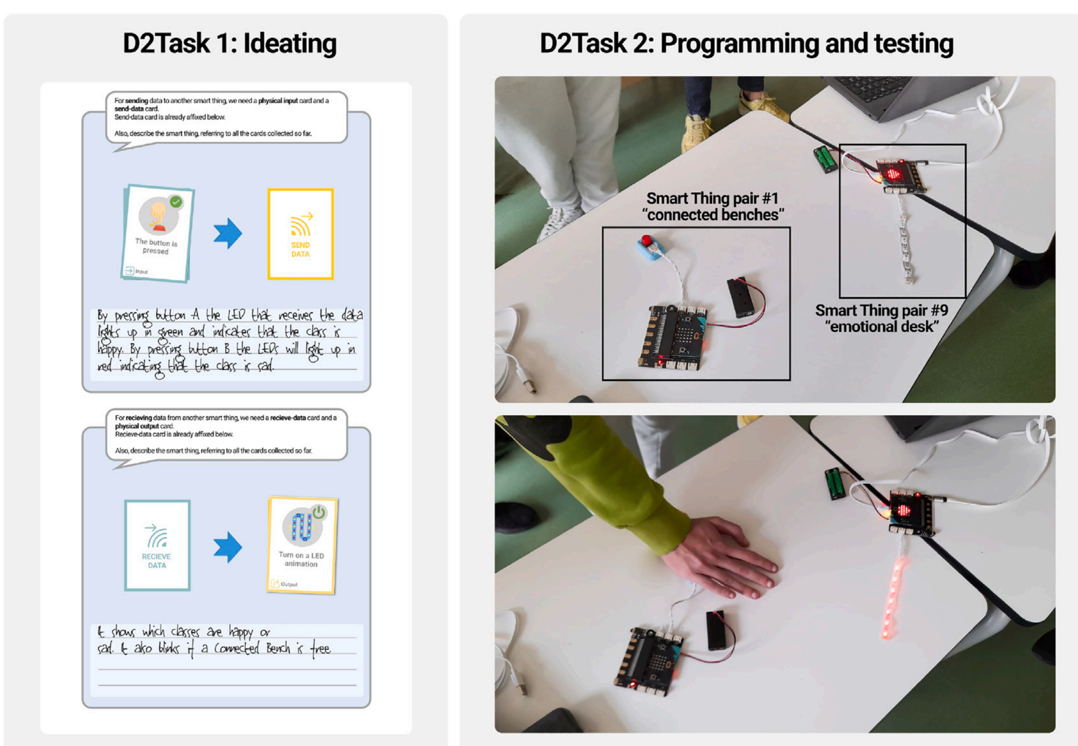


Fig. 13. On the left the outcomes of D2Task1: the two add-ons of the group, one per pair. On the right the pupils testing the communication between their smart things, after programming them with the IoTgo toolkit in D2Task2.

Table 6
Data measured and related research questions linked to the sample source, data collection instrument, and data analysis approach.

Data measured	Source	Instrument	Analysis
Engagement: R1a, R1b	Day 2: 22 pupils	NPS questionnaire (Hamilton et al., 2014)	NPS score Thematic analysis (Braun and Clarke, 2006)
	Day 1: 22 pupils Day 2: 24 pupils	Observations (BROMP (Bonani et al., 2021)) Notes	BROMP protocol Thematic analysis
	2 teachers	Interview with teachers	Thematic analysis
Reflections: R1a, R1b	Day 2: 22 pupils	Questionnaire	Thematic analysis
	Day 1: 22 pupils Day 2: 24 pupils	Reflection lenses	Thematic analysis
	2 teachers	Interview with teachers	Thematic analysis

D2Task1: Ideating. In groups, pupils ideated and conceptualised their peer-to-peer communication with the IoTgo toolkit.

D2Task2: Programming. In groups, pupils programmed and tested the communication with IoTgo. Fig. 13 illustrates a group of pupils testing the communication between their smart things, after programming it with the IoTgo toolkit.

D2Task3: Reflecting. Thanks to the IoTgo toolkit's cues, the pupils in groups reflected all together on their smart-thing ideas and their communication.

D2Task4: Revising. Pupils elaborated on their ideas and programs, firstly with the IoTgo toolkit and secondly without it, according to the reflections coming from the previous task and what teachers had said in relation to peer-to-peer communication. At the end of Day 2, each group had designed (i.e., ideated, programmed, reflected on, and revised) the communication between the two smart things designed on Day 1. Fig. 13 illustrates the outcomes of Day 2. Table A.10 in the Appendix reports examples of the smart things generated on Day 1 and inter-connected on Day 2.

Questionnaire and interviews. Finally, pupils were administered the questionnaires for engagement and for reflections related to the missions they had chosen for their design. Again, at the end of the day, the researchers interviewed the teachers.

4.3. Data collection, measures and analysis

The study adopted a mixed-method research design with different data collection instruments, summarised in Table 6; qualitative data were used to explain and contextualise quantitative findings (Ishtiaq, 2019). As discussed in the following, data were gathered from different sources in relation to the two groups of research questions, centred around *engagement* and *reflections* through design for social digital well-being.

4.3.1. Engagement

Questionnaire. The Net-Promote-score (NPS) questionnaire was administered after the IoTgo experience to investigate pupils' engagement with the toolkit. NPS is typically used to measure, on a scale between 0 and 10, or 0 to 5, how likely users would recommend an experience or product to a friend or a colleague (Hamilton et al., 2014). Past studies adopted NPS for assessing students' engagement (Matchett, 2022; Kara et al., 2022).

The questionnaire contained a single closed-format question: "How likely are you to recommend this experience to other peers", with a 5-value Likert scale, plus an open-ended question that asked pupils to freely comment on the reasons for their answer. The resulting score of the single question is an absolute number between −100 and +100, calculated as the difference between the percentage of promoters and detractors. In general, a positive score is considered good while a score over 50 is excellent. We used it to obtain a single value as a summary of the overall pupils' engagement in the experience and to answer **R1**a.

In relation to **R1**b, two researchers conducted an inductive thematic analysis of all pupils' answers to the open-ended question so as to define categories of reasons for engagement (answers by promoters) and disengagement (answers by detractors) (Braun and Clarke, 2006; Fereday and Muir-Cochrane, 2006). For analysing the data, researchers adopted the six-step iterative process by Braun and Clarke (2006): familiarisation with the data, coding, generating themes, reviewing themes, defining and naming themes, and finally writing up.

Observed task-engagement behaviours. Data concerning engagement were collected through the observation of pupils' behaviours by the two researchers in class. They tracked data in diaries, in the form of both codes and notes, based on the Baker–Rodrigo–Ocumpaugh Monitoring Protocol (BROMP) 2.0 (Ocumpaugh, 2015).

BROMP is a protocol for observing behaviours and affective states in learning with technology, which is suitable for analysing engagement in tasks, as demonstrated by prior research across grade levels in schools, e.g., (Ocumpaugh, 2015; Godwin et al., 2021). Since this study observed pupils working in group, it adopted the BROMP-based coding scheme for group-task behaviours, employed in field studies by Bonani et al. (2021):

- on-task indicators, related to collaborative behaviours (e.g.,: "pupils discuss together an idea"), or individual behaviours (e.g.: "pupils work in silence, each one separately on programming");
- off-task indicators, related to pro-social or asocial behaviours indicators, such as "pupils play with a paper-ball" or "pupils play with their smartphones individually".

In the reported study, researchers used a momentary-time sampling scan strategy, and observed for each task, at a given time, all the pupils present in the classroom, either a pupil or a group of pupils (sometimes the whole class). Following the aforementioned protocol, they annotated the presence of behaviours of interest as they occurred; besides coding behaviours systematically, they also wrote companion qualitative observations, i.e., notes. Observers used diaries. As shown in Fig. 14, the first page of a researcher's diary shows the visual arrangement of the working stations of pupils in the classroom. The subsequent pages are reserved for engagement observations, divided per day and task: an area is for coding behaviours, another is for notes. Diaries were compared at the end of each task. Such data were processed to answer **R1**b.

Interview. One of the researchers, who had not been in class with teachers and pupils, interviewed the teachers during and at the end of the intervention. Data were recorded, then transcribed and later thematically analysed in terms of reasons for engagement and disengagement, for triangulating the other engagement data analyses in relation to **R1**b.

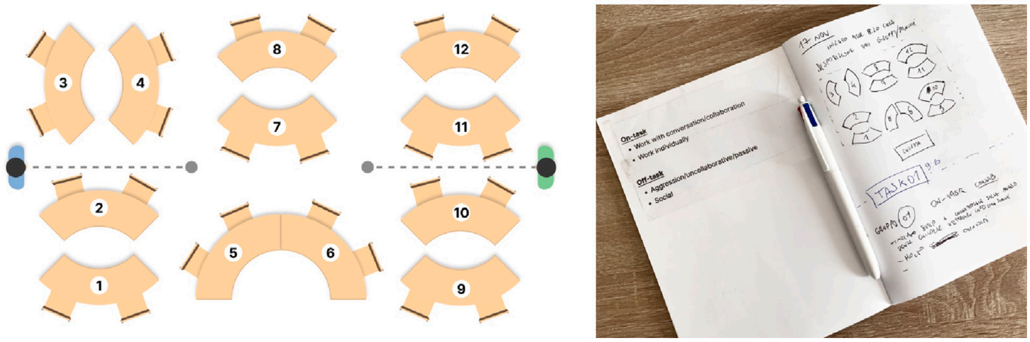


Fig. 14. On the left: the arrangement in class of the pupils' working stations and the position of the two observers. On the right: two pages of the diary of one of the observers.

4.3.2. Reflections

Questionnaire. Pupils were administered a questionnaire to assess their knowledge of design for social digital well-being. It had an open-format question that asked them to design a new smart thing for peers by setting, among other components, a mission of their own. Pupils were told that this novel smart-thing idea, with possibly new missions, did not necessarily have to be similar to what they had already designed. For answering **R2**a, researchers assessed the generated smart-thing ideas with their missions: they considered whether such ideas and missions were related to social digital well-being, or not, by conducing an inductive thematic analysis (Braun and Clarke, 2006).

Reflection lenses. All ideas conceptualised in IoTgo boards during Day 1 and Day 2 were thematically analysed in terms of reflections concerning well-being, in relation to **R2**b. Specifically, researchers considered the reflection lenses of the IoTgo toolkit, reported in Tables 3 and 4, besides those created by pupils themselves.

Interview. The teachers' opinions resulting from the interview were triangulated with the other data concerning the reflections that emerged through design to answer **R2**b.

5. Study results

This section reports on the analysis of the collected data, first in relation to engagement and then to reflections solicited through design for social digital well-being.

5.1. Results for engagement

The results related to engagement helped answer the research questions, namely, ***R1.a*** *whether pupils engaged in design for social digital well-being*, and ***R1.b*** *what engaged or disengaged them.*

5.1.1. Questionnaire

Only 22 out of 24 pupils were present on Day 2 and could fill in the engagement questionnaire, anonymously. In total, 18 out of 22 pupils reported high engagement values.

The questionnaire also contained an open-ended question, asking pupils about reasons for engagement or disengagement. The large majority of answers (17 out of 22) reported the innovative learning approach as a reason for engagement. Moreover, 6 pupils commented that the approach was "fun" or "interactive", besides instructive for Computer Science:

> *"It was a way to escape the monotonous life at school while having fun and at the same time it was also a period when I gained new experiences, which taught me new things about computing".*

Others (4) emphasised also the creativity and physical aspects of the experience. For instance, one commented as follows, stressing the creativity aspect:

Table 7
Summary of data concerning engagement behaviours in Day 1 tasks: for each task in the leftmost column, the tree central columns report the number of pupils coded with 2 (engagement with collaboration), 1 (individual engagement), 0 (disengagement). The rightmost column reports example notes by observers.

Days and tasks	Engagement behaviours by pupils:			
	Codes			Notes
Day 1: Smart Things	0	1	2	
D1Task1: Ideating	0	2	22	*They discuss about the meaning of the mission "connecting emotionally" in relation to technology [. . .]. They think this kind of mission is not easy for a thing.*
D1Task2: Programming	0	2	22	*At some point during the coding phase pupils move towards the working stations of others and start to test all together their programs, e.g., in order to switch on the LED strip.*
D1Task3: Reflecting	4	6	14	*They do not ask questions to each other and only write on the board. When the task is over, they use the PC for doing something different.*
D1Task4: Revising	2	0	22	*They continue playing with their smart things, trying to improve it!*

> "I recommend it because it is a innovative activity, interesting, engaging and also stimulates creativity".

Two pupils, instead, commented on the relevance of the physical approach, which made concrete abstract ideas, e.g.,

> *"It is an activity that immerses the student in something concrete".*

Only one disengagement motivation was given, in relation to "downtime", e.g., when pupils had to wait for others to finish:

> *"It was interesting but with a lot of downtimes and in my opinion we did very little in that time".*

5.1.2. Observed task-engagement behaviour

For all the tasks on Day 1 and Day 2, codes of pupils' engagement behaviours were analysed by considering on-task collaborative engagement, individual engagement, and off-task disengagement codes. For each task, each pupil was assigned an *engagement behaviour* code:

- 2 in case of collaborative engagement;
- 1 in case of individual engagement;
- 0 in case of disengagement.

Tables 7 and 8 summarise the engagement behaviours observed in Day 1 and Day 2 tasks. On Day 1, observers coded the large majority

Table 8
Summary of data concerning engagement behaviours in Day 2 tasks: for each task in the leftmost column, the tree central columns report the number of pupils coded with 2 (engagement with collaboration), 1 (individual engagement), 0 (disengagement). The rightmost column reports example notes by observers.

Days and tasks	Engagement behaviours by pupils:			
	Codes			Notes
Day 2: Communication	0	1	2	
D2Task1: Ideating	0	4	18	*In a group they show difficulties in working together to merge their ideas. Pairs keep playing with their own smart things.*
D2Task2: Programming	0	0	22	*They invested a lot of effort into making their two Micro:bit communicate and appeared to be very satisfied when they actually made the communication work: "Hold on, hold on… OK, try pushing now… It works! Yeahhhhhh!"*
D2Task3: Reflecting	8	4	10	*Many of them seem to lack abstraction… They do not want even to try to identify the effect of their idea.*
D2Task4: Revising	4	4	14	*They roam or stand in the back of the class, playing together or chatting.*

of pupils (22 out 24) as "engaged with collaboration" in all tasks but the third (D1Task3: Reflecting). As for the reflection task (D1Task3: Reflecting), only 14 pupils were "engaged with collaboration", while the others were either "engaged individually" (6) or "disengaged" (4).

Interestingly, as highlighted by the note in Table 7, observers reported collaboration behaviours in programming not only within groups but also at the class level (D1Task2: Programming):

> *At some point during the coding phase pupils move towards the working stations of others and start to test all together their programs, e.g., in order to switch on the LED strip.*

Also on Day 2, when pupils worked on the communication among smart things, programming was the task which engaged them all with collaboration (22 of all the pupils in class that day). According to notes by observers, they spent time and efforts to make their smart things communicate in collaboration with the other pupils of the group, e.g., see the following note by an observer:

> *In almost every group pupils invested a lot of effort into making their two micro:bits communicate and appeared to be very satisfied when they actually made the communication work. All the time they were exclaiming with sentences like this: "Hold on, hold on, hold on … OK, try pushing now… It works! Yeahhhhhh!'*

As for the other tasks for smart-thing communication:

- In ideating, 18 out of 22 were "engaged collaboratively", the others "individually" (D2Task1: Ideating);
- In reflecting, 10 were engaged with collaboration, 4 individually engaged, 8 disengaged (D2Task3: Reflecting);
- In revising, 14 were engaged with collaboration, 4 engaged individually, 4 disengaged (D2Task4: Revising).

5.1.3. Interview

During the interview, teachers commented on engagement and disengagement reasons. A thematic analysis of their observations helped researchers understand and contextualise the collected data for the observed engagement behaviours.

Among the reasons for engagement, teachers reported the innovative "learning approach", based on group work and hands-on activities with the toolkit. According to teachers, the "physical approach", in particular, engaged pupils because it enabled them to experience first-hand several aspects of digital technology and see the practical application of what they were designing. This, together with the collaboration with their peers facilitated by group work, engaged pupils in "finding solutions to real issues and challenges they are frequently exposed to during their life at school" (e.g., social exclusion, smartphone addiction). Teachers also stressed that another reason for engagement was "fun" with an activity that interrupted the typical class routine. Moreover, according to teachers, the toolkit seems to have engaged pupils also because it gave them a sense of competence and autonomy, guiding them to design their own ideas and acquire an awareness of the technology under design, so as to approach it in a more responsible way, a thought expressed by a teacher as follows:

> *Another source of motivation is the beauty of being able to develop one's own idea. So that is more or less it. In fact, one group then told me they would like to do this in their life* […]. *They really enjoyed the realisation [ideating, programming, and prototyping] phase with a purpose, that is having an idea and putting it into practice.*

As reasons for disengagement, teachers specifically reported "downtimes" and "theoretical explanations", remarking that pupils were least engaged when they were not interacting for realising their ideas, namely, when somebody explained theoretical concepts (e.g., peer-to-peer communication) and when, for other reasons, pupils had to patiently wait before working on their tasks:

> *They all told me that the most difficult part to pay attention to was the theory part. Perhaps because it is reminiscent of the classical lesson.*

5.2. Results for reflections

The results related to reflections helped answer the two research questions, related to (***R2.a***) *whether pupils reflect in design for social digital well-being*, and (***R2.b***) *what they reflect about.*

5.2.1. Questionnaire

Only 22 out of 24 pupils were present on Day 2 and submitted their answers to the questionnaire, anonymously. Every one defined a new smart thing and then formulated, on their own, new missions they deemed relevant. Table 9 illustrates the themes emerged from the thematic analyses of the new missions.

Table 9
Themes emerged from the analysis of new missions generated by pupils, entered in the post-study questionnaire (left); number of pupils per theme (right).

Themes for reflections from questionnaire	Number of pupils
Social engagement: use technology for engaging people and for improving socialisation among teens.	14
Social inclusion: use technology for including people with challenges or special needs.	4
Smartphone disengagement: use technology for disconnecting teens from smartphones.	2
Having fun: use technology for doing fun activities.	2

The majority of missions were related to social digital well-being, although this was not explicitly required by the questionnaire. Examples of such missions are *"making teens talk"* or *"creating connections among teens"*. An example of a related smart thing is as follows:

> *In the park there are several benches: when someone sits on a bench, it asks them "Are you feeling alone?". If they say yes (by pressing a button), the bench answers that there is another bench with someone else sitting on it alone and indicates (by displaying GPS coordinates) how to reach it.*

Another smart thing, related to the mission *"try to include all and help people feel less lonely"*, was as follows:

> *My idea is related to how to include people and bring them closer together: there is a fountain that produces sounds (a chosen song) only if more people are around it. To listen to the song more people have to stay in groups close to the fountain. This can motivate people to establish relationships.*

5.2.2. Reflection lenses

The activities of Day 1 and Day 2 guided pupils in conceiving ideas of smart things. Table A.10 in the Appendix lists examples of the outcomes of the two days and highlights the themes the designed smart things referred to. During these activities, the IoTgo boards also guided pupils to reflect on the relevance and safety of their smart things, in view of their social purpose. Furthermore, to solicit appropriation through spontaneous reflections, pupils were encouraged to define further reflection questions. Results are as follows, divided per lens.

Reflections on relevance and safety. On Day 1, all pupils answered in the positive to relevance and safety questions. Arguments related to relevance were of varying depth, independently of the mission they had worked on. Only for one pair, the answer simply rephrased the reflection question, without further arguments. In all other cases, pairs instead added further observations. For example, in relation to the mission titled "to behave responsibly", pupils wrote what follows:

> Yes, it is relevant to the mission because it would lead to greater respect for rules even by those who do not usually do so.
>
> Another example, related to "to trigger emotions", is as follows:
>
> *Yes, it is relevant to the mission because it can instil confidence in people by not making them feel alone but on the contrary by including them in the class.*

On Day 2, questions on relevance were left unanswered in most cases, probably because the original ideas were not modified but only refined for communication purposes. Only 6 pupils added new lenses that, however, mostly highlighted new interactive effects deriving from connecting their smart things, without adding any new substantial reflection on the relevance of their design.

From reflections about safety, *green concerns* emerged spontaneously, even if not specifically addressed by the guiding question they had to answer (e.g.: *"Yes, it is safe because it reduces the use of paper for books and is therefore good for the environment"*), as well as the belief that safety is guaranteed in the school setting (e.g.: *"Yes, it is safe because it is in a school environment"*).

New reflection lenses. On Day 1, different concerns emerged in the reflection questions that pupils elaborated on their own. They were related to *accessibility*, *universal usability* or *social engagement*. Examples are as follows:

- *Is the smart thing accessible to everyone? Yes, it is accessible to all people, it is easy and intuitive to use, it does not discriminate against anyone, rather it tries to integrate people in a homogeneous way.*
- *Is the smart thing usable by everyone? Yes, because it is simple to use and anyone can do it.*
- *Would the smart thing improve the relationship between parents and children"? Yes because it would lead parents and children to talk to each other and spend more time together and this would lead to understanding each other's point of view.*

On Day 2, many of the reflections were related to *technical issues* that pupils probably experienced during their work, for example:

> *Would peer-to-peer communication work between the smart things chosen by the groups?*

There were, however, interesting reflection questions that elaborated further Day 1's reflections and touched on the use and misuse of digital devices, e.g., smartphones, and their impact on social engagement not only for relationships with their peers but also with their parents:

> *Very often it happens that teens fail to meet their parents' expectations, who think their children are not trying hard in school, and not studying hard enough. This leads to misunderstandings for which teens lock up and prefer using their phones to being with their parents. The idea would be to create a smart thing in which timers can be set and react accordingly (with lights) if much time is spent using the smartphone. The device also records the time spent with parents. If enough time is spent together with parents, you receive a point. Our thing helps improve relationships with parents!*

5.2.3. Interview

The Computer Science teacher reported her enthusiasm for the approach to teaching Computer Science: she is willing to bring it into her own teaching activity so as to improve pupils' knowledge of JavaScript. She was positively impressed by the proposed paradigm; her opinion was that setting a design context improves pupil's engagement in learning.

The teaching assistant expressed additional comments in relation to the social-well-being goal and reflections by pupils (text inserted by researchers for explanatory reasons is square bracketed):

> *I noticed a bit like they were all projected on developing their idea, because of course they owned it. But when they have that part of control to answer the [reflection] questions, they actually answered, but [. . .] when I asked a [critical] question, because I had perceived a possible problem of inclusion [in one case], they did not understand my observation and re-proposed their idea. In my opinion, the continuous rethinking of the initial idea is necessary and it is important to further strengthen it to let the students acquire it [the habit].*

6. Discussion

The European Commission's Digital Competence Framework (DigComp2.2) positions digital well-being in relation to competencies connected to safety, and describes social well-being and inclusion as complementary objectives to pursue, especially in the area of digital technologies for learning (Vuorikari et al., 2022). For this reason, it is important to invest in education on digital well-being, i.e., helping learners understand how to use digital technologies in a safe and effective manner. The study illustrated in this paper aims to contribute to this challenge.

The study was with 24 pupils from the penultimate year of a high-school. It investigated two sets of research questions, one for engagement and the other for reflections through design for social digital well-being. The aim was to understand whether and how a toolkit, structuring both the design process and reflections on pervasive smart things, engages pupils in the *design of technology for social digital well-being, and fosters their critical stance on the impact that technological devices can have on society.*

The research questions of the study are based on literature findings, which show how engagement correlates to learning of technology design (Gennari et al., 2017a; Melonio et al., 2020), and how a structure can help reflect on technology, but that meaningful reflections are difficult to elicit from children or teens (Gennari et al., 2021a; Kinnula et al., 2020). Its novel contribution can be situated in the context of a broader research line that investigates methods for improving learners' awareness of technology, while also addressing and promoting reflections on social digital well-being (N.D. of Education, Communities, 2015).

The study, in fact, focused on how to guide pupils in approaching design for an extended view of digital well-being that also includes the pupils' social sphere. This is in line with recent works (e.g., (Vanden Abeele, 2020; Büchi, 2021)), which started reflecting on a perspective on digital well-being, expanding towards the satisfaction and quality of life that individuals can achieve in their social environment thanks to a proper use of digital media (Büchi, 2021).

As discussed in the following, the analysis of the collected data highlights interesting insights on engagement indicators and reflections, which suggest how to promote design for social digital well-being to increase young generations' level of sensitivity to this theme.

6.1. Engagement in design for social digital well-being

The first two questions, **R1**a and **R1**b, gravitated around pupils' engagement in design for social digital well-being: Do pupils engage in design for social digital well-being? What engages or disengages them? In general, pupils tended to be engaged: the NET promoter-score questionnaire highlighted that the 82% of students perceived a high engagement in the proposed design activities. This result answers in the positive the **R**1a research question. In relation to **R**1b, different factors emerged by triangulating the analysis of the open-ended question of the questionnaire and the coded behaviours of pupils.

Owning and rapidly prototyping physical solutions. Pupils' answers to the open-ended question of the questionnaire indicate that a reason for pupils' engagement was the innovative intervention, with a phygital toolkit which guided and structured the process, and enabled them to creatively imagine and then develop their own ideas of smart things for a purpose, that is, a social goal. This sense of appropriation, which the toolkit enabled, was also deemed a relevant engagement reason by teachers in interviews.

Moreover, the toolkit, with its app, enabled pupils to rapidly program physical prototypes of their smart-thing ideas. The analysis of teachers' interviews supported that the possibility of rapidly developing physical prototypes was also a reason for engagement: it enabled pupils to experience first-hand and immediately perceive the effects of their technological choices in design. This is further sustained by the coding of engagement behaviours of pupils: this indicated that, in both days of the activity, the physical programming tasks were the most engaging.

Interactivity also emerged as a key engagement reason. For the evolution of the toolkit, teachers suggested avoiding non-practical and non-interactive design tasks. Increasing interactivity and reducing downtimes "to do more" were also suggested by the pupils themselves.

Overall, on one side, the aforementioned results indicate that the toolkit-driven intervention supported pupils' engagement. On the other side, they also suggest that IoTgo or similar toolkits should enable for more freedom and customisation, so as to accommodate diverse pupils' needs. This is in line with recommendations in the education and usability literature, which led to the modular architecture of the IoTgo toolkit.

Collaboration and well-being. The analyses of coded observations highlighted that reflections with the IoTgo toolkit engaged teens less collaboratively than other design tasks did. If engagement with collaboration is sought in reflections as well, in the future, IoTgo toolkit would need to structure more social interactions for reflecting than the study reported in this paper did. As a recent study highlighted, the perception of support from others and the possibility to ask help when needed is fundamental to build social inclusive schools' environments (Sarti et al., 2019).

On the other hand, the engagement analysis seems to indicate that design with the IoTgo phygital toolkit engaged pupils collaboratively, a positive byproduct result of designing together for social digital well-being. This triggers an additional reflection on digital well-being, since it shows how technology in design can engage and make teens socially interact, in situ, for a shared social challenge and mission. This is in line with what is envisioned by Şerban et al. (2020): technology design and coding should be inclusive, so that no one is left behind regardless of gender, social and cultural background, learning status and any physical or mental limitations. If working in a group, each pupil can bring in their own strengths and the team can split tasks with regard to individual skills and preferences. In other words, collaboration can offer opportunities to reflect more broadly on inclusion.

6.2. Reflections in design for social digital well-being

The second set of questions, **R**2a and **R**2b, gravitated around pupils' reflections in design for social digital well-being: whether pupils were enabled to reflect across it, and what they reflected about, respectively. The answer to **R**2a seems in general positive: the majority of missions for future smart things, which pupils described in the questionnaire administered after the design experience, were related to social digital well-being (20 out of 22). Answers to **R**2b come from multiple sources and are varied, thematically reported in the following.

Social dimensions. Missions from the questionnaire were related to social engagement, inclusion, smartphone disengagement. The same and other concerns emerged in the reflection lenses that teens added when designing their own smart things: the reflection lenses and questions pupils added were mostly related to inclusion and engagement (accessibility, universal usability, social engagement) or the environment (green concerns). Such results indicate that the design experience for social digital well-being had an impact on the majority of pupils: they understood the problem and were able to design for it and, at the end of the design experience, they chose to imagine new smart things with new design missions related to it. Moreover, as also reported by a teacher in the interview, the toolkit-based structure helped pupils reflect on technology, its use and misuse. This is a contribution of the reported work; several findings show instead that meaningful reflections are difficult to elicit from children or teens (Gennari et al., 2021a; Kinnula et al., 2020).

Relevance and safety dimensions. Reflections related to other aspects of the designed solutions were solicited through the given reflection lenses, part of the toolkit. In Day 1, all pupils but one tackled relevance and safety reflection questions, and showed the capability of critically reflecting on them and going beyond simple yes/no answers or rephrasing questions. In Day 2, relevance questions were mostly left unanswered, probably because the related Day 1 and Day 2 questions were perceived to be too similar.

Overall, such results help tap a gap in the literature on Computer Science education. In fact, according to Iversen et al. Computational Thinking or, more generally, Computer Science education often focuses on computational patterns but neglects critical thinking which is necessary for achieving young generations' true "computational empowerment" and critically approaching technology (Iversen et al., 2018). Moreover, as purported by Kanafi et al. how to nurture critical reflections on technology in the youngest has been "addressed in a very limited manner" (Kanafi et al., 2021). This is instead a fundamental aspect to consider in education: due to the unprecedented penetration of ICT in every aspect of everyday life, a primary responsibility when teaching Computer Science is to educate the citizens of tomorrow (Di Cosmo, 2006).

Further reflections on communication. The activity in Day 2 related to the peer to peer communication and how to inter-connect smart things also led to reflections. As also reported by teachers in the interview, it helped pupils focus on realistic scenarios, similar to current digital-enhanced habits and situations, where teens are surrounded by multiple interconnected devices. Moreover, the smart-thing connectivity stimulated reflections on aspects generated by data processing and sharing, like privacy and security risks.

Fig. 15. A group of pupils sharing and reflecting with the class and adults on their design after the end of the entire design experience.

Obstacles to reflections. From the interview, one teacher noticed that once the program for the communication was revised, after reflecting on it, pupils were unwilling to again critically reflect on it ("this continuous rethinking of the initial idea is necessary"), attributing this to the fact that teens clearly "owned their final ideas". It is worth noticing that such a novel reflection round was not embedded in the IoTgo boards and design. Design with teens should probably make it explicit and tangible, e.g., it should be added on boards for guiding design. As highlighted above the IoTgo toolkit need to be revised to better support reflection.

Moreover, further voices should be embedded in reflections. In the study reported in this paper, reflections were between pairs or in groups, all sharing the same smart thing and hence probably owning it. An external critical voice could be added for reflecting, as done for instance in the work reported with in Gennari et al. (2021a), Roumelioti et al. (2022).

The ability of pupils to further share and reflect on their ideas, at the class level, also emerged after the reported design experience at school: as illustrated in Fig. 15, each group was asked to share with the entire class, teachers and design researchers their smart things, and explain the motivations that guided their design, in terms of possible benefits for different people. Although this activity was not initially scheduled, pupils exploited the opportunity for discussing among themselves and with adults the meaning of responsible design for social digital well-being, by emphasising aspects that could have a positive or a negative impact on individuals, society, or the environment. Overall, such results suggest embedding this further reflection round with different pupils and to include it in the IoTgo toolkit. This would further help students play an active role in learning, which is recognised as one key element for learners' well-being at school (N.D. of Education, Communities, 2015).

7. Conclusions

This paper centres around the IoTgo phygital toolkit, which organises design for a purpose along different tasks for non-seasoned designers or programmers, in line with the purpose-based approach recently advocated by Cunningham (2020). Tasks are for empathising, ideating and conceptualising, programming and testing, besides reflecting. It does so tangibly, with game boards, cards and digital tools. The physical boards and cards scaffold ideas of smart things for a given challenge, guide in their conceptualisation along patterns and trigger shared reflections on smart things and their communication. The digital tools of the IoTgo toolkit automatically generate programs for smart things and their communication along such patterns, and they invite their users to reflect and elaborate on them again in relation to the chosen design challenge.

7.1. Study results and limitations

The toolkit can be adapted to different design contexts and challenges. In the study reported in this paper, the toolkit was adapted to enable teens to design for their school (setting) and social digital well-being, focusing on inclusion (challenge). The study involved 24 pupils from the penultimate year of a high-school, besides two teachers. Research questions revolved around engagement in design and reflections for social digital well-being. Data were gathered and processed in relation to the research questions. Answers are positive and discussed from multiple perspectives in the related section above.

Limitations of the study are due to its context-bound nature, which makes it hard to generalise its findings. Moreover, information from interviews and related to reflections was rather limited. However, data were gathered in an ecological setting, from different sources and triangulated in relation to what engaged in the experience with IoTgo for social digital well-being, and in relation to reflections in it. Recent work has further adapted the toolkit to a new context, with fragile people co-designing for social digital well-being.

7.2. Lessons learnt

Overall it seems that, although the engagement in reflections on design was less collaborative than other design tasks were and another reflection round might be necessary with further stakeholders, engagement tended to be elsewhere collaborative and reflections were largely non superficial in IoTgo-design tasks. Thereby, results concerning collaborative engagement show how design with the IoTgo phygital toolkit can engage and make teens socially interact "for the social good", which is per se a positive outcome and a different view on technology than in past studies concerning digital well-being, reported in Section 2.

Moreover, by following what embedded in the IoTgo toolkit, teens were also able to critically reflect in design for social digital well-being. They could reflect from multiple perspectives through given lenses (relevance, safety) and spontaneously emerged lenses (accessibility,

Table A.10
Examples of smart things by pupils on Day 1; their Day 2's refinement for communicating; related social digital well-being themes.

ID	Smart thing ideas (Day 1)	Smart things communication (Day 2)	Reflection themes
6	**The Friendly Chair:** The chair helps appreciate good things in your life and inquires if you are feeling good or not, and how your friends, family, and school feel. If you are not feeling good, it plays music to cheer you up.	**Time to Connect:** When you sit on the Friendly Chair, and your are not feeling good about friends, family, or school, it invites you to play with the Catch-a-question ball, by lighting it up so that you talk about your feelings with a friend and feel better.	Green sustainability, social engagement, accessibility.
7	**The Catch-a-Question Ball:** It is s a smart ball, to help friends understand each other better. A friend asks a question, touches the ball to activate the animation, and throws the ball to the other friend who has to answer before the animation stops.		
1	**Emotional desk:** There are two buttons on each desk in class, representing the happy and sad emotions. Pupils can click on them to express how they feel at the end of the day. At the end of the month, one can see how happy or sad the class was as a whole.	**The Leaderboard:** It shows which classes are happy or sad. It blinks if a Connected Bench is free.	Universal usability, social engagement, green sustainability.
9	**Connected Benches:** In the school yard there is a smart bench that displays quizzes to pupils that sit on it. Depending on the answer to the quiz, it indicates another bench where pupils with similar interests can be found so as to socialise with them.		
12	**Book of Emotions:** It is an interactive book that shows lines of a story about emotions when buttons are pressed.	**Welcome Desk:** When it perceives a sound, it greets people with calming music and a welcoming note.	Universal usability, social engagement
7	**Magic Library:** When someone sits at the welcome desk, it suggests to look for the Book of Emotions that in the meantime has lighted up.		

universal usability, social engagement, green sustainability). It is worth reminding that the IoTgo toolkit automated the process of generating programs that follow certain patterns for smart things with physical devices, which can communicate peer-to-peer. This enabled pupils to quickly discover initial good solutions replicating given patterns, and to free time for reflecting as well as elaborating on their ideas. The possibility of continuing elaborating on the generated programs was eagerly picked up by all pupils.

7.3. Relevance for future research

The research reported in this paper can be relevant for different communities. It can help move the bar from Computational Thinking to "computational empowerment" so as to enable teens to responsibly master technology (Iversen et al., 2018; Di Cosmo, 2006). In fact, pupils were not only responsible for ideating, conceptualising algorithmic solutions with given patterns, and programming them. The IoTgo design enabled them to reflect critically on smart technology for social digital well-being, and consider what it can impact beyond individuals' physical and psychological well-being, e.g., (Schaber, 2010). Recent work with a further evolution of IoTgo for schools enabled in-service teachers and several of their classes to acquire the basics of Computational Thinking and Design Thinking (Bonani et al., 2023; Gennari et al., 2023).

The paper also contributes to shed a new light on the concept of digital well-being and sustains its relevance for the young generation, thereby widening the horizon of digital well-being (Monge Roffarello and De Russis, 2019). It enriches it with a novel social perspective, which teens showed to engage with and reflect on, during and after the design experience with the IoTgo toolkit.

Declaration of competing interest

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Data availability

The authors do not have permission to share data.

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Appendix. Examples of smart things by pupils

See Table A.10.

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