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The evolution of a toolkit for smart-thing design with children through action research

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ABSTRACT

Several workshops use toolkits to engage children in the design of smart things, that is, everyday things like toys enhanced with computing devices and capabilities. In general, the toolkits focus on one design stage or another, e.g., ideation or programming. Few toolkits are created to guide children through an entire design process. This paper presents a toolkit for smart-thing design with children. It revolves around SNaP, a card-based board game for children. The toolkit serves to frame the entire design process and guide them through their exploration, ideation, programming and prototyping of their own smart things. By embracing action research, the toolkit was adopted in actions with children, namely, design workshops. Results of actions were reflected over by considering children's benefits, and they were used to make the toolkit evolve across cycles of action, reflection and development. The paper reports on the latest evolution cycles, ending with the 2020 cycle for continuing smart-thing design during COVID-19 times. The paper concludes with general reflections concerning action research and design with children, toolkits for framing smart-thing design with children, on-going and future work.

1. Introduction

1.1. Rationale

A smart thing is a computationally enhanced version of an everyday thing, which can collect data through input devices, process data, and react via output devices (Kortuem, Kawsar, Sundramoorthy, & Fitton, 2010). Children are used to smart things but do not know how to create their own. This paper considers how to frame design workshops with children, so as to enable them to design and reflect on their own smart things.

In several countries, there have been design workshops or similar design initiatives with children, although few cover all design stages, e.g., Lechelt, Rogers, Marquardt, and Shum (2017). Diverse design workshops with children concentrate on the early design stages, namely, on exploration or ideation. Therein, workshops are supported with generative paper-based toolkits, such as probes and storyboards, and structured with specific methods for children, such as role playing or fictional enquiries (Druin, 2002; Fails, Guha, & Druin, 2013). The making community, on the other hand, has mostly focused on programming and prototyping with hands-on, tinkering, unstructured approaches (Blikstein & Krannich, 2013; Wood et al., 2019).

Recently, there has been an effort to tie such research threads, e.g., through FabLearn initiatives (Eriksson et al., 2019). However, there is still little research concerning toolkits for workshops which guide children throughout the entire design of their own smart things, stepping through the stages of exploration, ideation, programming and prototyping with reflections. The focus of this paper is on such a toolkit for framing smart-thing design with children.

1.2. The toolkit for framing design

The toolkit for framing smart-thing design gravitates around SNaP. This is a card-based game. It has different decks of cards and modular boards, related to smart things and how to design them.

Smart-thing design with children starts by playing cards on SNaP boards. In this manner, children step through the *exploration* and then the *ideation* of their own smart things. The ideation stage concludes with a conceptualisation of children's ideas on boards.

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Next children bring these boards with their ideas into the *programming and prototyping* stage of the design process. The toolkit comes in fact with common physical-computing devices for children, mainly, micro:bit boards and easy-to-connect input and output devices, such as microphones or sound speakers. Specific decks of SNaP cards match one-to-one with the input and output devices for physical computing, so as to enable children to smoothly move from ideation into programming and prototyping.

Guided by SNaP reflection cards with probing questions, children are challenged to *reflect* on smart things through the entire design process and from multiple perspectives, e.g., theirs, peers'.

1.3. Contribution

The toolkit evolved by means of action research. The toolkit was developed and adopted in actions in the field, namely, design workshops with 10–14 years old children and design researchers. Reflections on actions considered children's learning of smart-thing design, and specifically whether they succeeded in designing their own smart things, besides their usages of the toolkit. Reflections triggered decisions related to the development of the toolkit, and hence novel cycles of action-development-reflection.

The evolution of the toolkit through action research is the main contribution of this paper. The paper focuses on the most recent evolution cycles: the first cycles, related to workshops in 2019, in presence; the latest cycle, related to workshops in summer 2020, held at a distance, across two countries in Europe and a pandemic.

Results of 2019 actions were reported separately in other publications, however mainly in relation to quantitative data processing (Gennari, Matera, Melonio, Rizvi, & Roumelioti, 2020a, 2020b; Melonio et al., 2020; Roumelioti, Gennari, Matera, Melonio, & Rizvi, 2020). This paper instead considers qualitative data related to 2019 actions, and findings are presented in relation to the evolution of the toolkit for the first time. Moreover, this paper describes the 2020 evolution cycle for the first time.

1.4. Outline

The paper starts reporting on related work, firstly focusing on design with and for children, and then concentrating on design with cards and design toolkits for children. The paper continues and outlines the action-research approach. It explains how action research was used for evolving the smart-thing design toolkit, centred on SNaP, and it reports on the latest action-research cycles. Finally, the paper concludes by acknowledging limitations of the presented work. It also discusses results of the adopted action-research approach, and it draws general lessons concerning design toolkits for enabling children to design their own smart things and reflect on them. Considerations concerning on-going and future work conclude the paper.

2. Related work

2.1. Design with and for children

Children's roles in design evolved over time, from merely accompanying the process as users, testers or informants, to participating as design partners (Druin, 1999). In the work by van Mechelen et al. the role of design partners was extended to co-researchers, in order to enable children to conduct contextual user research (Mechelen et al., 2017). More recently the role of process designer emerged; in this role children co-design the process itself (Schepers, Dreessen, & Zaman, 2018). Similarly, Scandinavian researchers introduce a role which further empowers children as protagonists in design (Iversen, Smith, & Dindler, 2017; Kinnula & Iivari, 2019). Our work shares with such recent research the idea of involving children in the entire design process, and to place their benefits at the centre of design, providing them with tangible reflection opportunities and guidance. However, the focus of this paper is on how to structure design with children, with toolkits for smart-thing design, so as to enable them to design their own smart things.

There are different approaches or methods for structuring design with children and enable them to participate in design. In Participatory Design (PD) or co-design, researchers team up with children, albeit children are mainly involved in the ideation of future technologies (Dodero, Gennari, Melonio, & Torello, 2014; Gennari et al., 2017). Design thinking has been recently used to structure the design process and transfer to children design methods, tools and processes (Smith, Iversen, & Hjorth, 2015). When working with children, structuring the design process into stages is fundamental to help children grasp the different stages and move through these with confidence (Bekker, Bakker, Douma, van der Poel, & Scheltenaar, 2015; Iversen, Smith, & Dindler, 2018). For instance, Mazzone et al. introduce three main stages for designing with children: context exploration, generation of ideas, generation of prototypes and evaluation (Mazzone, 2012). Others also adopt similar stages but stress the need of embedding reflections along all stages, e.g., Kinnula and Iivari (2019) and Smith et al. (2015). All highlight the relevance and difficulty of promoting multiple types of reflection during design (e.g., individual, with peers or adults), as reflecting asks children to develop structured insights (Gennari et al., 2020b; Kinnula & Iivari, 2019; Zhang, Bekker, Markopoulos, & Brok, 2020). Finally, Smith et al. introduce a design brief at the start of the design process to motivate children and engage them in the design context (Smith et al., 2015).

To guide children, the design process reported in this paper is divided into similar stages, by means of SNaP and its cards.

2.2. Cards

Cards are used to engage non-experts in the design process and make it tangible, e.g., Baykal, Goksun, and Yantaç (2018), Darzentas et al. (2019) and Roeck, Tanghe, Jacoby, Moons, and Slegers (2019). In recent years, researchers and practitioners have also adopted cards for designing smart things, mainly for adults. They are overviewed in the following, according to their purpose in design, and summarised in Table 1.

2.2.1. Motivation cards

Cards can be used to motivate participants towards the design goal and help them understand the design context. Examples are scenario and mission cards of Tiles (Mora et al., 2017). Similarly, the Design Heuristics cards come with mission cards such as "add features from nature" and "allow users to assemble", although for expert adult designers (McKilligan et al., 2012). An ideation tool for public transportation contexts included context cards for presenting different scenarios, such as "making the ecological values of electric bus visible" (Hildén et al., 2017).

If not necessarily in the form of cards of games, motivation material is anyhow frequently used in workshops with children, e.g., in the work by Iversen et al. (2017). Their work used briefing statements to start immersing children in a scenario. SNaP employs similar briefing statements for immersing children in a context, as well as motivation cards in the form of mission cards for the context.

Table 1
Summary of different card decks, their context and users, their focus among motivation, technology, environment or reflection (they are marked with 1 in case they consider such focus, 0 otherwise).

Cards name	Context	Users	Motivation	Technology	Environment	Reflection
SNaP	Designing Smart Things	Children (10–14 years)	1	1	1	1
Tiles Cards (Mora, Gianni, & Divitini, 2017)	Internet of Things (IoT)	Teenagers, University Students, Experts	1	1	1	1
Design Heuristics cards (McKilligan, Christian, Daly, Seifert, & Gonzalez, 2012)	Design, Product Design	University Students, Adults	1	0	0	0
Context Cards (Hildén, Ojala, & Vä, 2017)	Public Transportation	University Students, Adults, Experts	1	0	0	0
Iversen et al. (2017)	Generic, Design	Children (11–13 years)	1	0	0	0
IoT Design Deck (Dibitonto, Tazzi, Leszczynska, & Medaglia, 2018)	Internet of Things (IoT)	University Students, Experts	0	1	1	0
LUX cards (Choi, Kim, & Suk, 2020)	Indoor Lighting	University Students	0	1	0	0
Know-Cards (Cards, 2019)	Product Design	Students, Professionals	0	1	0	0
Maker cards (Root, Heuten, & Boll, 2019)	Physical Computing	Children (10–14 years)	0	1	0	0
Scratch Coding cards (Scratch-Foundation, 2019)	Computer Game Design	Children, Teenagers	0	1	0	0
Generic cards for technology (Gennari, Melonio, Rizvi and Bonani, 2017)	Affective smart things	Children	1	1	0	0
Berger et al. (2019)	Indoor smart objects	Adults, University Students	1	0	1	0
Nudge Deck (Caraban, Konstantinou, & Karapanos, 2020)	Behaviour change technology	Experts	0	0	0	1
Customised DSD cards (Baykal et al., 2018)	Technology for Preschoolers	Experts	0	0	0	1
Klapwijk and Rodewijk (2018)	Prototyping, Product Design	Children (10–12 years)	0	0	0	1
Knowles, Beck, Finney, Devine, and Lindley (2019)	Technology Risks for Children	Experts	0	0	0	1
Dowthwaite et al. (2020)	Data Security and Privacy	Teenagers	0	0	0	1
Lechelt, Rogers, and Marquardt (2020)	Personal/Environmental Sensing	Children (9–11 years)	0	1	0	1
Troubleshooting Card Set (Booth, Bird, Stumpf, & Jones, 2019)	Physical Computing	No data	0	1	0	1
IoTT Card Set (Angelini, Mugellini, Couture, & Abou Khaled, 2018)	IoT and Physical Computing	Experts	1	1	1	1

2.2.2. Technology cards

Cards for smart things also tend to have decks for input (e.g., buttons) and output devices (e.g., LED matrix). Several researchers tend to design abstract input and output cards, which are independent of any technology. Examples are Tiles cards, which represent what people can do with input and output devices of smart things, such as human actions (e.g., touch) and feedback (e.g., sound) (Mora et al., 2017). Similarly, the IoT Design Deck includes input and output cards oriented to a perception and action mechanism, for helping non-experts design the behaviour of smart devices (Dibitonto et al., 2018). Lighting User Experience (LUX) contains input cards for the technology of smart lighting solutions (Choi et al., 2020).

Generic input and output cards, such as the above ones, can be used for ideating different smart things. However, they can be difficult to match with sensors or actuators, so as to engage non-experts into programming and prototyping. Cards for children, in particular, need to be have more concrete representations than cards for adults if their aim is to engage children in programming and prototyping. For example, Know-Cards include input and output cards that represent specific electronic components (Cards, 2019). Similarly, Maker and Scratch cards have cards for specific physical-computing input technology (Root et al., 2019; Scratch-Foundation, 2019). However, these cards are meant for programming, and they are strictly related to one technology or brand.

Cards for engaging children in different parts of the design of smart things should thus be easy, for children, to match with technology, and yet sufficiently general to apply to diverse design stages and technology devices, independently of their manufacturer. For example in the workshop reported in Gianni, Mora, and Divitini (2018), Tiles cards were used with matching electronic devices in a workshop with older adolescents. However, the workshop did not include an ideation stage, and the devices as well as the chosen programming environment were not designed for children. An example of such cards for children is instead reported in Gennari, Melonio, Rizvi et al. (2017); although input and output cards were for a specific technology, they were used to move children from ideation to programming.

Similarly, SNaP has decks of cards for inputs and outputs, with icons and language adequate for children. Input and output devices are represented in SNaP cards by considering diverse sorts of smart thing technology for children and teens, without committing to a specific one, and yet clearly matching common input and output devices (Gennari et al., 2020b).

2.2.3. Environment cards

Cards also consider the physical environment. For instance, Berger et al. adopted environment cards for domestic smart things (Berger et al., 2019). Smart-city things were added to Tiles cards for smart cities (Gianni & Divitini, 2017).

More often, the environment is also part of the framework. For instance, the IoT Service Kit provided specific environmental contexts in the form of pre-designed maps for creating IoT concepts, e.g., for a supermarket (Brito & Houghton, 2017). Instead, Stembert toolkit contains contextual packages, with cards and tokens for specific environments, such as smart entertainment (Nathalie, 2017).

Similar choices have been made in SNaP. This comes with a deck of cards for things of the chosen design environment, e.g., a tree if the environment is a park. The environment, with representations of such things, is also depicted as background scenario of the SNaP boards, to contextualise design even more concretely for children.

2.2.4. Reflection cards

Soliciting children's reflections during design is considered important for supporting their design competence, e.g., Bekker et al. (2015). However making children reflect on their ideas, programs or prototypes can be challenging (Iivari & Kinnula, 2018). Schut et al. suggested that reflection opportunities for children should be concrete, besides transparent and clear for children (Schut, Klapwijk, & Gielen, 2018). Reflection cards are concrete means which can support children's critical thinking across design. The attempts to offer reflection cards specific for children's design, though, are so far limited and addressing adults or a specific stage of design.

For instance, the Nudge Deck includes mechanism cards for generic technology, with questions and probes (so-called nudges) to enable adult designers to explore the technology context or reflect on ideas (Caraban et al., 2020). Similarly, DSD cards trigger adult designers' reflections in the ideation stage of technology albeit they are not for children (Baykal et al., 2018). Instead, Klapwijk et al. used cards for and with children to stir reflections before prototyping their ideas of generic technology so as "to increase intentionality" (Klapwijk & Rodewijk, 2018). Another work, instead focusing on smart things, identified reflection questions for children related to risks, such as harmful usage, related to imagined technology (Knowles et al., 2019). Dowthwaite et al. used cards with children to stimulate reflection on sharing personal data with online technologies, without involving them in design activities (Dowthwaite et al., 2020).

Other criteria or cards have been developed for reflecting on design during programming and prototyping with children. The study by Lechelt et al. identified criteria promoting reflections or critical thinking around reliability and accuracy of input or output devices, such as "extrapolate what the sensor actually measures and how", relevant for the programming and prototyping of smart-thing design (Lechelt et al., 2020). Similarly, Booth et al. introduced cards for reflecting on troubleshooting when developing physical-computing prototypes (Booth et al., 2019).

Other cards, albeit few, can be used in all design stages. For instance, the IoTT Card Set helped stir reflections on how tangible properties can be exploited for enhancing the interaction with IoT things (Angelini et al., 2018). However, they are addressed to experts and not children.

Tiles has cards for reflecting during the ideation of smart things which are applicable to other design stages and have been used with non-experts, some of whom were children. Not to overwhelm non-experts, Tiles cards are kept coarse-grained and to a minimal number. One card of Tiles, in particular, refers to feasibility, that is, whether the smart thing can be realised from a technical viewpoint. This is a crucial reflection criterion for children if they are expected to program and prototype, after ideating. In fact, it was also used for stirring reflections with children by Klapwijk and Rodewijk (2018). Therefore feasibility has been retained as reflection card in SNaP and adapted to children's usage, e.g., with a specific layout and probing questions. Relevance and elaboration have been separately used to reflect on children's ideas and prototypes as well, e.g., Thang et al. (2008). Thereby they have been added to the SNaP cards for reflecting on design with children.

2.3. Card-based toolkits

Besides cards, recent design initiatives with children also adopt further card-based toolkits, recapped in Table 2. The rationale is that a game-like environment is more likely to boost the exploratory and imaginative aspects of design and increase the overall engagement of children (Dodero et al., 2014; Vaajakallio & Mattelmaki, 2014).

The Tiles Inventor toolkit, with the aforementioned Tiles cards, is a design kit for smart things, which focuses on ideation (Mavroudi, Divitini, Mora, & Gianni, 2018). Its main purpose is not to engage children, and hence it is not designed as a card-based game, rather, as a general design kit for engaging anybody in design ideation. Instead, the IoT Service Kit is a board game that includes tokens, cards and maps for the creation of IoT experiences, addressed to domain experts, making it again difficult for young users (Brito & Houghton, 2017). LocaLudo is another card-based kit for designing interactive architectures (Huyghe, Wouters, Geerts, & Vande Moere, 2014). It aims at eliciting ideas and concerns of local communities, and not at guiding children through design.

On the other hand, Khandu is a card game expressively created to foster design thinking in children (Thinkers, 2019). It consists of four decks (challenges, tools, people, action cards), designed to help children solve problems and generate ideas for different contexts. Khandu's approach, however, is non-technology oriented; children are guided to design and prototype ideas without technology.

3. The research approach

Action research was adopted in order to make the SNaP toolkit evolve, and at the same time bring benefits to all participants in research, as explained next.

Table 2
Summary of different toolkits, their context and users, and if they focus on motivation, technology, environment, reflection (in case so they are labelled with 1, 0 otherwise).

Cards name	Context	Users	Motivation	Technology	Environment	Reflection
SNaP Toolkit	Designing Smart Things	Children (10–14 years)	1	1	1	1
Tiles Toolkit (Mora et al., 2017)	Internet of Things (IoT)	Teenagers, University Students, Researchers	1	1	1	1
Extended Tiles Ideation Toolkit (Gianni & Divitini, 2017)	Smart Cities	Teenagers, University Students, Researchers, Professionals	1	1	1	1
IoT Service Kit (Brito & Houghton, 2017)	IoT for Supermarket, Public Square, Harbour etc.	No data	0	1	1	0
Stembert Toolkit U4IoT (Nathalie, 2017)	Smart entertainment	Adults	0	0	1	0
CodeCube (Cleto, Sylla, Ferreira, & Moura, 2020)	Wearables	Children (9–13 years)	0	1	1	0
Localudo (Huyghe et al., 2014)	Interaction between neighbourhood and residents	Families	1	0	1	1
Khandu (Thinkers, 2019)	Foster creativity and design	Children (6–12 years)	1	0	1	1

3.1. Action research for developing tools

Action research was introduced by Kurt Lewin as "a spiral of steps, each of which is composed of a circle of planning, action, and fact-finding about the result of the action" thereby opening up possibilities for change (Lewin, 1946). It was originally born for the study of social processes, as it is based on the principle that complex social processes can be best studied by introducing changes in these processes, and observing the effects of these actions. Nowadays it is used in many general fields of enquiry, in particular, in information systems. In this context, the overall goal of action research is to develop tools that evolve according to the results of actions.

In the past action research was mainly adopted for evaluating tools. Recently, action research was embedded in further stages than the evaluation stage. For instance, in the work reported by Di Mascio et al. action research helped investigate the context of use and conceive novel tools (Di Mascio, Gennari, Tarantino, & Vittorini, 2017). In the research reported in this paper, the SNaP-based toolkit for designing smart things evolved through action research, as interactive tangibles evolved in the work by Rizvi et al. (Gennari, Melonio, & Rizvi, 2018, 2020; Rizvi, 2019). The evolution followed a spiral, in cycles of development, actions and reflections, in which the toolkit was kept open and adaptable so as to develop according to possibilities emerged through actions and reflections.

Specifically, novel versions of the toolkit were developed, based on past reflections. Novel versions mainly developed critical functionalities to explore through actions, or they were adapted to different contexts. Actions were workshops with children for designing smart things, framed around the latest evolution of the toolkit. Fig. 1 illustrates the evolution of the toolkit, through cycles of development, action and reflection, from 2018 to 2020.

3.1.1. Action research for bringing benefits

Another fundamental goal of action research is to enable all participants in actions to gain benefits. Therefore, across all actions with SNaP, data were processed by considering, as research questions,

- RQ1. children's learning, specifically, what children succeeded in designing,
- RQ2. besides their overall experience with the toolkit,

so as to make the toolkit evolve. Data were collected with a mixed-method research design, by means of:

1. observations: direct observations; indirect observations, mainly videos;
2. children's products, such as ideas and programs of children's smart things.

This paper focuses on the processing of such qualitative data. Adults present in actions mainly acted as facilitators for design or managed data processing. The other participants were 10–14 years old children. Across all actions, all children participated on a voluntary basis, and their parents authorised their participation through a consent form. See Table 3 for a recap of actions as reported in this paper, whereas details on the latest actions are reported below, split into in-presence and at-a-distance actions.

4. In-presence design in summer 2019

The following section details the first action-research cycle in summer 2019, conducted in presence, based on the available SNaP version for designing smart things with children. Firstly it reports the main features of SNaP, e.g., roles of players and storyline. Then how it was used in the action—design workshops with children. This section ends with reflections concerning the action.

4.1. Developed features

Role of players and collaboration. Players had two main roles across design. One was the Senior Designer, taken up by an adult expert of design (Gennari, Matera, Melonio, & Roumelioti, 2019). All others were Junior Designers, played by children. A third role was that of Mayor, setting the overall game goal, played by an adult. All Junior Designers collaborated throughout the game so as to achieve their goal. Specifically, they were invited to ideate initially individually, then reflect jointly on ideas to carry on in group in the programming and prototyping stage.

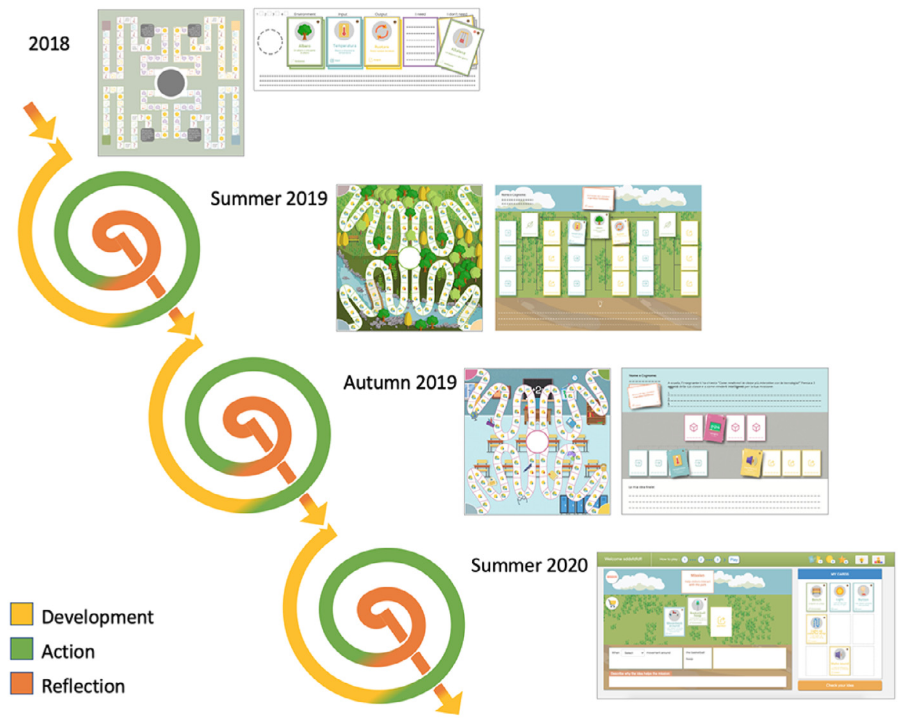

Fig. 1. The action-research evolution of SNaP, the core component of the smart-thing design toolkit, along spiralling cycles of development, action and reflections.

Table 3
Actions with SNaP across 2019 and 2020 with their location, participants, leading research questions and data gathering instruments.

When	Where	Participants	Questions	Instruments
Summer 2019	Bolzano, in presence	27 children, aged 11–14 years old, 5 researchers	Learning, experience	Observations, products
Autumn 2019	Bolzano, in presence	4 children, aged 11–13 years old, 2 researchers	Learning, experience	Observations, products
Summer 2020	Ioannina, Bolzano, at a distance	7 children, aged 10–14 years old, 3 researchers	Learning, experience	Observations, products

Story-line and goal. The goal and story-line, giving the setting of the game, were written on separate card-based material. Managing such material was the task of the Senior Designer. In particular, the story-line served to immerse Junior Designers in the design environment, namely, the city's town park nearby a river. The shared goal, stated in the story-line, was to design one smart thing per Junior Designer and make the environment smart.

Cards. Cards of SNaP were divided into different decks. See Fig. 2. Necessary components of smart things are environment things, inputs and outputs. Thereby SNaP had decks for them. Environment cards represent things specific to the environment of the design workshop, and hence they were related to the outdoors nature park. Technology cards were for inputs and outputs, easy to match with inputs (e.g., buttons) and outputs (e.g., LED matrix) of the physical-computing devices of the SNaP-based toolkit. SNaP had also mission cards, which offered players missions to accomplish, related to the chosen physical environment, such as "make people stay healthy". Finally, reflection cards of SNaP were related to common reflection criteria emerging from the above literature review, and spanning different design stages: (i) feasibility, (ii) relevance for the mission and (iii) elaboration, addressing clarity and complexity.

Levels. SNaP boards were modular and came into progressive levels. Players used the first board for collecting as many cards as possible; they explored components of smart things with cards and then ideated with them as many smart things as possible. The next boards made players converge on the conceptualisation of few ideas, and hence reflect on these. The selected ideas were carried over into the programming and prototyping stage. See such boards in Fig. 3.

4.2. Action

The aforementioned SNaP version was used to frame a series of workshops. In total, they hosted 27 children (33.3% females), with no experience in ideating smart things or programming them. Their mean age was $M = 12$ years, maximum age $max = 14$ and minimum age $min = 11$ years, and standard deviation $SD = 1$. The workshops were run in a makerlab facility for citizens.

The workshops covered the three main design stages: (1) exploration; (2) ideation; (3) programming and prototyping. The following part describes how the workshops were framed around SNaP. See also Fig. 4.

Exploration. The first workshop took half a day, under the guidance of a facilitator. It consisted of playful explorations of programmable micro-controllers, coupled with SNaP cards and scaffolding programs for the subsequent workshops, so as to make children familiar with the design toolkit. See examples in Fig. 5. For instance, for each scaffolding program, the facilitator challenged children, in a playful manner, to find matching SNaP input and output cards. Then the facilitator asked children to change little parts of the scaffolding programs, firstly by inviting them to explore related parts of the programming environment, and then by inviting them to tinker with those. Tangible outcomes were modifications of programs for the micro-controllers, with the companion cards for inputs and outputs necessary for programming smart things.

Ideation. The subsequent workshop, half-a-day long, involved children in ideating with SNaP boards. Their ideation progressed

Fig. 2. Examples of SNaP cards in summer 2019 from the decks for: (from left to right) reflection, mission, environment, input and output.

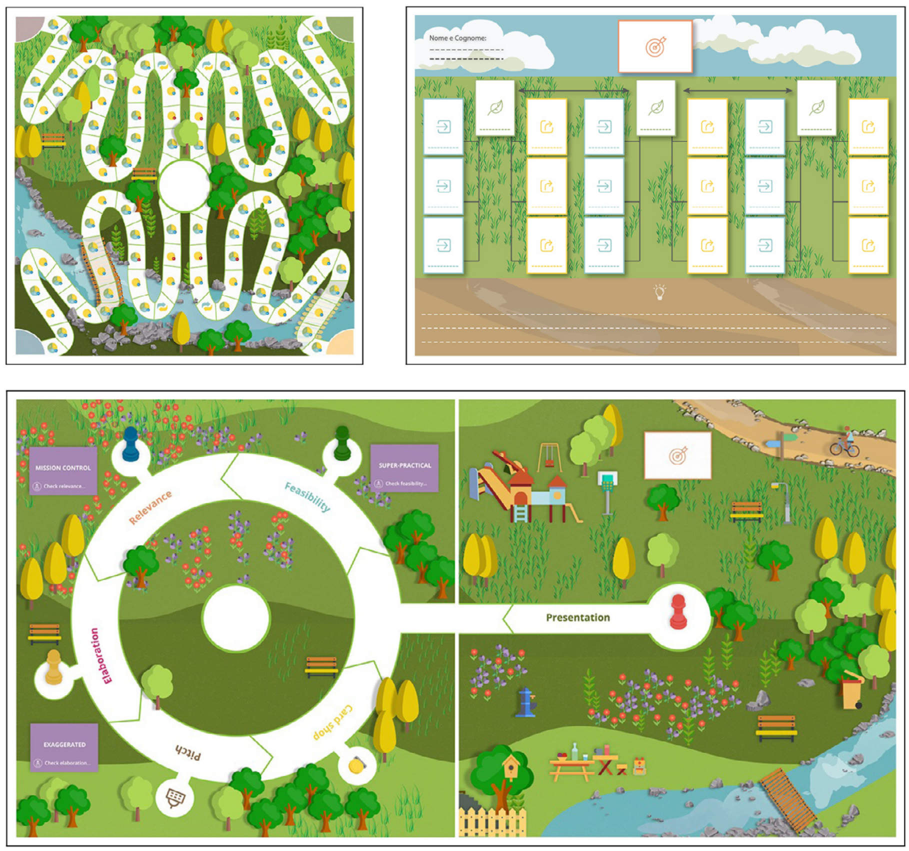

Fig. 3. The in-presence summer 2019 SNaP board: the first level with 4 paths for collecting cards and creating as many ideas as possible (top-left); the second level with the conceptualisation board (top-right); the third level with the reflection circular path (bottom).

Fig. 4. The design workshops in summer 2019 and the usage of SNaP within them.

along their play on SNaP game boards, alternating divergent thinking for creating as many ideas as possible, convergent thinking and reflections for converging and reflecting on selected ideas. Tangible outcomes of this workshop were children's conceptualisation boards, one per child, which conceptualised an idea of a smart thing to carry on in the last workshop.

Programming and prototyping. The final workshop took half a day, when children, in small groups, programmed and prototyped ideas of smart things, starting from conceptualisation boards. They used cards of SNaP to reflect on their smart things. Again, this stage enabled children to expand on ideas, and converge towards a program and prototype, with reflection stimuli. Tangible outcomes were programs and prototypes, by children, of their smart things.

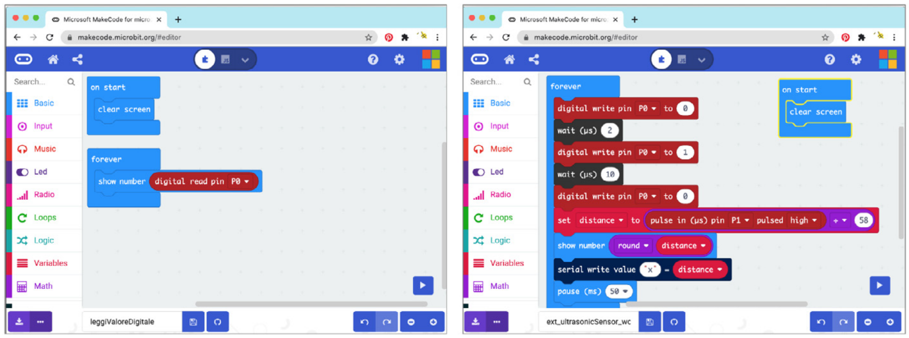

Fig. 5. Scaffolding programming examples for exploration and familiarisation in summer 2019: a basic example for adding an extra button (left); a comparatively complex example of making an ultrasonic sensor work.

4.3. Reflections

As explained in Section 3, all actions gathered data in relation to the following research questions: (RQ1) what children designed, in relation to their learning of smart-thing design, (RQ2) and their overall experience with design. That was the case in summer 2019 as well.

Observations related to learning and the overall experience of children were tracked in videos and structured notes by participant researchers; structure notes were diaries, with one page per research question (learning and experience), and design stage (exploration, ideation, programming and prototyping). Further data were design products, namely, children's ideas, conceptualised on SNaP boards, as well as their programs and prototypes. They are reflected over in the following, in relation to implications for the next cycle with SNaP.

Observations. In the exploration workshop, children rapidly understood how to tinker with the given programs and matching cards for explaining inputs and outputs of programs. Also the other workshops, gravitating around SNaP, seem to have positively affected children's learning of smart-thing design. However, as tracked by researchers in their notes, it was observed that several children needed further scaffolding in relation to the conceptualisation board: "the idea of F. has been re-conceptualised over with the facilitator. Also J. has some perplexities on how to use the board and where to place environment cards. The same holds for L. and R., who have difficulties in managing their (many) cards on their boards". Moreover, those participants who had difficulty in programming also tended to repeatedly have issues in conceptualising ideas as in SNaP conceptualisation boards. For instance, a researcher tracked the following in her notes for the ideation stage: "A. is confused, he is not respecting or not understanding rules [for ideating], he continues asking questions and annoying others". She also observed what follows during the programming and prototyping stage: "all participants, but A., seem to follow the first session (explanation about how to connect input and output devices) [...]. A. is not sitting around the table with the others during programming and does not try contributing to it".

Moreover, after the first round of reflections through the game, children tended to spontaneously role-play the experts and pose reflection questions without reading these, showing to have learnt the reflection criteria and to be able to apply them in general, with the exception of feasibility which required the scaffolding of the adult acting as Senior Designer. Given the more hands-on and "messy" nature and the number of participating children, it was not possible to trace similar reflections around cards of children during the programming and prototyping workshops.

Table 4
A smart thing (a smart path) of the 2019 summer design workshops.

Smart path	
Mission	The mission was to encourage people to do things in the park which are good for their health.
Input, environment, output	The smart thing used a pressure sensor as input, path as the environment thing, show icon and make sound as outputs.
Idea	When a person riding a bicycle goes over the smart path, activating the pressure sensor, animated icons are shown to encourage the cyclist to continue cycling; encouraging music is also played. See Fig. 6, left side.

Table 5
A smart thing (a smart gate) of the 2019 summer design workshops.

Smart gate	
Mission	The mission was to make visitors explore hidden spaces.
Input, environment, output	The smart thing used a distance sensor as input, the park gate as environment thing, show icon, make sound and rotate as outputs.
Idea	When a person visiting the park comes close to the gate (as sensed by the distance sensor), the gate opens up using a rotating motor, revealing a hidden area of the park; also, a heart icon/emoji is shown, while a pleasant tune is played in the background. See Fig. 6, right side.

Products. All children ideated at least one smart thing, programmed and prototyped it. Example ideas of smart things are in Tables 4 and 5. Their prototypes are in Fig. 6.

Children's ideas, programs and prototypes were in general rather complex in terms of the number of input and output devices that children considered. Specifically, the input devices that children used had mean number $M = 1.81$, with $max = 3$, $min = 1$, and $SD = 0.98$. The output devices had mean number $M = 2.72$, with $max = 4$, $min = 2$, and $SD = 0.64$. Moreover, in their programs and prototypes, children tried keeping the input and output devices they had used in the ideation stage, whenever feasible. They added mainly music and light effects. In the cases the original ideas were already complex per se in terms of the number of inputs and outputs, children focused on programming the devices they had already considered in the ideas.

However children's programs mainly referred to what children had learnt during the workshops: a reactive prototype, with an infinite loop with a conditional for checking if input data were available and, in case so, reacting accordingly with different output devices.

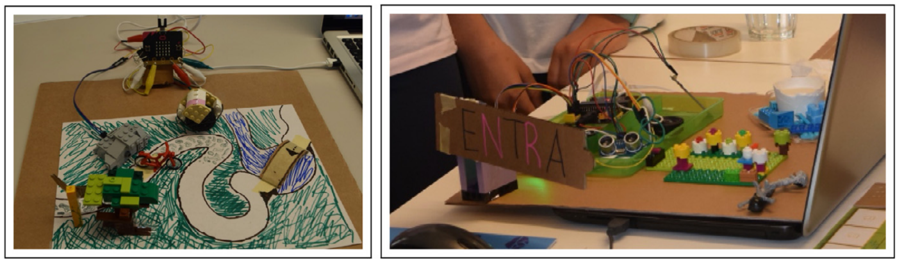

Fig. 6. Smart things of summer 2019: the smart path (left); the smart gate (right).

Implications. In view of the results above, concerning difficulties of children, an adaptation of the SNaP conceptualisation board was deemed necessary, for conceptualising ideas and stirring them through the programming stage. Instead, results related to reflections indicated that children could take up a more independent design role, and adults' scaffolding role could slowly fade, except possibly for the feasibility reflection card. Therefore the SNaP reflection cards seemed suitable, albeit requiring further scaffolding for feasibility.

Moreover, the overall complexity of children's products suggested that children could be challenged to program and prototype individually, and jointly reflect on their smart things during programming and prototyping.

5. In-presence design in autumn 2019

In view of the results of the 2019 summer workshops, SNaP and its usage in design evolved. Fig. 7 displays the new game board. This sections explains its novel development, the related action and reflections.

5.1. Developed features

Role of players and collaboration. The new design context was a school and hence, instead of the Mayor, there was a Teacher, setting the overall game goal. This was a role played by an adult teacher. Again, all children were invited to collaborate through design so as to reach their goal. However, children were given a more independent role in design from each other and, in general, the role of adults faded away. The previous roles of Junior and Senior Designers were fused so that one child could play them both. Whereas children were invited to work jointly on programs in Summer 2019, they were invited to work individually on programs, and at times share their ideas in Autumn 2019.

Story-line, goal and winning-condition. The goal and story-line were also changed according to the new context. The goal was to enhance classrooms. According to the new story-line, the Teacher challenged all other players to think of classroom things and how to make them smart to achieve this goal. The winning condition remained as in the past version.

Cards. Cards changed in terms of environment cards for school classroom. Moreover, different input and output cards were chosen so as to match the environment as well, e.g., cards for measuring water levels were removed. Finally, reflection cards and their number were maintained as in the summer version of the game, albeit questions were re-elaborated for the feasibility card.

Levels. The aesthetics of the boards changed so as to reflect the change in context. As for the mechanics, the conceptualisation board changed too. See Fig. 7, top-right. This came with extra space to describe the intended interaction, and track ideas in diary format at home, across workshops. Moreover, the spatial arrangement of cards mimicked how children tended to place cards in their conceptualisation boards in summer 2019, and considered how to best visually guide children for later programming their smart things.

5.2. Action

The second action consisted of a series of progressive design workshops, lasted two hours each, framed around the novel SNaP described above. They were organised along six weeks, detailed in the following. The workshops hosted 4 children, 1 female. Their mean age was $M = 12.25$ years, maximum age $max = 13$ and minimum age $min = 12$ years, and standard deviation $SD = 0.43$. The workshops were run in a makerlab facility for citizens.

The workshops covered again all design stages, as explained in the remainder. See also Fig. 8.

Exploration. The first three workshops served to make children further explore and familiarise with micro:bit boards and the programming environment of Makecode (Micro:bit-Educational-Foundation, 2019; Microsoft, 2019). Each workshop tackled specific programming concepts (i.e., conditionals, variables, loops), besides input and output devices, not yet explored in summer 2019, again correlated to SNaP cards. Children also explored the different pins of the micro:bit (ground, voltage, signal) for connecting further input and output devices.

Ideation. During the fourth workshop, children played cards on the adapted SNaP boards, and without adults, so as to conceptualise in novel conceptualisation boards and reflect with cards on ideas of smart things for their schools.

Programming and prototyping. In the last two workshops, programming and prototyping took place. Toolkits had input and output devices matching the input and output cards used in SNaP conceptualisation boards (e.g., buttons, LCD screens). The devices were marked with indications on the wire connections (ground, voltage, signal) so as to guide children on how to connect them, on their own, to the micro:bit boards. See Fig. 9. Children were again invited to reflect through reflection criteria offered by SNaP cards.

Subsequently, they jointly tested their prototypes and presented them to a guest teacher, role-playing as the SNaP Teacher.

5.3. Reflections

Data were collected as in summer 2019 in relation to the same research questions, RQ1 and RQ2. Reflections on results are reported below, divided per data: observations; products by children.

Observations. All children managed to replicate successfully the scaffolding examples given them in the exploration workshops. In fact, the majority of them (3 out of 4) wanted to modify and extend the examples by adding more features during the last 30 min of free exploration of the workshops. They also decided

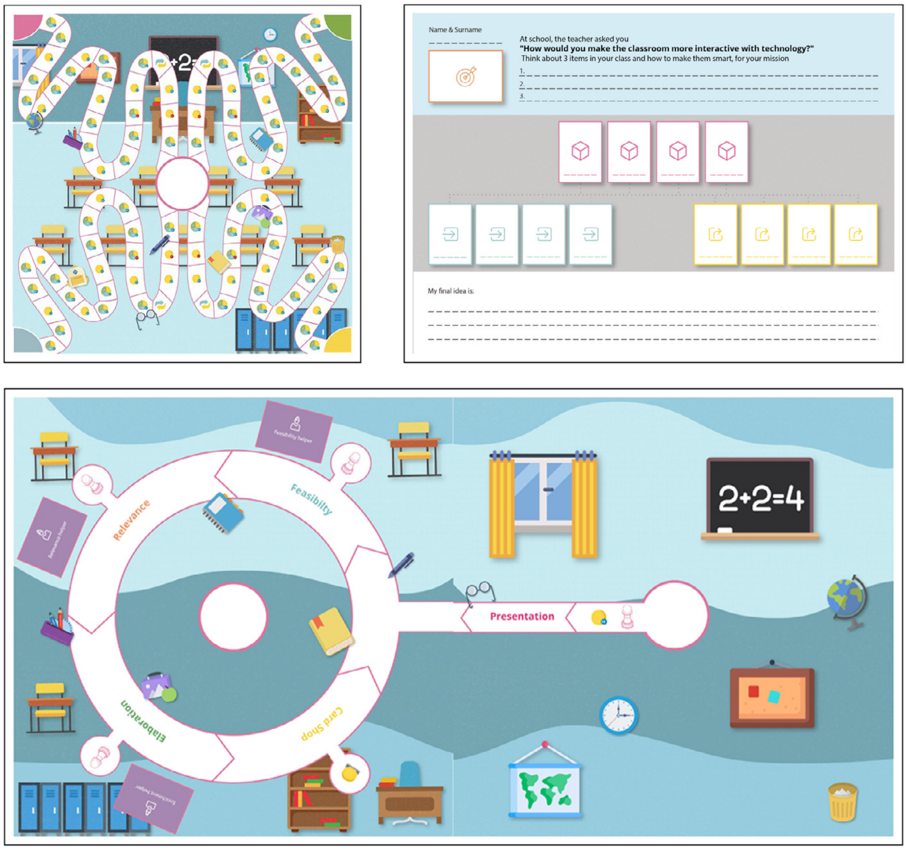

Fig. 7. The in-presence autumn 2019 SNaP board: the first level with four paths for collecting cards and creating as many ideas as possible (top-left); the second level with the conceptualisation board (top-right); the third level with the reflection circular path (bottom).

Fig. 8. The design workshops in autumn 2019 and the usage of SNaP within them.

to ideate smart things based on their programs, elaborating on examples, and to present their work to each other. For example a programming example, which involved a button, a buzzer and a motor, evolved into the following idea and program: "when a button on a table is pushed, the window next to it opens and music is reproduced".

Children were also able to play the game for ideating on their own, without extra help from adults, during the fourth workshop: they all collaborated and reflected on their ideas independently of any adult, also in terms of feasibility. See Fig. 10. In turn, each one of them argued on their ideas. For example while reflecting with others on the relevance of the idea with the mission, a child argued that the smart backpack can "facilitate a positive behaviour between the students and the teacher", because it is a gift that the teacher will give to students for rewarding a good behaviour; see it in Table 7. Feasibility issues were also properly spotted by the children themselves. For instance, a child chose the wrong output cards for moving the smart thing. The mistake was indicated by the player with the feasibility reflection card.

None of the children had issues with the novel conceptualisation board, e.g., all verbal descriptions of ideas matched with the chosen cards for input and output devices. In fact, a child commented that the new board helped her to "show the idea in concrete pieces".

During the two conclusive workshops, children were able to program and prototype their smart things rather independently of adults. Children overall worked on their own and delivered working programs of their smart things. Help was necessary only for explaining the radio blocks.

Products. Example smart-thing ideas are in Tables 6 and 7. Their prototypes are in Fig. 11. Children created rather complex prototypes also in this workshop in terms of the amount of inputs and outputs. They tended to use on average slightly more input devices and slightly less output devices compared to the summer

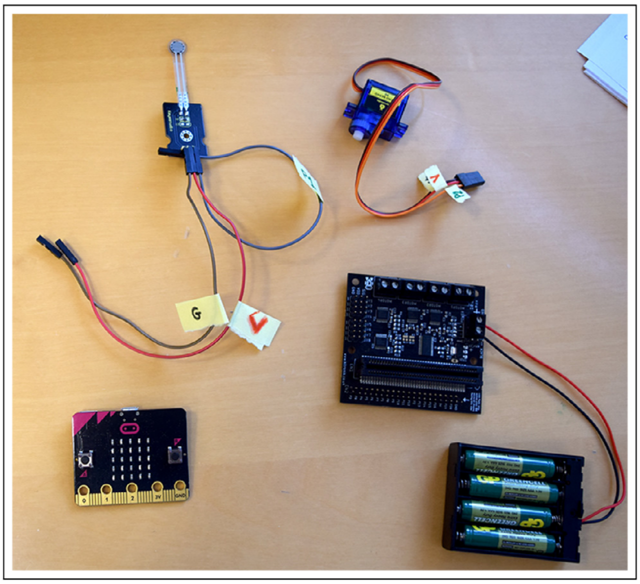

Fig. 9. In the autumn 2019 action, input and output devices were marked with indications on the wire connections (for ground, voltage, signal) so as to guide children.

Table 6
Smart things (smart desks) of the 2019 autumn design workshops.

Smart desks	
Mission	The mission was to improve the communication in class.
Input, environment, output	The smart thing used three buttons as inputs, a student desk and the teacher desk for environment things, then make sound, show text and light up as outputs.
Idea	When a student wants to tell something to the teacher in private, the student pushes the button on his/her desk; then a message appears on the teacher's desk and a light switches on in order to notify the teacher; the teacher can read the message or listen to it with his/her own headphones. The related prototype is on the left-side in Fig. 11.

Table 7
Smart things (smart backpack) of the 2019 autumn design workshops.

Smart backpack	
Mission	The mission was to facilitate a positive behaviour between the students and the teacher.
Input, environment, output	The smart thing used: a button and an accelerometer as input, a backpack as environment thing, make sound, show icon and vibrate as outputs.
Idea	When you press a button, it displays a heart and plays a song; a teacher gives this backpack as a gift to the students for rewarding a good behaviour inside the classroom. The related prototype is on the right-side in Fig. 11.

workshop. Specifically, the input devices that children used had mean number $M = 2.5$, with $max = 3$, $min = 2$, and $SD = 0.57$. The output devices had also mean number $M = 2.5$, with $max = 3$, $min = 2$, and $SD = 0.57$. They also tended to explore further blocks, besides the ones they were taught during the exploration workshops, and include them in their code. For example, two children decided to use event blocks in their code, a child used the radio blocks for sending and receiving data.

Implications. The results of the workshops were also reflected over in relation to the evolution of the design toolkit. As reported above, all children were eager to tinker with the given programming examples. They also ideated, programmed, prototyped and reflected on their ideas in general on their own. Such results were taken as indications that the presence of adults can be reduced and that the toolkit may be sufficient for guiding children across design, according to their experience. Such reflections were used to develop the new SNaP-based toolkit, affected also by the pandemic, as explained in the following.

6. At-a-distance design in 2020

The latest evolution of SNaP resulted from reflections on the 2019 workshops and the COVID-19 situation, e.g., forcing children to meet online or in small groups. The 2020 action consisted of smart-thing design workshops re-framed around the new SNaP, at a distance, and in two different countries: Greece, Italy. SNaP became digital for supporting children in Greece, unexperienced of design. This is accessible online, via any computer web browser supporting HTML5 and JavaScript (Roumelioti, 2020). SNaP remained physical for children in Italy, already used to smart design with past versions of SNaP.

This section is structured as the previous two, that is, it reports: the developed or adapted main features of SNaP; how SNaP was used to frame design workshops with children, namely, actions at a distance; conclusive reflections.

6.1. Developed features

Fig. 12 displays the novel digital SNaP used by children in Greece. Fig. 13 instead shows part of the novel physical SNaP used by children in Italy. The main novel features are described in the following.

Role of players and collaboration. Children in Greece role played as Junior Designers. Children in Italy role played as Senior Designers, picking up Junior Designers' ideas. Collaboration with adults was made available via the avatar of the digital SNaP. In Italy children could contact adults online.

Story-line, goal and winning-condition. The environment of the game was a city's town park, as in the 2019 summer cycle, which players had to make smart. The overall goal, story-line and winning condition were similar as well.

Cards. Technology cards of SNaP matched physical-computing devices of the SNaP-based toolkit. The environment and mission cards were related to the chosen physical environment, a smart park.

Levels. The digital SNaP was divided into four levels, for the exploration and ideation workshops of past actions. Each level came with a goal to achieve for players, explained as follows. The first level's goal was to explore and familiarise with technology cards and how to move them on the conceptualisation board. See Fig. 12, the top left part. The second level's goal was to explore and familiarise with the conceptualisation board itself. This helped players explore how to describe input and output cards by using a semi-controlled natural language. An example in English is in Fig. 12, the top right part: "when the temperature is high around the tree then show this text: 'I am thirsty"'. The goal of the third level was to explore and familiarise with how to create the player's own idea through the shop mechanism. See Fig. 12, the bottom left part. The final level is for ideating as many ideas as players wish. Last but not least, SNaP enabled children to automatically translate their ideas into programs, embed them into the Makecode environment and exploit its simulators of

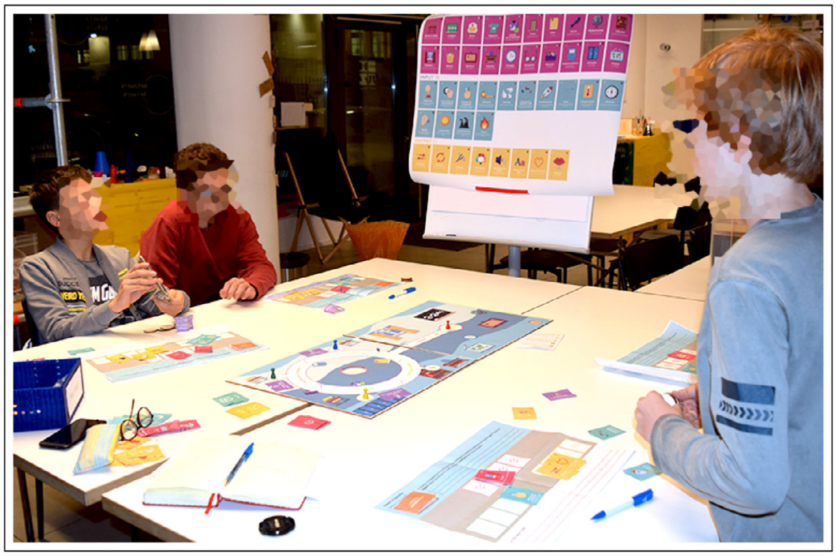

Fig. 10. Children reflecting on their ideas in the autumn 2019 action.

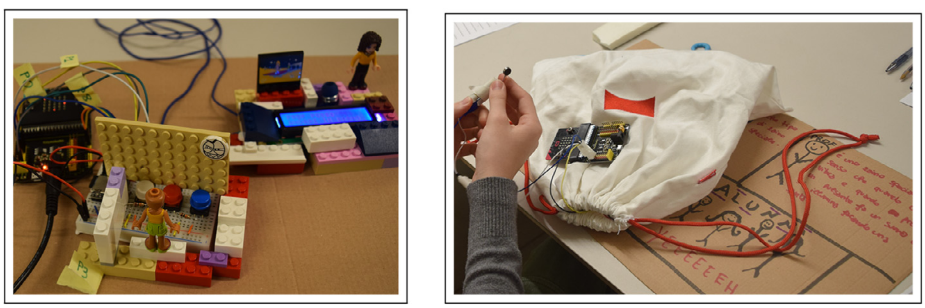

Fig. 11. Prototypes resulting from the autumn 2019 action.

Fig. 12. The digital summer 2020 SNaP: familiarising with technology cards in the first level (top, left); familiarising with the controlled-natural-language description of ideas in the second level (top, right); familiarising with how to acquire further cards for creating as many ideas as possible (bottom, left); downloading and sharing an idea with one's bought cards, stored in "my cards" (bottom).

physical-computing devices (Microsoft, 2019). See Fig. 12, the bottom right part.

The physical SNaP used the same cards as the digital SNaP game. It also had conceptualisation boards, with pre-printed cards and descriptions of ideas by children in Greece, besides URL links to the related programs in Makecode. See the right side of Fig. 15. Moreover, the physical conceptualisation board asked children to elaborate on ideas by other children, as suggested by the elaboration reflection card of SNaP in 2019. Specifically, children could change others' ideas by sticking new cards on the conceptualisation board (e.g., a mission card) or overwriting descriptions (e.g., from "if the temperature is low" to "if the temperature is above 30 degrees C"). Other types of elaborations were also possible: children would simply need to unfold horizontal

Fig. 13. A conceptualisation board of the SNaP physical kit, with cards, their descriptions, and program URL for an idea by children in Greece (top-left); the same conceptualisation board with flaps unfolded horizontally, asking a child to elaborate by adding further input or output cards with their descriptions (bottom-left); the reflection part of the conceptualisation board revealed by unfolding vertically, after elaborating, with further reflection questions and probes (right).

Fig. 14. The design workshops in autumn 2020 and the usage of SNaP within them.

flaps of the conceptualisation board and stick further cards on the uncovered side in order to augment the original idea with further input or output devices. Unfolding the board vertically would instead reveal further reflection cards. See Fig. 13.

6.2. Action

This action consisted of a series of workshops, one in Greece and the other one in Italy. All workshops were run in open spaces, with one or two children and an adult acting as observer, complying with all COVID-19 regulations in force in Greece and Italy at that time.

The workshops in Greece hosted 5 children, and 3 were females. Their mean age was $M = 12.6$ years, maximum age $max = 14$ and minimum age $min = 10$ years, and standard deviation $SD = 1.49$. The workshops in Italy hosted 2 children, all males, one aged 12 and the other 13 years old.

The workshops were for designing smart things with children and were reorganised slightly differently around SNaP, as follows: (1) exploring and (2) ideating with the digital SNaP in Greece; (3) elaborating ideas, (4) programming and prototyping in Italy with the physical SNaP-based toolkit. The following part describes the workshops in more details. See also Fig. 14.

Exploration, and ideation with the digital SNaP. Children from Greece, who had never participated in design workshops before the 2020 action, explored smart-thing design through the related levels of the digital SNaP. Their ideas, conceptualised on boards and programmed through simple conditionals in an infinite loop, were shared via the physical SNaP toolkit with Italian children.

Elaboration of ideas, programming and prototyping with the physical SNaP. Children in Italy, who had participated in past SNaP-actions, were invited to continue designing the ideas of children from Greece through the SNaP physical toolkit. Their toolkit contained also a micro:bit board, external input and output devices for children, matching the cards of SNaP. Fig. 15 shows it and a program given to children and linked on a conceptualisation board.

6.3. Reflections

Data were collected like in 2019 in relation to the same research questions, R1 and R2. Reflections on results are reported below, divided per observations and products by children.

Observations. The scaffolding step-by-step design of the digital game, with its semi-controlled natural language for describing ideas enabled children in Greece, who had never designed smart things, to grab how to ideate these. They were observed to follow SNaP levels one by one, in the given progression order. While reflecting on others' ideas, children in Italy were instead observed to display all physical cards on the table, to have "an overview of them all to choose best". They were also quickly shuffling them around and on their conceptualisation boards so as to understand which would fit best. These children were also already familiar with SNaP cards; for instance, they never read textual descriptions and they only referred to icons of cards in order to quickly spot what input or output devices cards represented. Finally, contrary to novice designers, who had ideated smart things for the first time, children in Italy did not wish for restraints in conceptualisation boards for describing their ideas: once probed about it, they declared that they wanted "to go beyond simple if-then rules".

Products. All children in Greece went beyond the first three levels and generated at least one idea. Both children in Italy reflected over ideas and programs with the provided reflection cards, part of the toolkit, and continued designing them by adding at least one input or output card, with a maximum of two per type. Table 8 gives an example of the original smart thing, its elaboration and final smart-thing idea, which was also programmed as shown in Fig. 16.

Implications. The design of the digital conceptualisation board catered for non-expert designers: it was suitable for novice designers in Greece, and also enabled for an automated generation of program snippets. The conceptualisation of their ideas and companion programs enabled other children to quickly pick them up and elaborate on them with the physical SNaP toolkit. As

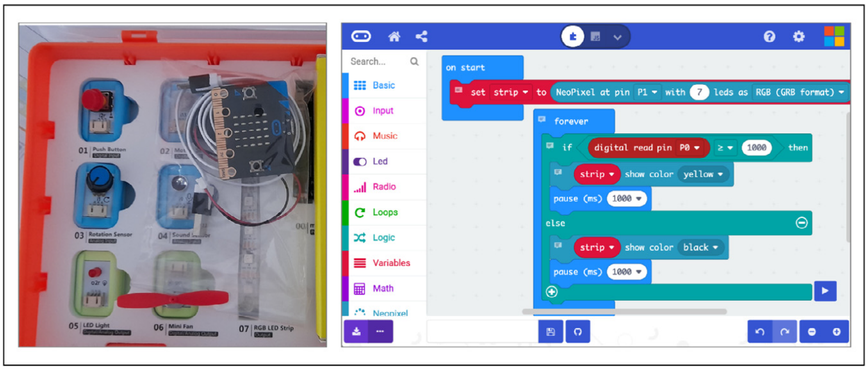

Fig. 15. Physical-computing devices of the physical SNaP toolkit for children in Italy (left); a program for an idea by children from Greece, linked on the conceptualisation board of the physical SNaP toolkit (right).

Table 8
Smart things (smart birdhouse) of the 2020 summer design workshops.

Smart birdhouse	
Starting mission	A child in Greece chose to help keep the park clean.
Starting input, environment, output	His smart thing used a temperature sensor as input, a bird house as environment thing, and a show text as output.
Starting idea	When the temperature is high around the bird house, then show the text ‘flowers will wilt’.
Elaborated mission	A child in Italy changed the mission into making nature thrive because of the relevance reflection card of SNaP.
Elaborated input, environment, output	His smart thing changed the original usage of the output card (i.e., the text shown referred to a flower) by reflecting on its relevance for the environment card (a bird house). It also added an output for an LED strip.
Elaborated idea	When the temperature is high around the bird house, then show the text ‘the bird house is over heating’ and a rainbow is shown to indicate a raise in temperature. See the related conceptualisation board and program in Fig. 16.

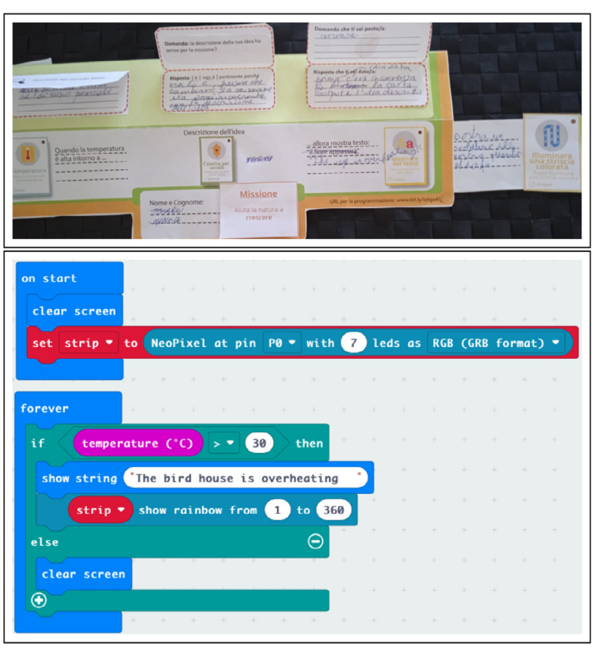

Fig. 16. Evolved idea and program from Greece to Italy in the 2020 action.

reported above, the open-nature of the paper-based conceptualisation boards of the physical SNaP enabled more experienced designers to freely customise them to their liking. They were also observed to use reflection cards while programming, e.g., they reflected on the relevance of a programming snippet with respect to the idea described in a conceptualisation board.

7. Conclusions

According to the reviewed literature, design with children tends to focus on a specific stage. The work reported in this paper offers a toolkit for framing smart-thing design with children, guiding them through the exploration, ideation, programming and prototyping of their own smart things, and offering them multiple, tangible reflection stimuli. The core of the toolkit are the SNaP game and its decks of cards.

The paper presents how SNaP evolved along the years through an action research spiral, made of development-action-reflection cycles. The first sub-section below reflects on the action-research approach itself. The second sub-section below draws lessons concerning toolkits for smart-thing design with children, resulting from all cycles of action research. The final sub-section of this paper reflects on limitations and presents on-going work.

7.1. Reflections on action research

Action research was adopted to make the SNaP toolkit evolve according to the possibilities unveiled by actions and reflections, namely, design workshops with children using the toolkit, and reflections on the gathered data. This approach enabled researchers to consider the benefits of participant children and, at the same time, evolve the toolkit along all action-research cycles.

In particular, the two 2019 cycles involved 27 and 4 children, respectively. During those design workshops with SNaP, children designed smart things for two different environments: an outdoor-nature environment in the first cycle, in summer 2019; a school classroom environment in the second cycle, in autumn 2020. Reflections on the workshops show that children learnt how to design their own smart things, in both settings.

The last cycle took place during the COVID-19 pandemic, in summer 2020, with 7 children in total. Results of past actions were reflected over in light of the completely mutated context, and SNaP evolved accordingly. A digital version of the game was developed, which is accessible via any computer web browser supporting HTML5 and JavaScript (Roumelioti, 2020). Specific features were developed so as to enable beginners to start designing, independently, at a distance, such as the usage of controlled natural language for describing ideas of smart things. Children in Greece, without design experience, used the digital SNaP and started designing simple smart things.

Their ideas and resulting programs were then shared with children in Italy. These children had already participated in SNaP design workshops in the past. They were experienced in smart-thing design, and they were familiar with SNaP cards and conceptualisation boards. These children were thus given physical SNaP toolkits, which enabled them to collaborate with children from Greece and make their ideas evolve into programmed prototypes.

Data were uniformly gathered and processed across all actions. The related results and reflections are next analysed thematically, so as to extract general lessons for conducting smart-thing design with children so that they are enabled to design their own smart things.

7.2. Lessons learnt for smart-thing design with children

Exploration. The design process suggested by several researchers, such as Smith et al. (2015), does not always involve a structured exploration stage. It is important, however, that the process is structured so that children become familiar with the components of the things under design before they move on to the next design stages. In smart-thing design with SNaP, the exploration and familiarisation stage was structured by the SNaP toolkit, as follows. The exploration stage employed SNaP cards for input and output devices, and it asked children to play and match them with devices for programming and prototyping, e.g., via quizzes. Last but not least, the exploration stage offered children many scaffolding examples, to freely tinker with. For instance, in Summer 2020, children had SNaP boards with ideas of smart things and matching programs to tinker with in the Makecode programming environment (Microsoft, 2019), e.g., they could change the threshold for the temperature input device and make the smart thing react when the environment was hot instead of cold.

Ideation. During ideation and conceptualisation of smart thing ideas, divergent and convergent thinking enable children to open up their design process, consider new perspectives and subsequently discard aspects during their attempt to reach a design solution (Iversen et al., 2017). Ideation and conceptualisation should guide children accordingly, and tangibly so. For instance, in the research reported in this paper, that was supported by the SNaP toolkit, and especially its game boards for firstly ideating as many ideas as possible (divergent thinking) and then reflecting on an idea to conceptualise (convergent thinking). Tangible outcomes were children's boards, one per child, which conceptualised an idea of a smart thing to carry on in the last design stage.

Programming and prototyping. Once an idea is conceptualised, the process should continue for programming and prototyping it. In SNaP-framed design, children programmed and prototyped their ideas of smart things, conceptualised with SNaP boards and cards, and they were thus motivated to continue. Again, this stage enabled children to elaborate on ideas, and converge towards a program and prototype in a rather short term. Tangible outcomes were programs and prototypes, by children, of their smart things.

Playful or gameful. Last but not least, the playful or gameful dimensions are fundamental and should be always present across the entire smart-thing design process with children; playful design aims at affording so-called "*paidic* qualities" (the experiential qualities characteristic for unstructured play), whereas gameful design aims at affording so-called "*ludic* qualities or gamefulness (the experiential qualities characteristic for gameplay) in nongame contexts" (Deterding, 2015). Both dimensions are relevant for children, especially without experience in design and programming. They can feel overwhelmed with smart-thing design, due to its inherent complexity. Play or games can help overcome such feelings (Raftopoulos, 2015). In the work reported in this paper, SNaP offered children not only a learning experience with a structured tangible design process, but also a gameful experience. Children, being in general familiar with playing games, easily grasped the game mechanics, and they were motivated to try reaching the winning condition even without prior experience in design. The collaborative nature of the game helped them work with each other, combining their "strengths" and knowledge to design their smart things, even at a distance.

7.3. Limitations, on-going and future research

The research reported in this paper has limits in that it is context-bound, and due to its sample size. However, we believe that the reported research can contribute to the advancement of child-centred-interaction research. Specifically, the reported work shows benefits of adopting an action-research approach: actions in the field made researchers aware of development opportunities, which made the design toolkit evolve rapidly according to the contextual requirements and possibilities. Cycles of action-research enabled researchers to draw action-informed, general lessons for framing future smart-thing design initiatives with children, which other researchers can easily pick up.

On-going work contemplates new hybrid design workshops, with the digital and physical SNaP games concluding the paper. The digital game is being used in novel actions with novice smart-thing designers, in order to stir their exploration and familiarisation with what it takes to design smart things, so as to enable them to rapidly ideate and program a basic smart thing, with if-then rule as in Fig. 15. The physical game is being used with more experienced smart-thing designers, because the physical game gives them more control and freedom over their design choices than the digital game does.

Another evolution of the SNaP game, named IoTgo, addresses the more experienced designers, who wish to continue designing more and more complex smart things. If used to frame smart-thing design, IoTgo enables them to play, so as to explore, ideate and program things which can interconnect and process data from the web, and reflect over them through further cards than those of SNaP. At present, IoTgo has been acted upon with adult designers and two children, and its design is evolving accordingly.

Declaration of competing interest

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

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References

Angelini, L., Mugellini, E., Couture, N., & Abou Khaled, O. (2018). Designing the interaction with the internet of tangible things: A card set. In *Proceedings of the twelfth international conference on tangible, embedded, and embodied interaction, TEI '18* (pp. 299–306). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3173225.3173288.

Baykal, G. E., Goksun, T., & Yantaç, A. E. (2018). Customizing developmentally situated design (DSD) cards: Informing designers about preschoolers' spatial learning. In *Proceedings of the 2018 CHI conference on human factors in computing systems, CHI '18* (pp. 592:1–592:9). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3173574.3174166.

Bekker, T., Bakker, S., Douma, I., van der Poel, J., & Scheltenaar, K. (2015). Teaching children digital literacy through design-based learning with digital toolkits in schools. *International Journal of Child-Computer Interaction*, *5*, 29–38, Digital Fabrication in Education.

Berger, A., Odom, W., Storz, M., Bischof, A., Kurze, A., & Hornecker, E. (2019). The inflatable cat: Idiosyncratic ideation of smart objects for the home. In *Proceedings of the 2019 CHI conference on human factors in computing systems, CHI '19* (pp. 401:1–401:12). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3290605.3300631, URL: http://doi.acm.org/10.1145/3290605.3300631.

Blikstein, P., & Krannich, D. (2013). The makers' movement and fablabs in education: Experiences, technologies, and research. In *Proceedings of the 12th international conference on interaction design and children, IDC '13* (pp. 613–616). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2485760.2485884, URL: http://doi.acm.org/10.1145/2485760.2485884.

Booth, T., Bird, J., Stumpf, S., & Jones, S. (2019). Designing troubleshooting support cards for novice end-user developers of physical computing prototypes. In *End-user development* (pp. 191–199). Cham: Springer International Publishing.

Brito, R., & Houghton, P. (2017). Iot service kit. http://iotservicekit.com. Accessed: 2019-09-06.

Caraban, A., Konstantinou, L., & Karapanos, E. (2020). The nudge deck: A design support tool for technology-mediated nudging. In *Proceedings of the 2020 ACM designing interactive systems conference, DIS '20* (pp. 395–406). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/3357236.3395485, URL: https://doi-org.libproxy.unibz.it/10.1145/3357236.3395485.

Cards, K. (2019). Learn. play. collect. - know cards. https://know-cards.myshopify.com. Accessed: 2019-09-06.

Choi, K., Kim, T., & Suk, H.-J. (2020). Lighting user experience (lux) cards: A card-based tool for the design of smart lighting solutions. *Archives of Design Research*, *33*, 55–64.

Cleto, B., Sylla, C., Ferreira, L., & Moura, J. M. (2020). Codecubes: Coding with augmented reality. In R. Queirós, F. Portela, M. Pinto, & A. Simões (Eds.), *OpenAccess series in informatics (OASIcs)*: *vol. 81*, *First international computer programming education conference (ICPEC 2020)* (pp. 7:1–7:9). Germany: Schloss Dagstuhl–Leibniz-Zentrum für Informatik, Dagstuhl, http://dx.doi.org/10.4230/OASIcs.ICPEC.2020.7, URL: https://drops.dagstuhl.de/opus/volltexte/2020/12294.

Darzentas, D., Velt, R., Wetzel, R., Craigon, P. J., Wagner, H. G., Urquhart, L. D., et al. (2019). Card mapper: Enabling data-driven reflections on ideation cards. In *Proceedings of the 2019 CHI conference on human factors in computing systems, CHI '19* (pp. 571:1–571:15). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3290605.3300801, URL: http://doi.acm.org/10.1145/3290605.3300801.

Deterding, S. (2015). The lens of intrinsic skill atoms: A method for gameful design. *Human-Computer Interaction*, *30*, 294–335.

Di Mascio, T., Gennari, R., Tarantino, L., & Vittorini, P. (2017). Designing visualizations of temporal relations for children: action research meets HCI. *Multimedia Tools and Applications*, *76*, 4855–4893.

Dibitonto, M., Tazzi, F., Leszczynska, K., & Medaglia, C. M. (2018). The IoT design deck: A tool for the co-design of connected products. In *Advances in usability and user experience* (pp. 217–227). Cham: Springer International Publishing, URL: https://doi.org/10.1007/978-3-319-60492-3_21.

Dodero, G., Gennari, R., Melonio, A., & Torello, S. (2014). Gamified co-design with cooperative learning. In *CHI '14 extended abstracts on human factors in computing systems, CHI EA '14* (pp. 707–718). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2559206.2578870, URL: http://doi.acm.org/10.1145/2559206.2578870.

Dowthwaite, L., Creswick, H., Portillo, V., Zhao, J., Patel, M., Vallejos, E. P., et al. (2020). It's your private information. it's your life.: Young people's views of personal data use by online technologies. In *Proceedings of the interaction design and children conference, IDC '20* (pp. 121–134). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/3392063.3394410, URL: https://doi-org.libproxy.unibz.it/10.1145/3392063.3394410.

Druin, A. (1999). The role of children in the design of new technology.

Druin, A. (2002). The role of children in the design of new technology. *Behaviour & Information Technology*, *21*, 1–25.

Eriksson, E., Iversen, O. S., Baykal, G. E., Van Mechelen, M., Smith, R., Wagner, M.-L., et al. (2019). Widening the scope of fablearn research: Integrating computational thinking, design and making. In *Proceedings of the FabLearn Europe 2019 conference, FabLearn Europe '19* (pp. 15:1–15:9). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3335055.3335070, URL: http://doi.acm.org/10.1145/3335055.3335070.

Fails, J. A., Guha, M. L., & Druin, A. (2013). *Methods and techniques for involving children in the design of new technology for children*. Hanover, MA, USA: Now Publishers Inc..

Gennari, R., Matera, M., Melonio, A., Rizvi, M., & Roumelioti, E. (2020a). Engaging pre-teens in ideating and programming smart objects through play. In *Methodologies and intelligent systems for technology enhanced learning, 10th international conference* (pp. 31–40). Cham: Springer International Publishing.

Gennari, R., Matera, M., Melonio, A., Rizvi, M., & Roumelioti, E. (2020b). Reflection and awareness in the design process children ideating, programming and prototyping smart objects. *Multimedia Tools and Applications*.

Gennari, R., Matera, M., Melonio, A., & Roumelioti, E. (2019). A board game and a workshop for co-creating smart nature ecosystems. In *Proc. of the 9th international conference in methodologies and intelligent systems for technology enhanced learning (Mis4TEL 2019)* (pp. 137–145). Springer.

Gennari, R., Melonio, A., Raccanello, D., Brondino, M., Dodero, G., Pasini, M., et al. (2017). Children's emotions and quality of products in participatory game design. *International Journal of Human-Computer Studies*, *101*, 45–61.

Gennari, R., Melonio, A., & Rizvi, M. (2018). Evolving tangibles for children's social learning through conversations: Beyond turntalk. In *ACM international conference on tangible, embedded and embodied interaction, TEI '18* (pp. 368–375). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/3173225.3173248.

Gennari, R., Melonio, A., & Rizvi, M. (2020). From turntalk to classtalk: the emergence of tangibles for class conversations in primary school classrooms. *Behaviour & Information Technology*, *39*, 88–107.

Gennari, R., Melonio, A., Rizvi, M., & Bonani, A. (2017). Design of IoT tangibles for primary schools: A case study. In *Proceedings of the 12th biannual conference on Italian SIGCHI chapter, CHItaly '17* (pp. 26:1–26:6). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3125571.3125591.

Gianni, F., & Divitini, M. (2017). Designing IoT applications for smart cities: extending the tiles ideation toolkit. *IxD & A*, *35*, 100–116.

Gianni, F., Mora, S., & Divitini, M. (2018). Rapid prototyping internet of things applications for augmented objects: The tiles toolkit approach. In *Ambient intelligence* (pp. 204–220). Cham: Springer International Publishing.

Hildén, E., Ojala, J., & Vä, K. (2017). Development of context cards: A bus-specific ideation tool for co-design workshops. In *Proceedings of the 21st international academic mindtrek conference, AcademicMindtrek '17* (pp. 137–146). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3131085.3131092.

Huyghe, J., Wouters, N., Geerts, D., & Vande Moere, A. (2014). Localudo: Card-based workshop for interactive architecture. In *Proceedings of the extended abstracts of the 32nd annual ACM conference on human factors in computing systems, CHI EA '14* (pp. 1975–1980). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2559206.2581348, URL: http://doi.acm.org/10.1145/2559206.2581348.

Iivari, N., & Kinnula, M. (2018). Empowering children through design and making: Towards protagonist role adoption. In *Proceedings of the 15th participatory design conference: Full papers–Volume 1, PDC '18* (pp. 16:1–16:12). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3210586.3210600, URL: http://doi.acm.org/10.1145/3210586.3210600.

Iversen, O. S., Smith, R. C., & Dindler, C. (2017). Child as protagonist: Expanding the role of children in participatory design. In *Proceedings of the 2017 conference on interaction design and children, IDC'17* (pp. 27–37). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3078072.3079725, URL: http://doi.acm.org/10.1145/3078072.3079725.

Iversen, O. S., Smith, R. C., & Dindler, C. (2018). From computational thinking to computational empowerment: A 21st century pd agenda. In *Proceedings of the 15th participatory design conference: Full papers - Volume 1, PDC '18* (pp. 7:1–7:11). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3210586.3210592, URL: http://doi.acm.org/10.1145/3210586.3210592.

Kinnula, M., & Iivari, N. (2019). Empowered to make a change: Guidelines for empowering the young generation in and through digital technology design. In *Proceedings of the FabLearn Europe 2019 conference, FabLearn Europe '19* (pp. 16:1–16:8). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3335055.3335071, URL: http://doi.acm.org/10.1145/3335055.3335071.

Klapwijk, R., & Rodewijk, N. (2018). Purposeful prototyping through a discussion game in primary education. In *Proceedings of FabLearn Netherlands 2018* (pp. 50–61). http://dx.doi.org/10.5281/zenodo.1413627.

Knowles, B., Beck, S., Finney, J., Devine, J., & Lindley, J. (2019). A scenario-based methodology for exploring risks: Children and programmable iot. In *Proceedings of the 2019 on designing interactive systems conference, DIS 2019, San Diego, CA, USA, June 23-28, 2019* (pp. 751–761). http://dx.doi.org/10.1145/3322276.3322315.

Kortuem, G., Kawsar, F., Sundramoorthy, V., & Fitton, D. (2010). Smart objects as building blocks for the internet of things. *IEEE Internet Computing*, *14*, 44–51.

Lechelt, S., Rogers, Y., & Marquardt, N. (2020). Coming to your senses: Promoting critical thinking about sensors through playful interaction in classrooms. In *Proceedings of the interaction design and children conference, IDC '20* (pp. 11–22). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/3392063.3394401.

Lechelt, Z., Rogers, Y., Marquardt, N., & Shum, V. (2017). Democratizing children's engagement with the internet of things through connectus. In *UbiComp 2016 adjunct–Proceedings of the 2016 ACM international joint conference on pervasive and ubiquitous computing* (pp. 133–136). http://dx.doi.org/10.1145/2968219.2971435, URL: https://uclic.ucl.ac.uk/publications/1189452.

Lewin, K. (1946). Action research and minority problems. *Journal of Social Issues*, *2*, 34–46.

Mavroudi, A., Divitini, M., Mora, S., & Gianni, F. (2018). Game-based learning for iot: The tiles inventor toolkit. In *Interactive mobile communication technologies and learning* (pp. 294–305). Cham: Springer International Publishing, URL: https://doi.org/10.1007/978-3-319-75175-7_31.

Mazzone, E. (2012). Designing with children : reflections on effective involvement of children in the interaction design process.

McKilligan, S., Christian, J., Daly, S., Seifert, C., & Gonzalez, R. (2012). Design heuristics support two modes of idea generation: Initiating ideas and transitioning among concepts. In *ASEE annual conference and exposition, conference proceedings* (pp. 25.394.1–25.394.18).

Mechelen, M. V., Høiseth, M., Baykal, G. E., van Doorn, F., Vasalou, A., & Schut, A. (2017). Analyzing children's contributions and experiences in co-design activities: Synthesizing productive practices. In P. Blikstein, & D. Abrahamson (Eds.), *Proceedings of the 2017 conference on interaction design and children, Stanford, CA, USA, June 27-30, 2017* (pp. 769–772). ACM, http://dx.doi.org/10.1145/3078072.3081314.

Melonio, A., Rizvi, M., Roumelioti, E., De Angeli, A., Gennari, R., & Matera, M. (2020). Children's beliefs and understanding of smart objects: An exploratory study. In *Proceedings of the 2020 international conference on advanced visual interfaces, AVI '20* (pp. 1–8). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/3399715.3399828.

Micro:bit-Educational-Foundation (2019). Micro:bit educational foundation | micro:bit. https://microbit.org, Accessed: 2019-09-06.

Microsoft (2019). Microsoft makecode. https://makecode.microbit.org. Accessed: 2019-09-06.

Mora, S., Gianni, F., & Divitini, M. (2017). Tiles: A card-based ideation toolkit for the internet of things. In *Proceedings of the 2017 conference on designing interactive systems, DIS '17* (pp. 587–598). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3064663.3064699.

Nathalie, S. (2017). Co-creative workshop methodology handbook. https://u4iot.eu/pdf/U4IoT_CoCreativeWorkshopMethodology_Handbook.pdf. Accessed: 2020-09-16.

Raftopoulos, M. (2015). Playful card-based tools for gamification design. In *Proceedings of the annual meeting of the australian special interest group for computer human interaction, OzCHI '15* (pp. 109–113). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2838739.2838797.

Rizvi, M. (2019). *Tangibles for supporting children's conversations* (Ph.D. thesis), Italy: Free University of Bozen-Bolzano, URL: https://bia.unibz.it/handle/10863/10770.

Roeck, D. D., Tanghe, J., Jacoby, A., Moons, I., & Slegers, K. (2019). Ideas of things: The iot design kit. In *Companion publication of the 2019 on designing interactive systems conference 2019 companion*.

Root, E., Heuten, W., & Boll, S. (2019). Maker cards: Evaluating design cards for teaching physical computing to middle-school girls. In *Proceedings of Mensch und computer 2019, MuC'19* (pp. 493–497). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3340764.3344445, URL: http://doi.acm.org/10.1145/3340764.3344445.

Roumelioti, E. (2020). Snap web site. URL: http://snap.inf.unibz.it/.

Roumelioti, E., Gennari, R., Matera, M., Melonio, A., & Rizvi, M. (2020). Towards making children independent in design. In *Companion publication of the 2020 ACM designing interactive systems conference, DIS' 20 Companion* (pp. 227–232). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/3393914.3395849.

Schepers, S., Dreessen, K., & Zaman, B. (2018). Rethinking children's roles in participatory design: The child as a process designer. *International Journal of Child-Computer Interaction*, *16*, 47–54.

Schut, A., Klapwijk, R., & Gielen, M. (2018). Effects of convergent and divergent feedback on creative thinking during children's design processes. In *36th international pupils' attitudes towards technology conference* (p. 506).

Scratch-Foundation (2019). Scratch cards - scratch wiki. https://en.scratch-wiki.info/wiki/Scratch_Cards. Accessed: 2019-09-06.

Smith, R. C., Iversen, O. S., & Hjorth, M. (2015). Design thinking for digital fabrication in education. *International Journal of Child-Computer Interaction*, *5*, 20–28.

Thang, B., Sluis-Thiescheffer, W., Bekker, T., Eggen, B., Vermeeren, A., & de Ridder, H. (2008). Comparing the creativity of children's design solutions based on expert assessment. In *IDC '08: Proceedings of the 7th international conference on interaction design and children* (pp. 266–273). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/1463689.1463765.

Thinkers, S. (2019). Khandu: Building little thinkers!. http://khandus.com/en/. Accessed: 2019-09-06.

Vaajakallio, K., & Mattelmaki, T. (2014). Design games in co-design: As a tool, a mindset and a structure. *Co-Design*, *10*.

Wood, G., Dylan, T., Durrant, A., Torres, P. E., Ulrich, P., Carr, A., et al. (2019). Designing for digital playing out. In *Proceedings of the 2019 CHI conference on human factors in computing systems, CHI '19* (pp. 679:1–679:15). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3290605.3300909, URL: http://doi.acm.org/10.1145/3290605.3300909.

Zhang, Z., Bekker, T., Markopoulos, P., & Brok, P. d. (2020). Children's reflection-in-action during collaborative design-based learning. In *The challenges of the digital transformation in education* (pp. 790–800). Cham: Springer International Publishing.