Design and Computational Thinking with IoTgo: What Teachers Think

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Abstract. Computational and design thinking are orthogonal and complementary ways of thinking, which are fundamental for nowadays' learners and yet taught in isolation. Teachers' understanding of them can be a barrier to their introduction. This paper reports on an intervention for primary- and secondary-school teachers, introducing them to both forms of thinking through hands-on laboratories, revolving around the IoTgo game-based toolkit. Teachers' ideas of computational and design thinking were investigated with a questionnaire before and after the intervention. Their answers suggest that the intervention was effective and indicate future work related to computational and design thinking.

Keywords: Design · Design thinking · Computational thinking · Smart thing · IoT · Teacher · Study

1 Introduction

Computational and design thinking are specific ways of thinking, rooted in a large body of knowledge and expertise in design and computer science, respectively, and useful in other fields. The ontological analysis of the two ways of thinking by Kelly and Gero suggests that "design thinking and computational thinking are processes that are ontological mirror images of each other, and are the two processes by which thinkers address problems" so that "thinkers can

This work is supported by the project SNaP of the Free University of Bozen-Bolzano and by DAIS - Ca'Foscari University of Venice within the IRIDE program.

M. Temperini et al. (Eds.): MIS4TEL 2022, LNNS 580, pp. 165–174, 2023.
https://doi.org/10.1007/978-3-031-20617-7_21

move fluently between the two". However, they are rarely employed together and even less taught together [11].

In fact, although both are considered fundamental 21st-century skills for learners, they are usually taught in isolation one from the other. Teachers' beliefs can be a barrier to their introduction in school settings, as Slotta et al. found in their investigation concerning the teaching of design and computational thinking with prospective teachers [19]. Relevant outcomes of their investigation for this paper are as follows: (1) teaching strategies which involve both forms of thinking employ project-based or design-centred approaches, (2) and, whereas a wide range of toolkits support computational thinking, few consider or encompass design thinking. They conclude that teacher support materials should explicit connect the two forms of thinking and engage learners through hands-on activities. This paper picks up their recommendation, and the one by Kelly and Gero: "given that these two forms of thinking are complementary ways of approaching problems, they might be taught in a way that emphasizes this relationship".

This paper presents an intervention for Italian in-service teachers from primary and secondary schools, concerning computational and design thinking. It engaged 32 of them in a one-month-long intervention. It introduced them to both forms of thinking through laboratories, with gamified IoTgo phygital toolkit that teachers can use at school on their own. This paper starts by presenting the most relevant background concerning interventions for teachers related to design thinking or computational thinking. Then it outlines the design of the intervention, sketching how the IoTgo toolkit was employed therein. Next the paper reports on the results of a study concerning participant teachers' ideas of the two forms of thinking, before and after the intervention. The results of the study are discussed in the conclusions to the paper.

2 Background

2.1 Design Thinking

Design thinking can be defined as a method of problem-solving that help people generate collaboratively novel solutions to open-ended, unstructured or ill-defined problems, which are to be understood as situated in a context [12]. However, the process is goal-oriented, constrained, and the resolution is specific and depends upon a designer's understanding of the situation [8]. In spite of its many definitions, a typical design thinking process includes the following stages: empathising with the problem/situation and people part of it, then defining and ideating a specific solution for a given goal, prototyping and testing it [9,13].

In recent years, design thinking has been adopted in educational settings, especially by the Maker movement [3]. In their view, educating children to think and act like designers helps them face difficult real-life situations and find "a solution" by themselves [15,18]. Much of past research on design thinking for education purposes focused on the potential benefits for learners [1]. Little research seems to investigate educators' ideas, perceptions or experience with design thinking [16]. In particular, the study by Hennessey et al. assessed teachers' impression of applying design thinking in their curricula [10]. Teachers reported positive impressions about its use for eliciting collaboration among students. However teachers also raised issues, especially concerning how to successfully make design thinking part of their curricula, e.g., specific toolkits or guidelines.

2.2 Computational Thinking

Computational thinking is considered as a set of skills and processes that enable students to face computational problems, e.g., problems which could be programmed and resolved with a computing machine [20]. Problems that require computational thinking are "typically recurrent problems, problems that either occur in many places or recur within the same place", and "the solutions provided by computational thinking aim to be generally applicable" [11].

That said, there is no single operational definition of computational thinking. However, the majority of them include the following stages: firstly abstraction of details, then pattern recognition for finding a general resolution, decomposition for breaking the problem or resolution into smaller more manageable parts, algorithms and programs to develop the resolution with computers.

Computational thinking has been widely advocated as a key component for education and teachers' training is considered a crucial factor for bringing it into school. Recently, researchers have investigated teachers' perceptions or understanding of computational thinking, their relation with smart technologies and their usage in class.

3 Study Design

3.1 Research Goal and Questionnaire

The research goal was to investigate teachers' ideas of computational thinking and design thinking, before and after the intervention, so as to assess possible effects of this on teachers' ideas.

An ad-hoc pre-post questionnaire was created, based on available ones in the literature, e.g., [2,19]. It was divided into a closed-format part and an open-format part. The closed-format part asked teachers to use a 5-point Likert scale and assess 3 groups of statements (Q1–Q3), each concerning either computational thinking (_CT) or design thinking (_DT). Statements to assess are reported in Table 1. Their order was randomised when the questionnaire was administered. Open-format questions completed the questionnaire, similar to those in the paper by Corradini et al., which investigated teachers' understanding of computational thinking [2]. Relevant open-format questions for this paper are as follows: (1) fill in freely "in my view, design thinking is...". (2) fill in freely "in my view, computational thinking is...".

The questionnaire was administered the first day of the intervention (Day 1), after presenting teachers definitions of computational and design thinking, with

Table 1. Closed-format part of the pre-post questionnaire for teachers, with three groups of statements (Q1–Q3) to be assessed on a 5-point Likert scale

Item	Statement to assess
Q1_CT	Computational thinking is useful in technical-scientific subjects
Q1_DT	Design thinking is useful in technical-scientific subjects
Q2_CT	Computational thinking is fundamental in today's society
Q2_DT	Design thinking is fundamental in today's society
Q3_CT	Computational thinking is useful in humanistic and artistic-musical subjects
Q3_DT	Design thinking is useful in humanistic and artistic-musical subjects

companion examples. The questionnaire was again administered at the end of the fourth day of the intervention (Day 4), after teachers had experienced the laboratories of the intervention.

3.2 Participants and Setting

Participants were 12 primary-school teachers and 20 secondary-school teachers. The intervention was held in the computer room of a secondary school, so that each teacher had a computer, a micro:bit physical-computing board and related devices (e.g., buttons, LEDs), besides internet access.

Notice that, in Italy, primary school teachers can teach all subjects. However, the 12 primary-school teachers participating in the intervention usually teach maths, science or technology related subjects, except one who is a support teacher for special-needs pupils. Out of all 20 secondary-school teachers of the study, 19 teach mathematics, science or technology, and one teaches art. Briefly, 96% of participants taught maths, science or technology subjects at school.

3.3 IoTgo Material

IoTgo is a phygital toolkit with game-boards and cards, besides digital tools, e.g., [5]. Its boards progressively and tangibly guide people through the creation of smart things and reflections around them, moving them fluidly across design and computational thinking, as recommended by Kelly and Gero [11]. In particular, the physical and cloud boards immerse people in a context via a mini-story, and help them choose things to make smart for certain personas and goals (presented as missions) as in design thinking (e.g., by empathising with personas). Next, they guide people to develop their ideas of smart things by means of physical inputs (e.g., touch sensors, buttons), physical outputs (e.g., LEDs, speakers), and by connecting them to cloud services via IoT communication, and reason as in computational thinking (e.g., by decomposing smart-thing ideas with given patterns, abstracting away details). Figure 1 shows a filled-in physical board.

The IoTgo toolkit includes ad-hoc hardware and software, namely, a scanner and a web app for: (1) reading cards and automatically generating programs

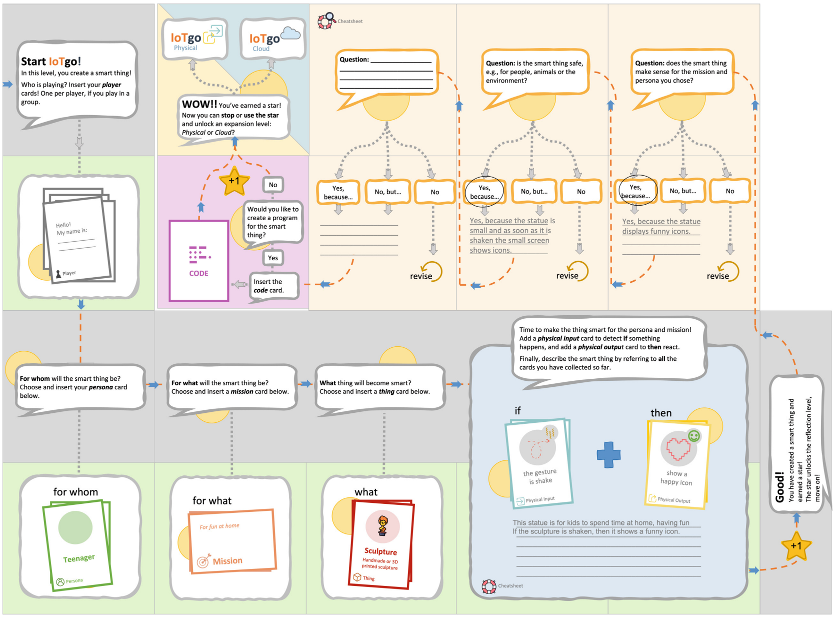

Fig. 1. A filled-in physical board of IoTgo

for smart things in the MakeCode environment, which follow and teach typical patterns for smart things interacting with people; (2) testing them rapidly with micro:bit physical-computing boards and devices [14]. The IoTgo app with MakeCode for micro:bit, English version, is partly accessible at https://share.streamlit.io/iotgo-app/iotgo-io/main/versions/bz_teachers_EN.py, protected by a non-commercial, share alike CC license.

Over time, the IoTgo toolkit has been co-designed with diverse people, such as pupils of different school levels, university students of art and design and of applied linguistics, besides professional artists, e.g., see https://made4me.it/iotgoarts/ and [5,7,17]. Usages and co-design actions led to the evolution of IoTgo, making it more modular, adaptable and adaptive, catering to varying needs, desiderata and expertise. The version presented in this paper was specifically adapted to school teachers.

3.4 IoTgo Protocol

Table 2 recaps the schedule of tasks of the intervention for teachers, organised per day. Each day had shared as well as specific tasks with IoTgo for moving teachers, tangibly, from design thinking into computational thinking, and evolve a smart-thing solution for an initially wicked problem.

Each day, specific tasks for design or computational thinking were gamified with IoTgo, so as to be replicable as-is with learners at school. For instance, during Day 2, participants had the following task: to play a conceptualisation game with IoTgo for groups of 3–4 members. Firstly, groups were split in pairs, whenever feasible. Each pair was given "rough" descriptions of ideas of smart things for tackling a problematic situation for given personas, with missions representing personas' goals in certain environments. These ideas had been created by children. Teachers were asked to revise and conceptualise ideas with input and output cards of IoTgo so as to abstract away details and decompose them with the pattern given by the IoTgo physical board in Fig. 1. Next pairs had to share their results in groups and reflect in groups on challenges related to children's ideas, which teachers may experience in class as well.

Each day ended with a common task, namely, to share reflections all together. Therein, researchers and participants reflected on what teachers had learnt in terms of design thinking and/or computational thinking, what was clear or unclear, what the next steps would be.

Table 2. Schedule of the main tasks per day of the intervention.

When	What for
Day 1	Exploring, reflecting
Day 2	Exploring, ideating, conceptualising, programming, reflecting
Day 3	Ideating, conceptualising, programming, prototyping, generalising, reflecting
Day 4	Programming, prototyping, generalising, reflecting

4 Study Results

The following part reports results of data collected through the pre-post questionnaire, administered in Day 1 and 4. It reports results concerning firstly the closed-format part of the questionnaire in Table 1, and secondly the open-format part asking to report freely ideas of design and computational thinking.

4.1 Closed Format

Teachers had to assess 3 groups of statements (Q1–Q3) on a 5-point Likert scale:

Q1. Computational/design thinking is useful in technical-scientific subjects.
Q2. Computational/design thinking is fundamental in today's society.
Q3. Computational/design thinking is useful in humanistic and artistic-musical.

Data were kept only if teachers provided answers to the pre- and post-questionnaire (18). For analysing answers, "absolutely no" was coded as -2, "no" as -1, "neutral" as 0, "yes" as 1, "absolutely yes" as 2. Overall, means for answers by teachers tended to increase after the intervention: from a 0 representing neutrality or uncertainty, especially for design thinking, towards 2 for

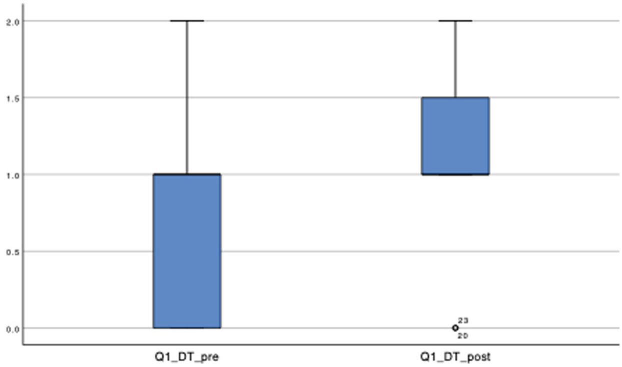

Fig. 2. Box-plot for the Q1-statement for design thinking, pre and post intervention

Table 3. Pre and post Means (M) and standard deviations (SD) computed with SPSS

Pre item	M	SD	Post item	M	SD
Q1_CT_pre	1.2400	.43589	Q1_CT_post	1.3200	.47619
Q1_DT_pre	.8750	.67967	Q1_DT_post	1.1667	.56466
Q2_CT_pre	1.2083	.50898	Q2_CT_post	1.3333	.56466
Q2_DT_pre	.708333	.750604	Q2_DT_post	1.083333	.653863
Q3_CT_pre	.833333	.564660	Q3_CT_post	1.041667	.550033
Q3_DT_pre	.666667	.761387	Q3_DT_post	1.041667	.690253

"absolutely yes". See Table 3 for means and standard deviations, and Fig. 2 for the box-plot related to the Q1-statement for design thinking.

We used a paired t test to test if there was a significant difference in the pre- and post-means. As Table 4 shows, with the exception of the pre- and post-means for the Q3 statement for computational thinking, for all other statements there was a statistically significant average increase following the intervention.

4.2 Open Format

Two researchers performed a deductive thematic analysis of teachers' answers to the two open-format questions concerning their ideas of computational thinking and design thinking, respectively: they looked for terms similar to those pertaining to design and computational thinking from the literature. They worked first independently and then they compared their analysis. Data were kept only if teachers provided answers to both questions (19). Thus, researchers counted such terms. Terms for computational thinking which were counted were: pattern, abstraction, problem-decomposition, algorithm, program. For design thinking they were: empathy, problem/situation, idea, prototype. The relative frequencies were computed for computational-thinking terms, pre and post (FCT_pre,

Table 4. Paired t test results with SPSS

Item	N	Correlation	Sig.
Q1_CT_pre & Q1_CT_post	25	.618	**.001**
Q1_DT_pre & Q1_DT_post	24	.623	**.001**
Q2_CT_pre & Q2_CT_post	24	.504	**.012**
Q2_DT_pre & Q2_DT_post	24	.760	**.000**
Q3_CT_pre & Q3_CT_post	24	.303	.150
Q3_DT_pre & Q3_DT_post	24	.689	**.000**

FCT_post), and design-thinking terms, pre and post (FDT_pre, FDT_post). In all cases, there was an increase in the mean relative frequency of terms related to design and computational thinking, following the intervention: for FCT_pre, the mean is 0.283, standard deviation is 0.235, and for FCT_post, the mean is 0.408, standard deviation is 0.253; for FDT_pre, the mean is 0.219, standard deviation is 0.185, and for FDT_post the mean is 0.333, standard deviation is 0.262.

We run the paired t test on the relative frequencies of terms associated to computational thinking and to design thinking, before and after the intervention. According to the outcome of the test, the intervention seems to have elicited a statistically significant increase in the mean relative frequency of terms associated to computational thinking ($t(23) = -2.128$, $p = .044$) and in that of terms associated to design thinking ($t(23) = -2.2$, $p = .038$).

5 Discussion and Conclusions

This paper outlines an intervention for 32 Italian primary and secondary school teachers concerning design and computational thinking. The work intercepts recent recommendations for interventions guiding teachers to both design and computational thinking, and leveraging on their understanding of them [11,19]. This paper reports results of a pre-post questionnaire with closed-format and open-format questions, investigating teachers' ideas of both types of thinking. They are discussed in the remainder, together with limitations and future work.

5.1 Discussion of the Study Results

Computational and design thinking are both considered relevant skills for learners. In spite of that, as the background section shows, they are seldom taught together. One of the many barriers are teachers' ideas of them, besides "a need for additional guidance, case studies, and other forms of teacher professional development" [19]. The intervention reported in this paper was organised tangibly in hands-on laboratories with IoTgo, so as to be replicable at school as-is. Results of the data analyses seem to point out the effectiveness of the intervention.

Both the closed- and open-format part of the questionnaire show a change in teachers' ideas. The closed-format part asked teachers to assess three groups of statements (Q1–Q3), related to computational and design thinking; see Table 1. Given that the large majority of participants (96%) teach maths, science or technology subjects, their answers to Q1 and Q2 are particularly relevant. According to the result of a t-test analysis, these statements received higher points after the intervention, indicating that such teachers tended to perceive both of them more useful for their subjects and society, following the intervention.

The open-format part of the questionnaire asked teachers to freely report their ideas of computational and design thinking. Their ideas were analysed, counting terms which are found in definitions of the two forms of thinking, presented the first day of the intervention. Their relative frequencies tended to increase after the intervention, and statistically significantly so. This is taken as an indication that teachers had internalised the concepts they had mastered during the intervention via hands-on activities, guided by the IoTgo toolkit.

5.2 Limitations and Future Work

The main limitation of the reported study is that it only analyses teachers' ideas, before and after the intervention, although in two different manners. During the intervention, teachers also produced their own smart things starting from wicked problems, by means of the IoTgo toolkit, and reflected over them. Future work will analyse teachers' artefacts and reflections so as to complement the findings reported in this paper, and study what to adapt of the IoTgo toolkit to best match teachers' mental models [4,6]. Moreover, several participants already implemented what they had learnt with their own classes. Their activities are still on-going at the time of writing. Future work will consider what they have done in class as a further indicator of the effectiveness of the intervention reported in this paper.

References

1. Chamberlain, L., Mendoza, S.: Design thinking as research pedagogy for undergraduates: project-based learning with impact. Counc. Undergraduate Res. Q. **37**, 18–22 (2017). https://doi.org/10.18833/curq/37/4/15
2. Corradini, I., Lodi, M., Nardelli, E.: Conceptions and misconceptions about computational thinking among Italian primary school teachers. In: Proceedings of the 2017 ACM Conference on International Computing Education Research, ICER 2017, pp. 136–144. Association for Computing Machinery, New York (2017). https://doi.org/10.1145/3105726.3106194
3. Crichton, H., McDaid, A.: Learning intentions and success criteria: learners' and teachers' views. Curric. J. **27**(2), 190–203 (2016). https://doi.org/10.1080/09585176.2015.1103278
4. Di Mascio, T., Gennari, R., Melonio, A., Tarantino, L.: Supporting children in mastering temporal relations of stories: the TERENCE learning approach. Int. J. Distance Educ. Technol. **14**(1), 44–63 (2016). https://doi.org/10.4018/IJDET.2016010103. Cited by: 11

5. Gennari, R., Melonio, A., Rivi, M., Matera, M.: Physical or on the cloud: play with IoTgo and design smart things. In: CEUR Proceedings of the Joint Workshop on Games-Human Interaction (GHItaly 2021) and Multi-Party Interaction in eXtended Reality (MIXR 2021) Co-Located with CHItaly 2021: 14th Biannual Conference of the Italian SIGCHI Chapter, Bolzano, Italy, 12 July 2021 (2021)
6. Gennari, R., Melonio, A., Rizvi, M.: Evolving tangibles for children's social learning through conversations: beyond turntalk. In: Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction, TEI 2018, pp. 368–375. Association for Computing Machinery, New York (2018). https://doi.org/10.1145/3173225.3173248
7. Gennari, R., Rizvi, M.: At the frontiers of art and IoT: the IoTgo toolkit as a probe for artists. In: CHItaly 2021: 14th Biannual Conference of the Italian SIGCHI Chapter, CHItaly 2021. Association for Computing Machinery, New York (2021). https://doi.org/10.1145/3464385.3464727
8. Gero, J.S.: Design prototypes: a knowledge representation schema for design. AI Mag. **11**(4), 26 (1990)
9. Plattner, H., Meinel, C., Leifer, L.: Design Thinking: Making Design Thinking Foundational. Springer, Cham (2016)
10. Hennessey, E., Mueller, J.: Teaching and learning design thinking (DT): how do educators see DT fitting into the classroom? Can. J. Educ./Revue canadienne de l'éducation **43**(2), 498–521 (2020)
11. Kelly, N., Gero, J.S.: Design thinking and computational thinking: a dual process model for addressing design problems. Des. Sci. **7**, e8 (2021). https://doi.org/10.1017/dsj.2021.7
12. Margot, K.C., Kettler, T.: Teachers' perception of stem integration and education: a systematic literature review. Int. J. STEM Educ. **6**, 1–16 (2019). https://doi.org/10.1186/s40594-018-0151-2
13. Melles, G., Howard, Z., Thompson-Whiteside, S.: Teaching design thinking: expanding horizons in design education. Procedia. Soc. Behav. Sci. **31**, 162–166 (2012). https://doi.org/10.1016/j.sbspro.2011.12.035
14. BBC micro:bit (2022). https://microbit.org/
15. Razzouk, R., Shute, V.: What is design thinking and why is it important? Rev. Educ. Res. **82**, 330–348 (2012). https://doi.org/10.3102/0034654312457429
16. Retna, K.S.: Thinking about "design thinking": a study of teacher experiences. Asia Pac. J. Educ. **36**(sup1), 5–19 (2016). https://doi.org/10.1080/02188791.2015.1005049
17. Rizvi, M.: Supporting end users in designing IoT smartthings with the IoTgo toolkit. In: CEUR Proceedings of the 2nd International Workshop on Empowering People in Dealing with Internet of Things Ecosystems (EMPATHY) Co-Located with INTERACT 2021, Bari, Italy (2021)
18. Rotherham, A.J., Willingham, D.T.: 21st century skills: the challenges ahead. Educ. Leadersh. **67**, 16–21 (2009)
19. Slotta, J.D., Chao, J., Tissenbaum, M.: Fostering computational thinking and design thinking in the PYP, MYP and DP (2020)
20. Wing, J.: Computational thinking. Commun. ACM **49**, 33–35 (2006). https://doi.org/10.1145/1118178.1118215