Engaging Learners in the Collaborative Design of Sustainable Smart Cities

Rosella Gennari[1], Alessandra Melonio[2] and Mauro D'Angelo[3,*]

[1]Free University of Bozen-Bolzano, Piazza Domenicani 3 - 39100 Bolzano, Italy
[2]Ca' Foscari University of Venice, Via Torino 155 - 30170 Venezia Mestre, Italy
[3]Perlatecnica, Via Napoli 60 - 81024 Maddaloni (Caserta), Italy

Abstract

During the last few years, more researchers and educators have proposed workshops to familiarize learners with concepts based on smart cities, such as smart object design and autonomous vehicles. The designing process is demanding, as it requires exploring sensors and actuators that behave as activators of smart city design, but also ideate, program, and prototype new solutions to enhance smart city features. While workshops usually are based on educational boards and block-based programming environments, this paper reports on the design of an in-person workshop, which aims at engaging high-school and university learners across the entire design process of sustainable smart city solutions while exploiting professional technologies and components like that of STMicroelectronics and FBK. An engagement questionnaire was administered online after the workshop to understand whether participants considered the proposed workshop enjoyable and easy to follow and how learners perceived the aspect of collaboration during smart city workshops. According to the results, participants are highly engaged in designing sustainable smart city solutions taking advantage of groups to share ideas and distribute the load.

CCS CONCEPTS

Empirical studies, Collaboration in software development, Sustainability

Keywords

Sensor, Smart city, Design, Making, Programming, Engagement, Collaboration, University, Hands-on

1. Introduction

A smart city can be defined as the process of searching and identifying intelligent solutions that allow cities to enhance the quality of the services provided to citizens [1]. Recently, more and more researchers have explored the opportunity to let citizens assume an active role in smart city design, e.g., [2, 3], making them aware of the sustainability requirement. It means communicating complex concepts in a language clear to citizens without giving for granted their technical skills while introducing them to smart city technical components and working mechanism [4, 5, 6]. Many methods have emerged to make citizens participate actively in

S3C'23: Sustainable, Secure, and Smart Collaboration Workshop, Hosted by CHITALY 2023, SEPTEMBER 20–22, 2023, TURIN, ITALY

*Corresponding author.
gennari@inf.unibz.it (R. Gennari); alessandra.melonio@unive.it (A. Melonio); mauro.dangelo@perlatecnica.it (M. D'Angelo)
0000-0003-0063-0996 (R. Gennari); 0000-0001-6655-1946 (A. Melonio); 0009-0002-9368-5864 (M. D'Angelo)

designing smart cities, such as creating public services collaboratively [7, 8, 9, 10], ensuring early user involvement [11], guaranteeing inclusiveness [12] through workshops, living labs, and online platforms [13].

When discussing citizen participation, it is often assumed that citizens are adults. An increasing effort is invested in letting future citizens, alias current learners, design smart solutions [14, 15, 16, 17], covering all the school ages. This paper reports a workshop involving high-school and university learners working in groups to design smart cities and autonomous vehicles. Engagement of learners, besides their perceived utility of designing sustainable smart city solutions collaboratively, was assessed through an online survey administered at the end of the experience.

The workshop is part of a wider initiative related to the *GREEN* project[1], positively evaluated and financed with the favorable opinion of the national evaluation committee of the National Youth Agency under the Key Action KA154 of the Erasmus+ Program. On one side, the GREEN project aims to support the design and development of innovative solutions for environmental sustainability. It is also made evident by the project motto "*Together for a sustainable city*". On the other side, it desires to encourage youths to express their opinion and take advantage of the spaces that can enable comparison and dialogue with peers from different realities through non-formal methods. This interest arises from the need highlighted by young people from peripheral areas in our Region to propose initiatives and spaces that favor the exchange of ideas and youth aggregation. It is mainly related to difficulties experienced by young citizens in participating in social and political life due to the limited communication channels with local authorities, few infrastructures dedicated to young people, and the need for more initiatives in which young people can express their proposals and needs. To reach its goals, the *GREEN* project organized four keynotes online that let participants be inspired by engineers and experts in the field while listening to discussions related to sustainability, the internet of things and its implications in smart city design, and air pollution. Then, it proposed the Roobopoli[2] hackathon, where Roobopoli is an educational project that aims to make learners familiarize themselves with smart cities and autonomous vehicles. It lets participants familiarize themselves with concepts related to sustainable mobility, sustainable development, smart cities, and atmospheric pollution. Finally, it organized a hybrid meeting to disseminate the project results publicly. This paper focuses on the Roobopoli hackathon.

The paper is structured as follows. Section 2 overviews related work. Section 3 details the workshop structure in terms of research questions, participants and settings, the performed protocol, and the data collection approach. Section 4 reports and discusses results split by research questions. Finally, the paper concludes with final remarks.

2. Related work

According to the survey of smart solution design authored by Pellegrino et al. [16], smart solution design workshops rarely target high schools, only targeted by Roobopoli [14] and Gianni et al. [18].

---

[1] The GREEN project: https://green.erasmusplus.perlatecnica.it
[2] Roobopoli: https://www.roobopoli.org

Workshops targeting young participants tend to adopt card-based approaches as they democratize access to sensors and actuators to an early stage. Some examples in this direction are IoT Design Deck [19], SNaP [20], DigiSNaP [15], Tiles cards [18], Know-Cards [21], Maker [22] and Scratch [23]. As we target the oldest and more experienced learners, we can adopt a more pragmatic based on introducing real sensors and actuators, presented as they are and contextualized in real but simplified use cases. It is the case of Roobopoli [14] and the workshop presented by D'Angelo [24], which introduces STMicroelectronics boards, sensors, and actuators. The workshop, at the basis of this contribution, adopts a similar approach by challenging high-school and university learners to design and develop sustainable smart city solutions. It follows standard settings and modality, as it took place in presence, exploiting collaboration [25] and focus on hands-on hardware-centric projects [26].

Concerning the evaluation stage, researchers are increasingly focused on participants' gains during design, mainly evaluating their learning [27] and engagement across the design experience [28]. Engagement is an important benefit to consider in design with learners as it is often correlated to learning [29, 30, 31]. Furthermore, the article poses emphasis on the role of collaboration during the design process, grounding on the consolidated psycho-pedagogical literature concerning collaborative learning [32] and trialogical learning [33, 34].

3. Workshop design

This section details the research questions (RQs) of the proposed workshop, ii) participants and setting, iii) the protocol of the workshop, and iv) the data collection instrument.

3.1. Research Questions

The overall purpose of the research around the workshop is about the participants' *engagement* and their feelings with respect to the role of *collaboration* during the in-person smart city design workshop. It can be translated into the following research questions (RQs):

- RQ1 Are participants engaged in programming smart cities and autonomous vehicles?
- RQ2 Do they envision the utility of collaborating while programming smart cities and autonomous vehicles?

3.2. Participants and Settings

A total of 41 participants (9 females) joined the workshop, belonging to different Italian institutes belonging to the Campania and Trentino regions and the cities of Brescia. Participants' ages range from 15 to 26, according to constraints explicitly posed by the GREEN project.Most of them were already familiar with concepts related to sensors and actuators and their programming for their affiliation to technician high schools or universities. Moreover, according to the auto-assessment of their competencies in programming smart cities on a 5-Likert scale, the minimum score was two, selected by only two participants, the maximum score was 5, selected by two participants, while the majority opted for an intermediate level of competence with a mean score of 3.47. A similar trend can be observed with respect to their competencies in programming autonomous vehicles on a 5-Likert scale, ranging from 2 to 5, with a mean score of 3.2. Concerning the selection mechanism, a call for selection has been published and sent to all the Italian universities that agreed to support the project. All the participants were required to have skills in C++, which a technical and motivational interview verified. The workshop was held in Trento in collaboration with Fondazione Bruno Kessler (FBK)[3] and the Department of Industrial Engineering of the University of Trento[4]. The workshop was free of charge for learners, and it took place over three days in May 2023 as an in-person activity at the FBK site, letting learners experience the prototyping phase with STMicroelectronics boards and FBK components. Figure 1 reports the working settings and the participants, making evident the limited female participation, the organization in groups, and the Roobopoli city to simulate the designed and implemented solutions.

Figure 1: The GREEN project participants and workshop setting.

3.3. Protocol

The workshop combines an introductory phase, where the moderator introduces sensors and actuators, and a hands-on session, where participants experience circuit design, programming, and prototyping assisted by the moderator if needed. Following the traditional phases to let learners experience smart cities' underpinnings, the proposed protocol is based on familiarization, ideation, programming, and prototyping stages [15].

- **Familiarization**: the exploration and familiarisation stage starts the design process and lets participants experience FBK sensors as isolated components. In particular,

[3]FBK: https://www.fbk.eu
[4]University of Trento: https://www.dii.unitn.it

participants have been introduced to a quality air sensor developed by FBK researchers. Then, the moderators moved to the introduction of the STMicroelectronics boards as the core component of the Roobopoli autonomous vehicle named Roobokart. This stage is moderated by experts in the field that introduce all the concepts as theoretical lessons, welcoming questions and providing participants with any required clarification. This phase lasted half a day.

- **Ideation**: the ideation stage continues the design process and adopts the hands-on approach. From this stage on, learners working in groups of 3-5 members are invited to program boards, sensors, and actuators, supported by the moderator if required. Groups have been organized by the moderators balancing technical expertise and guaranteeing geographical heterogeneity. During the ideation stage, the moderator assigns incremental challenges to all the groups. Each challenge is assigned when a group has completed the previous one. First, participants have been challenged to program autonomous vehicles, named karts, by implementing line-following, horizontal road sign interpretation, and being able to avoid obstacles, such as city inhabitants. Once implemented kart mobility, participants are challenged to deal with air pollution. In particular, they are required to incorporate the quality air sensor developed by the FBK on the kart. To test the proposed implementation, a container is filled with ethyl alcohol in such quantity as to be identified by the sensor but not harmful to the health of the participants. The third challenge is the most creative one and challenges the participants to fantasize about the city of the future, keeping in mind the sustainability aspect and technological innovation. Finally, they have to design the road signs of the future, unambiguously interpreted by karts. This phase lasted one day and a half and relied on collaboration among participants.
- **Programming and Prototyping**: this stage interleaves with the ideation stage, letting groups refine the solution to the assigned project iteratively. It concludes with the submission of the proposed solution. This phase has been organized as a hackathon with a formal winner. It lasted an entire day, letting participants work collaboratively.

3.4. Data collection

A few days after the end of the workshop, a self-report questionnaire for learners was administered at a distance via Google Form in order to assess learners' engagement, in line with the work of [28]. The moderator sent the questionnaire link to the involved participants, informing the teachers that the collected results, in an anonymous way, would be used in scientific contributions. The questionnaire had two close format questions concerning the engagement assessment, asking to what extent a learner considers *easy* and *enjoyable* programming sensors and actuators. Moreover, it contained four questions concerning the role of collaboration: the three close questions asked the *perceived utility* and *experienced challenges* of working in groups, and if they felt that they would have reached the same results working alone. The open question asked them which *gain* they see in designing and developing smart cities and autonomous vehicles collaboratively. Ratings to close questions were given with the Smiley-o-meter 5-point Likert scale, ranging from not at all (1) to very much (5).

4. Results and Discussion

The questionnaire obtained 17 replies, out of which 3 where from females. Participants' scores were analyzed with SPSS for Windows. Results are reported in relation to the aforementioned research questions RQs.

4.1. RQ1 - Engagement

Engagement is measured in terms of easiness and fun in designing smart city vehicle behavior within Roobopoli, referred to as Roobokart. Concerning the perceived easiness of programming the Roobokart components, participants needed some help as scores cover the entire score range, from 1 to 4. The mean score to the easiness question was $M_{easiness} = 3.29$ with the standard deviation 0.92 and $95\% - CI$ (i.e., confidence interval) equal to $[2.86, 3.73]$. However, participants declared to have fun in the attended workshop: the mean score to the fun question was $M_{fun} = 4.41$ with the standard deviation 0.80 and $95\% - CI$ (i.e., confidence interval) equal to $[4.03, 4.79]$. Such results make us confident that learners were highly engaged in the design experience, being the lower level of the intervals more than 4, with 5 being the maximum rating. The overall engagement results are graphically reported in Fig. 2.

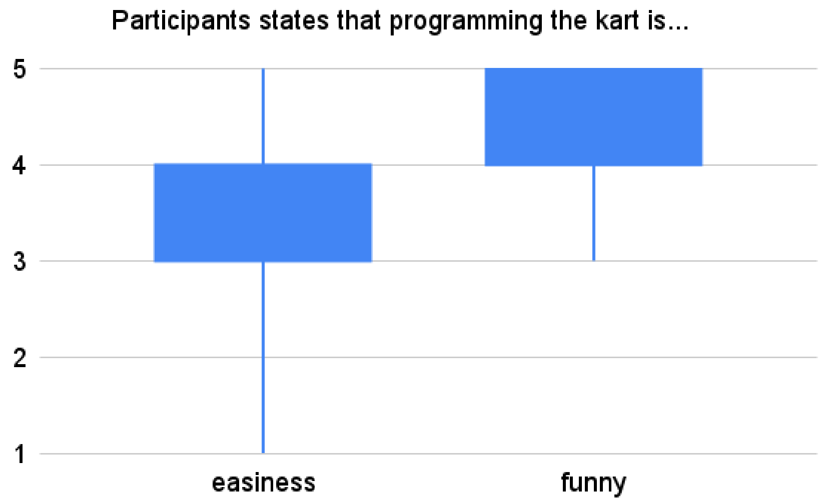

Figure 2: Overall engagement measured in terms of easiness and fun in programming Roobokart.

As the Roobokart is based on the STMicroelectronics boards, it lets us compare this outcome with the one achieved during the *STEM your way program* [5] to let educators, learners, enthusiasts learn about and actively experience STMicroelectronics components. D'Angelo [24] adopted a similar protocol in terms of phases and used technologies and measured the achieved engagement via the same questionnaire. It makes results fairly comparable. Both experiences

[5]STEM your way: www.st.com/STEMyourway

confirm a similar trend: while participants enjoyed programming and experiencing the proposed workshop concerning smart cities and autonomous vehicle programming, they perceived technologies as not trivial to learn. It might be justified by the fact that the STMicroelectronics ecosystem is not designed as an educational resource. Further effort should be invested in making it more accessible, such as supporting further participants with documentation, tutorials, and use cases.

4.2. RQ2 - The role of collaboration

The role of collaboration is measured in terms of usefulness, the feeling of obtaining the same results working individually, challenges experienced, and the perceived gain in working collaboratively. Concerning the perceived usefulness of designing and programming smart cities and autonomous vehicles in groups, participants stated that it is extremely useful. The mean score was $M_{usefulness} = 4.65$ with the standard deviation 0.49 and $95\% - CI$ (i.e., confidence interval) equal to $[4.41, 4.88]$. This result is partially reflected by replies related to the questions that aim to quantify if they feel that the same results can be achieved by individual activities. Most of them consistently stated that it would not be the same working alone. However, the mean score is 2.23 with a standard deviation of 1.35, and scores cover the entire range. The role of collaboration results is graphically reported in Fig. 3.

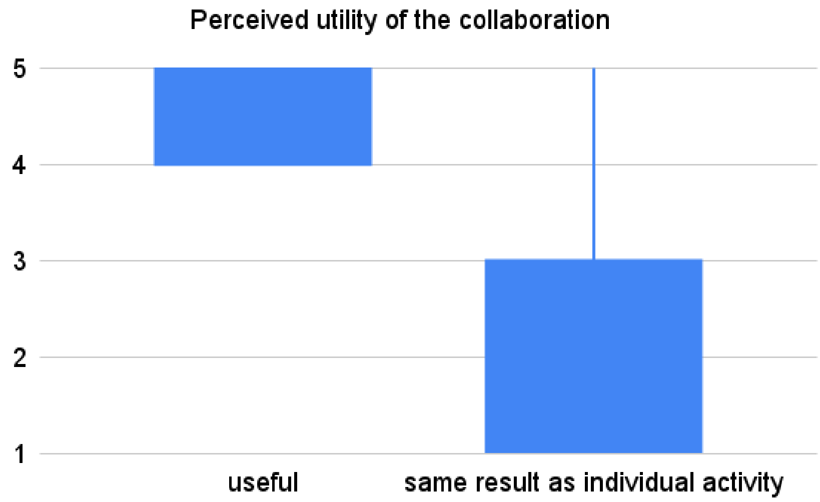

Figure 3: Overall collaboration results.

All of them, but one, did not experience any challenges in working collaboratively. According to the open questions, they envision the utility of working collaboratively in brainstorming, exchanging ideas and points of view in looking for the best solution to a given problem (reported by 10/17 replies), considering unforeseen possibilities, and in task partitioning (reported by 5/17 replies). They explicitly reported that the challenges assigned during the workshop stimulated competition while the atmosphere was so friendly that they were able to help each other both with each group and among groups. In conclusion, collaboration let participants distribute the load and exchange point of view. However, further effort should be invested in understanding what negatively impacted the experience for some of the participants.

5. Conclusions

This article reports an educational workshop proposed within the context of the GREEN project to let high-school and university learners experience the collaborative design of sustainable smart city solutions via introductory theoretical lessons and hands-on. Their engagement has been evaluated via a questionnaire measuring the perceived easiness and enjoyment of programming smart city components and autonomous vehicles. While participants enjoyed the proposed workshop and really appreciated working in groups, they perceived technologies as not trivial to learn.

Limitations and Future directions. The study presented in this article has some limitations, such as the limited number of participants. Moreover, the article assesses participants' engagement without analyzing the relation between the learning outcome and the quality of the produced artifacts. Further analysis is required on this aspect. Finally, they explored smart cities in a controlled and simulated environment. As a future direction, we are interested in moving from simulation in a controlled environment to implementing these projects in real contexts. We are already in contact with our local administration to implement learners' ideas in our municipalities, mainly concerning waste management, air pollution, and video surveillance.

Acknowledgments

We thank FBK for hosting the event and for providing participants with the implementation details concerning the air sensor. This work has been partially supported by i) the GREEN project funded by the European Union's Erasmus+ program under grant agreement n.2022-3-IT03-KA154-YOU-000093660 and ii) the SteamCity project funded by the European Union's Erasmus+ program under grant agreement n.2022-1-FR01-KA220-SCH-000087922.

References

[1] A. Clarinval, C. Deremiens, T. Dardenne, B. Dumas, Introducing the smart city to children with a tangible interaction table, in: 32e Conférence Francophone sur l'Interaction Homme-Machine, 2021.

[2] R. G. Hollands, Will the real smart city please stand up?: Intelligent, progressive or entrepreneurial?, in: The Routledge Companion to Smart Cities, Routledge, 2020, pp. 179–199.

[3] A. R. M. C. Wanderley, R. Bonacin, Designing mobile and iot solutions for sustainable smart cities: Studies with electronic waste disposal, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11587 LNCS (2019) 212 – 226. doi:10.1007/978-3-030-21935-2_17.

[4] F. Gianni, M. Divitini, Designing IoT Applications for Smart Cities: extending the Tiles Ideation Toolkit, IxD&A 35 (2017) 100–116.
[5] A. Simonofski, B. Dumas, A. Clarinval, Engaging children in the smart city: A participatory design workshop, in: Proceedings of the 1st ACM SIGSOFT International Workshop on Education through Advanced Software Engineering and Artificial Intelligence, 2019, pp. 1–4.
[6] A. Wolff, M. Barker, L. Hudson, A. Seffah, Supporting smart citizens: Design templates for co-designing data-intensive technologies, Cities 101 (2020) 102695.
[7] S. Peacock, J. Harlow, E. Gordon, Beta Blocks: Inviting Playful Community Exploration of Smart City Technologies in Boston, USA, Springer Singapore, Singapore, 2020, pp. 131–147. doi:10.1007/978-981-13-9765-3_7.
[8] N. Ochoa Guevara, C. Díaz, M. Davila Sguerra, M. Herrera Martínez, O. Acosta, J. Suarez, A. Munar Rodrìguez, G. Acuña, A. García, Towards the design and implementation of a smart city in bogota, colombia, Revista Facultad de Ingeniería Universidad de Antioquia (2019). doi:10.17533/udea.redin.20190407.
[9] N. Goodman, A. Zwick, Z. Spicer, N. Carlsen, Public engagement in smart city development: Lessons from communities in canada's smart city challenge, The Canadian Geographer / Le Géographe canadien 64 (2020) 416–432. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/cag.12607. doi:10.1111/cag.12607.
[10] A. Wolff, A. V. Juarez, M. Barker, S. Potter, D. Gooch, E. Giles, J. Miles, Engaging with the smart city through urban data games, in: A. Nijholt (Ed.), Playable Cities: The City as a Digital Playground, number 1 in Gaming Media and Social Effects, Springer, 2017, pp. 47–66. doi:10.1007/978-981-10-1962-3_3.
[11] J. Díaz, O. Ancán, An agile product design in a smart city context: A use case for air pollution awareness, in: G. Meiselwitz (Ed.), Social Computing and Social Media. Participation, User Experience, Consumer Experience, and Applications of Social Computing, Springer International Publishing, Cham, 2020, pp. 483–500.
[12] G. Kbar, S. H. Mian, M. H. Abidi, Unified Interface for People with Disabilities (UI-PWD) at Smart City (Design and Implementation), Springer Singapore, Singapore, 2018, pp. 3–20. URL: https://doi.org/10.1007/978-981-10-1741-4_1. doi:10.1007/978-981-10-1741-4_1.
[13] A. Simonofski, E. S. Asensio, J. De Smedt, M. Snoeck, Citizen participation in smart cities: Evaluation framework proposal, in: 2017 IEEE 19th Conference on Business Informatics (CBI), volume 01, 2017, pp. 227–236. doi:10.1109/CBI.2017.21.
[14] M. D'Angelo, M. A. Pellegrino, Roobopoli: a project to learn robotics by a constructionism-based approach, in: Methodologies and Intelligent Systems for Technology Enhanced Learning, Workshops: Vol. 2, Springer, 2021, pp. 249–257. doi:10.1007/978-3-030-52287-2_25.
[15] E. Roumelioti, M. A. Pellegrino, M. Rizvi, M. D'Angelo, R. Gennari, Smart-thing design by children at a distance: How to engage them and make them learn, International Journal of Child-Computer Interaction 33 (2022) 100482. doi:10.1016/j.ijcci.2022.100482.
[16] M. A. Pellegrino, E. Roumelioti, M. D'Angelo, R. Gennari, Children's participation in the design of smart solutions: A literature review, Smart Cities 5 (2022) 475–495.
[17] R. Gennari, M. Matera, D. Morra, A. Melonio, M. Rizvi, Design for social digital well-being with young generations: Engage them and make them reflect, International Journal of

Human-Computer Studies 173 (2023) 103006. URL: https://www.sciencedirect.com/science/article/pii/S1071581923000125. doi:https://doi.org/10.1016/j.ijhcs.2023.103006.
[18] S. Mora, F. Gianni, M. Divitini, Tiles: a card-based ideation toolkit for the internet of things, in: Proceedings of the 2017 conference on designing interactive systems, 2017, pp. 587–598. doi:10.1145/3064663.3064699.
[19] M. Dibitonto, F. Tazzi, K. Leszczynska, C. M. Medaglia, The IoT design deck: A tool for the co-design of connected products, in: Advances in Usability and User Experience: Proceedings of the AHFE International Conference on Usability and User Experience, Springer, 2018, pp. 217–227. doi:10.1007/978-3-319-60492-3_21.
[20] R. Gennari, M. Matera, A. Melonio, M. Rizvi, E. Roumelioti, The evolution of a toolkit for smart-thing design with children through action research, International Journal of Child-Computer Interaction 31 (2022) 100359. doi:10.1016/j.ijcci.2021.100359.
[21] K. Cards, Learn. play. collect.-know cards, 2019.
[22] E. Root, W. Heuten, S. Boll, Maker cards: Evaluating design cards for teaching physical computing to middle-school girls, in: Proceedings of Mensch und Computer, 2019, pp. 493–497. doi:10.1145/3340764.3344445.
[23] Scratch-Foundation, Scratch cards - scratch wiki, 2019. URL: https://en.scratch-wiki.info/wiki/Scratch_Cards, [Online, Last access April 2023].
[24] M. D'Angelo, Engaging learners in familiarizing themselves with sensors and actuators, in: Methodologies and Intelligent Systems for Technology Enhanced Learning, Workshops: Vol. 2, Springer, 2023. In press.
[25] R. Gennari, A. Melonio, M. Rizvi, A. Bonani, Design of iot tangibles for primary schools: A case study, in: Proceedings of the 12th Biannual Conference on Italian SIGCHI Chapter, ACM, 2017. doi:10.1145/3125571.3125591.
[26] B. Bajracharya, V. Gondi, D. Hua, IoT education using learning kits of IoT devices, Information Systems Education Journal 19 (2021) 40–44. URL: https://eric.ed.gov/?id=EJ1329491.
[27] M. Carroll, S. Goldman, L. Britos, J. Koh, A. Royalty, M. Hornstein, Destination, imagination and the fires within: Design thinking in a middle school classroom, International Journal of Art & Design Education 29 (2010) 37 – 53. doi:10.1111/j.1476-8070.2010.01632.x.
[28] R. Gennari, M. Matera, A. Melonio, M. Rizvi, E. Roumelioti, Engaging pre-teens in ideating and programming smart objects through play, in: Methodologies and Intelligent Systems for Technology Enhanced Learning, Springer, 2020, pp. 31–40. doi:10.1007/978-3-030-52538-5_4.
[29] M. N. Giannakos, M. Divitini, O. S. Iversen, Entertainment, engagement, and education: Foundations and developments in digital and physical spaces to support learning through making, Entertainment Computing 21 (2017) 77–81. doi:10.1016/j.entcom.2017.04.002.
[30] E. Mazzone, N. Iivari, R. Tikkanen, J. C. Read, R. Beale, Considering context, content, management, and engagement in design activities with children, in: Proceedings of the 9th International Conference on Interaction Design and Children, IDC '10, Association for Computing Machinery, New York, NY, USA, 2010, p. 108–117. URL: https://doi.org/10.1145/1810543.1810556. doi:10.1145/1810543.1810556.
[31] L.-A. Noel, T. Liu, Using design thinking to create a new education paradigm for elementary level children for higher student engagement and success, 2016. doi:10.21606/drs.2016.

200.
[32] P. Resta, T. Laferrière, Technology in support of collaborative learning, Educational psychology review 19 (2007) 65–83.
[33] N. Sansone, D. Cesareni, M. Ligorio, The trialogical learning approach to innovate teaching, Italian Journal of Educational Technology 24 (2016) 82–82.
[34] S. Paavola, M. Lakkala, H. Muukkonen, K. Kosonen, K. Karlgren, The roles and uses of design principles for developing the trialogical approach on learning, Research in Learning Technology 19 (2011) 233–246. doi:10.1080/21567069.2011.624171.