Educ Inf Technol (2018) 23:2531–2544
https://doi.org/10.1007/s10639-018-9729-z

Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work

Andri Ioannou[1] · **Eria Makridou**[1]

Received: 20 August 2017 / Accepted: 26 April 2018 / Published online: 31 May 2018

Abstract Educational robotics are increasingly appearing in educational settings, being considered a useful supporting tool for the development of cognitive skills, including Computational Thinking (CT), for students of all ages. Meanwhile, there is an overwhelming argument that CT will be a fundamental skill needed for all individuals by the middle of the twenty-first century and thus, should be cultivated in the early school years, as part of the child's analytical thinking and as a principal component of Science-Technology-Engineering-Mathematics (STEM) education. This study reviews published literature at the intersection of CT and educational robotics, particularly focused on the use of educational robotics for advancing students' CT skills in K-12. The reviewed articles reveal initial evidence suggesting that educational robotics can foster students' cognitive and social skills. The paper discusses specific areas for further inquiry by learning researchers and learning practitioners. Such inquiry should start from a widely agreed definition of CT and validated measurement instruments for its assessment. A practical framework for the development of CT via robotics is next in demand, so as instructional designers and educators can implement it consistently and at scale.

Keywords Computational thinking · Educational robotics · Robotics in education

1 Introduction

It is argued that the ability to express ideas in a computationally meaningful way is becoming one of the most crucial skills of the twenty-first century (National Research

✉ Andri Ioannou
andri.i.ioannou@cut.ac.cy

[1] Cyprus Interaction Lab, Cyprus University of Technology, 30 Archbishop Kyprianou Str., 3036 Lemesos, Cyprus

Council 2010, 2011; Papert 1980, 1993; Wilensky 2001; Wing 2006). A few researchers have already considered Computational Thinking (CT) as an essential skill that should be taught from a very young age, just like reading, writing and doing mathematics (Wing 2006; Yadav et al. 2011). Repenning et al. (2010), for example, suggested how courses such as game design and robotics can be a means for gradual and iterative exploration of transferable CT patterns. Beyond question, opportunities must be given to today's students to work with algorithmic problem solving and computational methods and tools in K-12; everyone must get the essential education, knowledge and skills to be able to do this (Wing 2006; Czerkawski 2015; National Research Council 2010).

Angeli et al. (2016) and Mikropoulos and Bellou (2013) stressed that early exposure to computer science is vital for developing and fostering all aspects of CT. Dealing with educational robotics, via the programming of a robot, can give students the additional benefit of interacting with a concrete object in constructing their knowledge. In accordance with constructionist and constructivist approaches to teaching and learning, as well as design of learning environments, educational robotics appear to be a needed tool in children's hands, offering embodied and situated learning experiences. Students working with educational robotics, can think, design, create, and manipulate objects, while they reflect and collaborate amongst them (Alimisis 2013; Eguchi 2010). Educational robotics seem to encourage students to think creatively, analyze situations and apply critical thinking and problem solving to real world problems (Bers et al. 2014). Furthermore, educational robotics is seen as a tool for advancing CT, coding, and engineering (Eguchi 2014a, b). It not only offers an appropriate platform for developing skills in a fun and meaningful way, but also gives opportunities to deal with a range of disciplines such as technology, engineering and mathematics (STEM), literacy, social studies, dance, music and art (Eguchi 2014a, b).

The striking new interest in integrating robotics in educational settings is obvious. From kindergarten to high school and after-school activities, learning practitioners seem to adopt educational robotics to teach various subjects and domains (Benitti 2012). Nevertheless, scientific inquiry in the area is sporadic, whilst the processes and conditions under which any specific learning goals are achieved are far from being documented (Berland and Wilensky 2015).

This study summarizes published literature focused on the use of educational robotics for the advancement of CT skills in K-12 (from kindergarten to high school). The review aims to gather relevant evidence and present the most important aspects researchers and practitioners should take into consideration when conducting research on, or teaching with, educational robotics for the advancement of CT. The investigation was guided by an overarching research question:

> *How (and how much) educational robotics have been used in K-12 contexts to foster students' CT skills?*

1.1 Computational thinking (CT)

Although Papert was the first to describe CT, Wing (2006) brought back considerable attention to the term, which continues to date (Brennan and Resnick 2012). CT is defined as the thought processes involved in formulating problems and their solutions so that they can be represented in a form that can be implemented by a human or computer (Wing 2006, 2008). The main substance of CT is the ability to think like a computer scientist when confronting a problem (Barr and Stephenson 2011). Grover and Pea (2013) have commented on the interchangeable use of the terms "computational thinking" and "computational literacy."

> "The term computational literacy is perhaps susceptible to confusion with earlier ones like computer literacy, information literacy, and digital literacy that have assumed various meanings over the years ... Although the phrase and notion of computational thinking now seems to be preferred over computational literacy, in research and practice today the two phrases are often used interchangeably"(Grover and Pea 2013, p. 39).

Despite the attention CT has gained in K-12, there is no unanimous definition or theory of what it looks like in practice and how it can be assessed and measured (Grover 2011). In this review, we adhere to an inclusive definition of computational thinking as the range of computing skills including decomposition, abstraction, algorithms, and debugging (e.g., Berland et al. 2013; Resnick et al. 1988).

In terms of assessment, efforts have been made to assess CT in the context of using visual languages to teach programming and CT skills. Among others, Koh et al. (2010) proposed another two approaches: The Program Behavior Similarity (PBS) and the Computational Thinking Pattern Graph (CTPG) in which student-created games and simulations are analyzed towards depicting the CT concepts implemented by the students. Other approaches, mainly in the elementary school, include project portfolio analysis with the use of a 'User Analysis tool' for the understanding of design patterns, and design scenarios (Brennan and Resnick 2012). Another model has been proposed by Franklin et al. (2013) which measures proficiency in event-driven programming, initialization, synchronization and animation. Also, Seiter and Foreman (2013) proposed a framework called 'Progression of Early Computational Thinking (PECT) Model' for elementary students which maps elements from students' projects into CT concepts. One of the most cited operational definitions of CT comes from Brennan and Resnick (2012), based on which CT can be considered as:

> "a device for conceptualizing learning and development with the following characteristics: (i) formulate problems in a way that enables us to use a computer and other tools to help solve them; (ii) logically organize and analyze data; (iii) represent data through abstractions such as models and simulations; (iv) automate solutions through algorithmic thinking (a series of ordered steps); (v) identify, analyze, and implement possible solutions with the goal of achieving the most efficient and effective combination of steps and resources; and (vi) generalize and transfer this problem-solving process to a wide variety of problems" (Brennan and Resnick (2012), as cited in Vallance and Towndrow 2016, p. 222).

Further attempts to address the lack of an operational definition for CT as well as issues of measurement from a psychometric approach, have only recently appeared and are in progress (Román-González et al. 2017).

1.2 Educational robotics and computational thinking

Educational robotics suggest learning through design and include activities such as constructing and operating robot platforms (Verner et al. 1999). Educational robotics are also seen as tools for advancing CT, coding, and engineering (Eguchi 2014a, b). Not only they offer an appropriate platform for developing skills in fun and meaningful way, but also give opportunities to deal with a range of disciplines such as science, technology, engineering, and mathematics (STEM), literacy, social studies, dance, music and art (Eguchi 2014a, b). That said, they have been used to teach specific content in a domain (e.g., engineering) or rather more often, to act as construction and programming tools for promoting problem solving and CT (Virnes et al. 2008). Indeed, recently, there is a strong evidence supporting that CT can be taught using educational robotics (Berland et al. 2013; Resnick et al. 1988; Schweikardt and Gross 2006; Sklar et al. 2003; Berland and Wilensky 2015). Even though, there is a sufficient body of literature on CT and educational robotics, there has been very little work connecting the two (Berland and Wilensky 2015). Also, the limited work in the intersection of CT and educational robotics is not always positive, with non-significant impact on learners observed in some cases (Benitti 2012). In any case, the impact of the robotics in promoting CT needs to be validated through research evidence. This work aims to expand the dialog by mapping the current research in the area. Overall the review is situated in an emerging space for academic inquiry and aims to provide useful information, making suggestions for future research.

2 Methodology

The data set was searched and filtered by two researchers and co-authors of this review, resulting in only nine studies precisely dealing with studies at the intersection of CT and educational robotic, as follows:

Step 1 - Database search. A search was conducted by the first author of this work in the following electronic databases, to which the researchers had access and considered possible venues for educational research: EdITLib, ACM Digital Library, Emerald, ERIC, JSTOR, Proquest, Sage, Science Direct, Scopus, Springer Link, Taylor and Francis Online, and Google Scholar. The search keywords were: (education*) AND (robot*) AND ("computational thinking"). The database search yielded thousands of manuscripts as shown in Table 1.

Step 2 - Filtering for empirical work addressing the exact topic. Step 2 was an extremely tedious process aimed at isolating these studies which, based on empirical data, studied the very use of educational robotics for advancing students' CT skills in K-12. The first author of this work carefully inspected the titles and abstracts of all papers of Table 1. First, theoretical or position papers were excluded; only papers with empirical data were of interest in this review. Second, papers which limited CT to only one or two isolated skills (e.g., papers testing only the "sequencing" skill (Kazakoff et al. 2013; Wagner 1998) were excluded from the pool as they did not match the

Table 1 Initial database search results

Library name	Results
EdITLib	30
ACM digital library	13
Emerald	4
ERIC	3
JSTOR	3
SAGE	285
Science direct	28
Springer link	158
Scopus	30
Taylor and Francis online	32
Google scholar	2270
Total number of papers in the corpus	2856

inclusive definition of CT adopted in this work. In the end, only nine papers remained in the pool satisfying the above-mentioned criteria (see Table 2). All excluded papers were reviewed, independently, by the second author of this work, to ensure exclusion criteria was correctly applied (100% agreement existed between coders).

Step 3 - Synthesis. The resulting nine papers were thoroughly read by both authors independently with the prospect of identifying: (1) theoretical assumptions, (2) research designs, (3) setting and duration of the experience, (4) roles and procedures, (5) assessment issues, and (6) learning outcomes. Then, the authors discussed and synthesized their findings. Table 2 provides an overview of the context and platform used in each study of CT via educational robotics. Next, the section on findings, analyzes these nine papers providing insight into the current stage of knowledge.

3 Findings

3.1 Theoretical assumptions

Constructionism, constructivism, and learning-for-use, or a combination of these theoretical approaches, seems to underline research on CT via educational robotics. The dominant theory in this area is Constructionism (Atmatzidou and Demetriadis 2016; Bers et al. 2014; Penmetcha 2012). Constructionism has its roots in the 1960s by the MIT Logo Group (Bers et al. 2002). According to constructionism, the learning process is successful once students create their own ideas, whether this is a robot, a story or a computer program and then reflect carefully on the process (Papert 1980; Harel and Papert 1991). Papert argued that one gains knowledge while interacting with physical artifacts and being an active learner using technologies (Bers et al. 2014). While constructionism is an extension of Piaget's constructivism, the former focuses on

Table 2 Empirical studies on CT via educational robotics

ID	Title	Authors	Target age	Platform
1	Advancing students' computational thinking through educational robotics.	Atmatzidou and Demetriadis 2016	Junior high and high vocational students	Lego Mindstorms NXT
2	Computational thinking and tinkering.	Bers et al. 2014	Kindergarten students	CHERP
3	Robotics & engineering for middle & high school student to develop computational thinking.	Grover 2011	Middle and high school students	Gogo board
4	Comparing virtual and physical robotics environments for supporting computational thinking	Berland and Wilensky 2015	Middle school students	VBOT learning environment: VBOT with virtual robots and VBOT with physical robots
5	Using robotics and game design to enhance children's self-efficacy, STEM attitudes, and computational thinking skills	Leonard et al. 2016	Middle school students	LEGO EV3 robotics
6	Exploring the effectiveness of robotics as a vehicle of computational thinking	Penmetcha 2012	Undergraduate students	Robotis and roboplus software
7	Learning experience through Robocup junior.	Eguchi 2014a, b	Primary and secondary level students	Not mentioned
8	Supporting the development of computational thinking: A robotic platform controlled by smartphone	Almeida and Tacla 2015	Undergraduate students	The Coffee Platform
9	A Framework and an instructional design model for the development of students' computational and algorithmic thinking	Ioannou and Angeli 2016	Secondary level students	Lego Mindstorms NXT

new technologies and on the significance of making them aid the learning process. Computers are seen as a powerful tool for exploring new ideas, new ways of thinking and applying knowledge (Papert 2000). Eguchi (2014a, b) uses Piaget's Constructivism as a lens for the study of CT through robotics. The theory supports that knowledge is not passively received by a student, but it is actively built up in the mind of the learner, while one interacts with the environment and with physical artifacts. Knowledge is gained merely through experience and while doing through a hands-on project-based learning experiences (Piaget 1964). Learning-for-Use (Edelson 2001) is a technology design framework adopted by Leonard et al. (2016). According to this framework, there are four principles for game design and robotics applications: (a) knowledge construction is incremental in nature, (b) learning is goal directed, (c) knowledge is situated, and (d) procedural knowledge needs to support knowledge construction (Edelson 2001).

While the above-mentioned theoretical assumptions seem to frame the overall aims of research on CT via educational robotics, a direct link or translation of theory into practice is not real apparent in the reviewed studies. A practical framework for the development of CT through robotics appears to be in demand.

3.2 Research designs

A variety of research designs have been utilized to study CT via educational robotics. For example, a design-based research approach was adopted by Berland and Wilensky (2015) and Bers et al. (2014). In their work, Berland and Wilensky (2015) compared two curricular units, one using a physical robotics simulation and one using a virtual robotics simulation, to explore their effectiveness on students' CT skills. Bers et al. (2014) examined the learning outcomes of three kindergarten classrooms when they were exposed to computer programming concepts and robotics. On the other hand, a mixed method approach (questionnaires, think-aloud, interview data) was adopted by Atmatzidou and Demetriadis (2016) to assess the development of students' CT skills, with special focus on age and gender differences. Similarly, Grover (2011) in a mixed method study examined the elements and dimensions of CT as expressed by children verbally. A counter-balanced, quasi-experimental research design was adopted by Leonard et al. (2016) in a 3-year long investigation in which robotics and game design were used to develop middle school students' CT strategies. Overall, the variety of research designs appears to be helpful in revealing different aspects of the value of educational robotics for the advancement of CT.

3.3 Setting and duration of experience

Educational robotics can occur anytime and anywhere, yet school environments seem to be mainly used in the papers included in this review. With the exception of Eguchi's (2014a, b) study linked to a robotics competition, all other studies took place within school settings with varying duration depending on the aims of the researchers. For example, the study by Atmatzidou and Demetriades took place in public schools in Thessaloniki-Greece, during school time; in total, 11 robotics sessions (2 h each) were conducted, once a week. In Bers et al. (2014), the study took place in three kindergarten classrooms, two at a public urban school and one at private suburban school in USA, in periods of 60–90 min' sessions. Likewise, the study of Grover (2011) was conducted in two classes of two public schools in Chicago and lasted about eight hours per day for five school days. In all studies, the authors presented a constructivist learning environment, typically designed to bridge abstraction and reality in a concrete way, helping students to develop problem-solving strategies, creativity, and social skills. Yet, decisions about the duration of the experience in relation to specific learning goals or curricula were inadequately discussed in the reviewed studies, making it difficult to guide future decisions for follow-up studies and replication.

3.4 Roles and procedures

In terms of the roles of the learners and instructors, there was a consistent pattern in the studies of Table 2. The instructor typically assumed role of a facilitator of the knowledge and provided support for technical issues. Students were encouraged to actively interact with the physical or virtual robotics platforms and to play, design, and reflect, in order to construct their own understandings. For example, in Atmatzidou and Demetriadis (2016), teachers introduced the robotics platform and managed the classroom during the activity; trainers helped with practical issues, for example for the organization of the students' groups, and they also acted as facilitators who encouraged and scaffolded groups during solving programming tasks. Students were active participants in the learning process; they had to program the robot in groups and were expected to collaborate and discuss before they solved a given task. They were prompted to follow activities and reflect on specific concepts.

The role of the learners in the study of Leonard et al. (2016) included similar activities and tasks. Students learned how to program and modify coding to make the robot move, turn and do specific tasks using the software Lego Mindstorms EV3. They also constructed a robot using the LEGO EV3 hardware and learned how to use the sensors aiming at specific goals. Although the role of the instructors was not explicitly stated in this work, it appears that they had demonstrated the variety of programming challenges to students and how to use the robotics platform. Grover (2011) reported similar involvement of instructors and learners. In their study, a researcher and an assistant were present, facilitating, managing, leading the workshop activities and the data collection and scaffolding students during the activities. Students were encouraged to follow activities, discuss their progress, and write their reflections at the end of each session. Similarly, the role of the instructor in the study of Berland and Wilensky (2015) was to demonstrate the physical/virtual robotics system to the respective classes, while the role of students was to program the robot, collaborate, compare, reflect and apply the knowledge and skills gained to new activities.

Overall a student-centered, constructivist learning environment was promoted in all reviewed studies with students being active participants in the learning process. Yet, none of the studies elaborated on the reasons for the selection of robotics platforms (see Table 2 for a variety of platforms utilized), whilst the curriculum and learning goals guiding the learning activities were not adequately presented, making it difficult to test hypotheses about the value of different platforms linked to specific curricular objectives.

3.5 Assessment issues

Ways of assessment of CT (and overall learning outcomes) varies greatly across studies. For example, Atmatzidou and Demetriadis (2016) used different types of instruments to assess learning outcomes. First, students were asked to solve programming problems with two intermediate questionnaires. Then, opinion questionnaires were administered to measure students' perceived understanding of CT concepts and their perceived learning experience with regard to the development of basic programming concepts, collaboration and likes/dislikes relevant to the overall activity. An online questionnaire was also used by Eguchi (2014a, b) to assess students' perceived learning outcomes upon their participation in the RoboCupJunior competition. In this case, the online questionnaire was designed to assess learning experience in STEM, engineering thinking and CT skills, other soft skills, STEM interests, and interests in pursuing college education. On the other hand, Grover (2011) assessed students' prior technological experiences via a questionnaire but also pre/post interviews focused on students' experiences. Berland and Wilensky (2015) worked with video data of student activity during their learning in virtual vs. physical robotics environments, logs of students' interaction with the robotics software, as well as pre/post-tests designed to assess students' CT. Leonard et al. (2016) utilized qualitative and quantitative data sources to evaluate the development of CT during game design; quantitative data were collected via a self-efficacy survey as well as a STEM attitude and career survey, while qualitative data included students' work samples (programming code and actual games) and observation field notes. Last, Penmetcha (2012) analyzed data from a pre/post-test questionnaire assessing the participants' interest in robotics, engagement with the learning module, and interest in algorithmic thinking, programming and robotics overall. In fact, while the various different ways of assessment of CT across studies could have given a holistic perspective on the issue, the results of all nine studies should be interpreted with caution; the psychometric properties of the instruments used were not reported and therefore, there is no evidence of validity of the data produced.

3.6 Learning outcomes

In accordance with the lack of validated measurement instruments for CT, the documentation of learning gains in the reviewed studies was also problematic in the reviewed articles. In general, the absence of a system of indicators and a standardized evaluation methodology created doubts in students' real progress (Alimisis 2013). In all nine works, the attempt to support CT via educational robotics seemed to have resulted in the development of relevant twenty-first century skills, which of course has its own value; yet, the advancement of CT as a more complex ability (including decomposition, abstraction, algorithms, debugging) was unclear. For example, problem-solving, collaboration, and communication skills were emphasized as a learning gain in Eguchi (2014a, b), whilst the study reported students' positive interest in STEM learning, after their participation in the robotics competition. Also, Leonard et al. (2016) reported technology-related efficacy gains from pre-to-post testing for the robotics group. In Penmetcha (2012), participants felt robotics was more engaging and increased their interest in programming. Yet, in order to mind learning outcomes as well as the efficacy of curriculums integrating CT skills, an inclusive assessment of CT needs to take place and CT instruments need to be validated (Grover and Pea 2013) which was not the case in the reviewed articles.

4 Discussion

In this paper, we summarized the current state of research of the development of CT via the use of educational robotics. Interestingly, only nine empirical investigations were found at this intersection. Together these articles reveal initial evidence suggesting that educational robots can foster students' cognitive and social skills. Yet, a few important aspects and challenges remain understudied. We provide recommendations for learning scientists aiming to guide further research in this emerging research area. We expend this discussion to include insights, based on what we've found in the literature, as to what learning practitioners can do to help move toward solving those challenges you've identified.

4.1 Recommendations for learning researchers

Four distinct areas appear to warrant further study and clarification based on our review.

1. Agree on the operational definition of CT. It is quite evident that much of the recent work on CT has focused mostly on definitional issues (Grover 2011; Grover and Pea 2013); yet, there is still no widely agreed upon definition of CT (Barr and Stephenson 2011). In light of this fact, developing an approach to CT through robotics is especially challenging. A consensus operational definition of CT is urgently needed before moving on to the practical integration of CT in K-12. Although we acknowledge that obtaining consensus could take years, if not decades, we hope this result will trigger more studies to explicitly make effort to define CT and validate relevant instruments (e.g., Román-González et al. 2017).
2. Establish instruments for the assessment of CT. Linked to the lack of a widely accepted operational definition of CT, validated instruments for its assessment are still lacking. Despite some previous attempts (see earlier discussion e.g., Repenning et al. 2010), systematic assessment methods tracking the development of CT components such as abstraction, automation and analysis have only recently appeared and are still in progress (Román-González et al. 2017). This adds an extra complexity to understanding the value of educational robotics in helping to advance CT. Therefore, a systematic assessment of the learning outcomes and benefits from using educational robotics in this context can become viable only after researchers can establish a valid measurement of CT.
3. Research educational robotics classroom orchestration. The reviewed studies reveal that integration of educational robotics in the classroom can create significant extra work for the teacher. The teacher is called to design collaborative and creative learning activities around educational robotics and to provide arrangement (e.g., scripts) to facilitate the interaction between all students in the class and within smaller groups. Such teacher activity is recently researched under the agenda of "classroom orchestration" (Dillenbourg 2013) which highlights the need for supporting teachers in challenges associated with technology use in real classroom (Roschelle et al. 2013) enabling them to manage the complexities and constraints faced in the learning environment (Dillenbourg 2013). Based on findings from this review, the dynamic robotics classroom environment and the changing roles of educators and leaners necessitate relevant research on classroom orchestration toward practical guidelines for successful technology integration.
4. Work on a practical framework for the development of CT through robotics. The computer science education community can play an important role in advancing CT across disciplines and in helping to integrate the application of CT and tools across diverse areas of learning (Barr and Stephensons 2011). Meanwhile educational robotics, via the programming of robots, can give students the additional benefit to interact with a concrete object and construct knowledge efficiently (Angeli et al. 2016; Mikropoulos and Bellou 2013). The intertwining of the above

in a set of clear examples and curricular activities will present practitioners with a concrete method on how to facilitate CT for their students.

4.2 Recommendations for learning practitioners

Three directions for learning practitioners can help move toward solving the above-mentioned challenges, whilst inform future practice in using educational robotics in the classroom.

1. Develop curriculum for CT via robotics. There is lack of curriculum that can support learners and educators in the development of CT via the use of educational robotics. In the reviewed studies, the robotics curriculum, and learning goals guiding the learning activities, was not adequately presented. Also, individual studies seem to have adopted their own curricula without evidence of curriculum evaluation. A CT curriculum framework for K-6 has been proposed by Angeli et al. (2016); yet, this framework lacks empirical evidence of its application in the classroom and consequently evidence of learning outcomes intersection of CT and educational robotics. Linked to the previous argument however, although curriculums integrating CT skills are in demand, minding their efficacy first requires valid assessment of CT learning outcomes (Grover and Pea 2013).
2. Create a robotics platforms repository. Many different educational robotic platforms are now commercially available with various capabilities and costs. The reviewed studies did not elaborate on the selection of their robotics platform, making it difficult to understand their possibilities and limits with respect to CT learning goals. A compilation of a database with all available platforms, capabilities, pros/cons etc. will help learning practitioners integrate educational robots in their classroom and test hypotheses about their value linked to specific curricular objectives.
3. Include the details of the robotics interventions. Understanding the processes and conditions under which specific CT goals are achieved in the educational robotics environment demands in-depth descriptions of the procedures utilized in each study. For example, much of the "learning" around educational robotics may come from collaboration within groups and from dynamic discussions of trial and error. Details of the learning activities, the learning resources, the social environment, as well as decisions about the duration of the experience are often missing from previous studies, making it difficult to follow-up with replication as well as expanding on research areas such as classroom orchestration.

5 Conclusion

CT is a universal skill that everyone has the potential to learn and use; it represents a general model of problem solving in which an algorithmic approach is taken to reasoning about complex systems using levels of abstraction. Tailoring educational robotics to serve the development of this skill, from kindergarten to high school, is an emerging space for academic inquiry. Nevertheless, scientific inquiry in the area is sporadic, whilst the processes and conditions under which any specific learning goals are achieved are far from being documented. An increasing number of researchers seem to argue that various CT skills can be advanced via educational robotics, particularly skills such as decomposition, abstraction, algorithms, and debugging, yet, there is very little empirical evidence confirming or refusing these arguments (Berland and Wilensky 2015). Such inquiry should start from a widely agreed definition of CT and validated measurement instruments for its assessment. A practical framework for the development of CT via robotics is next in demand, so as instructional designers and educators can implement it consistently and at scale. Overall, research on CT via educational robotics is still in its infancy with only initial evidence, which requires replication. This review calls from more research in this area to take full advantage of the affordances of educational robotic to advance learning.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Alimisis, D. (2013). Educational robotics: Open questions and new challenges. *Themes in Science and Technology Education, 6*(1), 63–71.

Almeida, L. D., & Tacla, C. A. (2015). Supporting the Development of Computational Thinking: A Robotic Platform Controlled by Smartphone. In Learning and Collaboration Technologies: Second International Conference, LCT 2015, Held as Part of HCI International 2015, Los Angeles, CA, USA, August 2–7, 2015, Proceedings (Vol. 9192, p. 124). Springer.

Angeli, C., Voogt, J., Fluck, A., Webb, M., Cox, M., Malyn-Smith, J., & Zagami, J. (2016). A K-6 computational thinking curriculum framework: Implications for teacher knowledge. *Journal of Educational Technology & Society, 19*(3), 47–57.

Atmatzidou, S., & Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. *Robotics and Autonomous Systems, 75*, 661–670.

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads, 2*(1), 48–54.

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education, 58*(3), 978–988.

Berland, M., & Wilensky, U. (2015). Comparing virtual and physical robotics environments for supporting complex systems and computational thinking. *Journal of Science Education and Technology, 24*(5), 628–647.

Berland, M., Martin, T., Benton, T., Petrick Smith, C., & Davis, D. (2013). Using learning analytics to understand the learning pathways of novice programmers. *Journal of the Learning Sciences, 22*(4), 564–599.

Bers, M., Ponte, I., Juelich, K., Viera, A., & Schenker, J. (2002). Teachers as designers: Integrating robotics in early childhood education. *Information Technology in Childhood Education, 1*, 123–145.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education, 72*, 145–157.

Brennan, K., & Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. In Proceedings of the 2012 annual meeting of the American Educational Research Association, Vancouver, Canada (pp. 1–25).

Czerkawski, B. (2015). Computational Thinking in Virtual Learning Environments. In Proceedings of E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2015 (pp. 993–997).

Dillenbourg, P. (2013). Design for classroom orchestration. *Computers and Education, 69*, 485–492.

Edelson, D. C. (2001). Learning-for-use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching, 38*(3), 355–385.

Eguchi, A. (2010). What is Educational Robotics? Theories behind it and practical implementation. In *Society for information technology & teacher education international conference* (pp. 4006–4014). Jacksonville: Association for the Advancement of Computing in Education (AACE).

Eguchi, A. (2014a). Educational robotics for promoting 21st century skills. *Journal of Automation Mobile Robotics and Intelligent Systems, 8*(1), 5–11.

Eguchi, A. (2014b). Learning experience through RoboCupJunior: Promoting STEM education and 21st century skills with robotics competition. In Proceedings of Society for Information Technology & Teacher Education International Conference.

Franklin, D., Conrad, P., Boe, B., Nilsen, K., Hill, C., Len, M., ... & Laird, C. (2013). Assessment of computer science learning in a scratch-based outreach program. In Proceeding of the 44th ACM technical symposium on Computer science education (pp. 371–376). ACM.

Grover, S. (2011). Robotics and engineering for middle and high school students to develop computational thinking. In annual meeting of the American Educational Research Association, New Orleans, LA.

Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. *Educational Researcher, 42*(1), 38–43.

Harel, I. E., & Papert, S. E. (1991). *Constructionism*. Westport, CT: Ablex Publishing.

Ioannou, I., & Angeli, C. (2016). A Framework and an Instructional Design Model for the Development of Students' Computational and Algorithmic Thinking. In MCIS (p. 19). Chicago.

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal, 41*(4), 245–255.

Koh, K. H., Basawapatna, A., Bennett, V., & Repenning, A. (2010). Towards the automatic recognition of computational thinking for adaptive visual language learning. In 2010 I.E. Symposium on Visual Languages and Human-Centric Computing (pp. 59–66). IEEE.

Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O. S., Hubert, T., & Almughyirah, S. (2016). Using robotics and game design to enhance Children's self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology, 25*(6), 860–876.

Mikropoulos, T. A., & Bellou, I. (2013). Educational robotics as mindtools. *Themes in Science and Technology Education, 6*(1), 5–14.

National Research Council. (2010). *Report of a workshop on the scope and nature of computational thinking*. Washington, DC: The National Academies Press.

National Research Council. (2011). *Report of a workshop of pedagogical aspects of computational thinking*. Washington, DC: The National Academies Press.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.

Papert, S. (1993). *The children's machine: Rethinking school in the age of the computer*. New York: Basic Books.

Papert, S. (2000). What's the big idea? Toward a pedagogy of idea power. *IBM Systems Journal, 39*(3.4), 720–729.

Penmetcha, M. R. (2012). Exploring the effectiveness of robotics as a vehicle for computational thinking (Doctoral dissertation, Purdue University).

Piaget, J. (1964). Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching, 2*(3), 176–186.

Repenning, A., Webb, D., & Ioannidou, A. (2010) Scalable game design and the development of a checklist for getting computational thinking into public schools. In: Proceedings of the 41st ACM technical symposium on computer science education. Milwaukee, WI, pp 265–269.

Resnick, M., Ocko, S., & Papert, S. (1988). LEGO, Logo, and design. *Children's Environments Quarterly, 5*, 14–18.

Román-González, M., Pérez-González, J. C., & Jiménez-Fernández, C. (2017). Which cognitive abilities underlie computational thinking? Criterion validity of the computational thinking test. *Computers in Human Behavior, 72*, 678–691.

Roschelle, J., Dimitriadis, Y., & Hoppe, U. (2013). Classroom orchestration: Synthesis. *Computers and Education, 69*, 523–526. https://doi.org/10.1016/j.compedu.2013.04.010.

Schweikardt, E., & Gross, M. D. (2006). roBlocks: A robotic construction kit for mathematics and science education. In Proceedings of the 8th international conference on Multimodal interfaces (pp. 72–75). ACM.

Seiter, L., & Foreman, B. (2013). Modeling the learning progressions of computational thinking of primary grade students. In Proceedings of the ninth annual international ACM conference on International computing education research (pp. 59–66). ACM.

Sklar, E., Eguchi, A., & Johnson, J.. (2003). RoboCupJunior: Learning with educational robotics. RoboCup 2002: Robot soccer world cup VI, pp. 238–253.

Vallance, M., & Towndrow, P. A. (2016). Pedagogic transformation, student-directed design and computational thinking. *Pedagogies: An International Journal, 11*(3), 218–234.

Verner, I. M., Waks, S., & Kolberg, E. (1999). Educational robotics: An insight into systems engineering. *European Journal of Engineering Education, 24*(2), 201–212.

Virnes, M., Sutinen, E., & Kärnä-Lin, E. (2008). How children's individual needs challenge the design of educational robotics. In Proceedings of the 7th international conference on Interaction design and children (pp. 274–281). ACM.

Wagner, S. P. (1998). Robotics and children: Science achievement and problem solving. *Journal of Computing in Childhood Education, 9*(2), 149–192.

Wilensky, U. (2001). Modeling nature's emergent patterns with multi-agent languages. In the Proceedings of EuroLogo, 1–6. Retrieved May 2015, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.294.8094&rep=rep1&type=pdf.

Wing, J. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–36.

Wing, J. M. (2008). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 366*(1881), 3717–3725.

Yadav, A., Zhou, N., Mayfield, C., Hambrusch, S., & Korb, J. T. (2011). Introducing computational thinking in education courses. In the Proceedings of the 42nd ACM technical symposium on Computer science education (pp. 465–470). Retrieved February 2016, from http://cs4edu.cs.purdue.edu/_media/sigcse11-final.pdf.