Robotics and Autonomous Systems 75 (2016) 661–670

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

journal homepage: www.elsevier.com/locate/robot

Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences

Soumela Atmatzidou *, Stavros Demetriadis

Aristotle University of Thessaloniki, Department of Informatics, Greece

HIGHLIGHTS

- Students reach the same level of Computational Thinking (CT) skills development independent of their age and gender.
- Computational Thinking skills in most cases need time to fully develop (students' scores improve significantly towards the end of the activity).
- Girls appear in many situations to need more training time to reach the same skill level compared to boys.
- The different modality (written and oral) of the CT skill assessment instrument may have an impact on students' performance.

ARTICLE INFO

Article history:
Available online 30 October 2015

Keywords:
Computational thinking
Educational robotics
Secondary education
Skill development

ABSTRACT

This work investigates the development of students' computational thinking (CT) skills in the context of educational robotics (ER) learning activity. The study employs an appropriate CT model for operationalising and exploring students' CT skills development in two different age groups (15 and 18 years old) and across gender. 164 students of different education levels (Junior high: 89; High vocational: 75) engaged in ER learning activities (2 hours per week, 11 weeks totally) and their CT skills were evaluated at different phases during the activity, using different modality (written and oral) assessment tools. The results suggest that: (a) students reach eventually the same level of CT skills development independent of their age and gender, (b) CT skills in most cases need time to fully develop (students' scores improve significantly towards the end of the activity), (c) age and gender relevant differences appear when analysing students' score in the various specific dimensions of the CT skills model, (d) the modality of the skill assessment instrument may have an impact on students' performance, (e) girls appear in many situations to need more training time to reach the same skill level compared to boys.

1. Introduction

This work presents and discusses a specific didactic approach to support the development of students' computational thinking (CT) skills in educational robotics (ER) activities. As Wing [1] argues, computational thinking (CT) is a fundamental skill for everyone and it should be considered as an important component of every child's analytical ability along with reading, writing, and arithmetic. Recently, there has been growing recognition of the importance of CT in controlling and managing cognitive activities, as well as understanding and solving problems in a wide range of contexts, not only in the field of computer science, but in all disciplines [2].

Robotics can be used as a tool that offers opportunities for students to engage and develop computational thinking skills [3,4]. Educational robotics is being introduced in many schools as an innovative learning environment, enhancing and building higher order thinking skills and abilities, and helping students solve complex problems [5]. Furthermore, a guided instruction approach using robots facilitates teamwork, develops conceptual understanding, enhances critical thinking, and promotes higher-order learning in the domains of mathematics and science [6].

This paper describes the implementation of ER activity in secondary school, focusing on the different possible impacts that the instructional approach might have on the development of students' CT skills depending on their age and gender. Guided by worksheets, students worked in small groups to solve robot programming problems. The level of their CT skills was evaluated at different times during the activity, with focus on five key CT constructs—abstraction, generalisation, algorithm, modularity and decomposition.

---

* Corresponding author. Tel.: +30 6977718143.
E-mail addresses: atmatzid@csd.auth.gr (S. Atmatzidou), sdemetri@csd.auth.gr (S. Demetriadis).

http://dx.doi.org/10.1016/j.robot.2015.10.008

2. Background

Robotics is usually seen as an interdisciplinary activity drawing mostly in Science, Mathematics, Informatics and Technology and offering major new benefits to education in general at all levels [7,8]. Educational robotics is a powerful, flexible, teaching and learning tool, encouraging students to construct and control robots using specific programming languages [7]. The roots of ER are to be found in Seymour Papert's work, creator of the Logo programming language [9]. Papert suggests that learning is most effective when students are experiencing and discovering things for themselves. He also argues that robotics activities have tremendous potential to improve classroom teaching [9,10]. Drawing on the theoretical underpinnings of Papert's constructionism and Vygotsky's socio-cognitive approaches, ER activities help students transform themselves from passive to active learners, constructing new knowledge by collaborating with their peers and developing essential mental skills by acting as researchers. Many studies indicate that ER activities have a positive impact on the development of students' critical thinking, problem solving and metacognitive skills [5,11,12] and also on the learning of a programming language [7,13,14]. Other studies demonstrate how ER promotes a joyful mode of learning, while advancing students' motivation, collaboration, self-confidence and creativity [15–17]. Many researchers argue that robotics programs provide a valuable avenue to increase students' interest and participation in science, technology, engineering and mathematics (STEM), while they motivate them to pursue a career in one of these fields (e.g. [18–20]). However, certain researchers point out that although robotics seems to be an excellent tool for teaching and learning and a compelling topic for students of all ages, the pedagogy of teaching with robotics is still in its infancy [7,21]. It is also noted that more research is needed to point out how to work with educational robotics to help students develop specific skills [10,22].

As this study focuses on ER as a means for advancing students' CT skills, we concisely review next the CT theoretical framework and studies on the ER-CT relationship. Wing [1] describes CT as a type of analytical thinking that draws on concepts fundamental to computer science and provides a way for solving problems, designing systems, and understanding human behaviour. CT roots go back to Papert's ideas of the computer being the children's machine that would allow them to develop procedural thinking through programming, and refers to ways of algorithmically solving problems and to the acquisition of technological fluency [9].

In the literature there are multiple definitions of CT and several suggestions about which skills and abilities are relevant to CT and how to integrate CT in the curricula of all grades. Wing [2] asserts that CT has the potential to advance the students' problem-solving skills through processes such as abstraction, generalisation, decomposition, algorithm design and separation of concerns. Astrachan et al. [23] emphasise skills such as: developing computational artefacts, abstracting, analysing problems and artefacts, and communicating and working effectively in teams. Still others argue that the key concepts of CT are abstraction, automation, simulation, evaluation, algorithm building, conditional logic, debugging, decomposition, problem analysis, distributed computing and effective teamwork [24–26]. Emphasis is also given to the view that the educational benefits of CT transfer to any domain – not only in the field of computer science – by enhancing and reinforcing intellectual skills [1,27]. Yadav [28] argues emphatically that '*CT in education has the potential to significantly advance the problem-solving skills of K-12 students*'.

Naturally, researchers have started exploring also the potential of educational robotics to promote the development of CT [4,29–31]. Certain studies emphasise that children who program robots learn and apply core CT concepts such as abstraction, automation, analysis, decomposition, modularisation and iterative design [4,29,30]. A 2011 study by National Science Foundation [4] provided evidence that student programmers in a robotics project, developed abstraction, automation, and analysis related skills, while programming the robot agent to interact with its environment. However, it is worth mentioning according to researchers that the field requires systematic assessment procedures.

Research engaging younger children reported also positive outcomes, demonstrating that children 4–6 years old can build simple robotics projects becoming acquainted with powerful ideas of engineering, technology, and computer programming while also building CT skills [30,32,33]. More specifically, a study with 53 kindergarten children [33] using Lego WeDo robots and the CHERP (Creative Hybrid Environment for Robotics Programming) language, reported that the children were involved and understood basic programming and CT concepts relevant to sequencing and choosing the correct instructions. A similar study by Kazakoff et al. with 27 kindergarten children, focusing solely on sequencing, showed improvement of the students' scores from the first activity to the last [29].

Regarding elder children (Junior and High School students), studies report also positive results on the development of CT skills. Grover [27] developed a curriculum for teaching CT Language and CT principles in schools. The results indicated that students after the intervention were capable of using certain CT related vocabulary and principles (such as conditional logic and decomposition), whereas other concepts like abstraction, representation and algorithmic flow control were seldom used. Another study by Touretzky et al. [34] engaging children aged 10–17 (some of them with special abilities), focused on abstraction across different programming environments and especially on deep and abstract understanding of programming concepts. The researchers concluded that – despite the limitations – robotics is a helpful tool for young students, "*facilitating a more abstract understanding*". Penmetcha [35] investigated the effects of ER activity on university students exploring the relationship between robotics and developing programming and algorithmic thinking. The results showed that robotics fulfil their purpose as a medium for incorporating CT practices, regardless of the students' background, and can be used to teach concepts such as designing, programming and testing at a more abstract level. As in the other studies, limitations were reported relevant to the study small sample size [27]. Finally, a case study by Eguchi [36] explores the effects of a robotics competition on students' CT and problem solving skills reporting an overall very positive effect.

Overall, although the CT concept has attracted considerable attention, the literature on implementing CT in a K-12 setting is still relatively sparse [28]. There is also lack of empirical evidence in defining the explicit CT boundaries [37], although recent articles begin to describe what it looks like [4,30,38,39]. More than that, research into how CT can be introduced in the classroom is on the early stages and there is shortage of description about how children can learn and develop CT skills [27,28,37]. Another issue is to understand at what age – or grade level – children are ready to be familiar with advanced concepts such as abstraction, automation, decomposition, etc. and how to teach those skills progressively [4]. Likewise, there is little agreement on strategies for assessing the development of CT in young people [23,38,40,41]. Existing studies typically employ a student group of specific age thus limiting the generalisation of the results to other age groups (e.g. [8,29,33]), have small sample sizes (e.g. [27,29,34,35]), and do not provide explicit teacher guidance on how to organise a well-guided ER activity to promote students' CT skills. Researchers also differ in the way they build an operational CT skills framework to apply to their studies. Table 1 presents the various CT skill models employed in various ER studies.

Another issue of interest is the gender differences observed in studies on STEM learning activities. Much research has