European Journal of Educational Research
Volume 11, Issue 4, 1997 - 2012.
ISSN: 2165-8714
http://www.eu-jer.com/

Computational Thinking Development: Benefiting from Educational Robotics in STEM Teaching

Cucuk Wawan Budiyanto*
Universitas Sebelas Maret, INDONESIA

Kristof Fenyvesi
University of Jyväskylä, FINLAND

Afra Lathifah
Universitas Sebelas Maret, INDONESIA

Rosihan Ari Yuana
Universitas Sebelas Maret, INDONESIA

Received: February 20, 2022 ▪ Revised: May 21, 2022 ▪ Accepted: August 7, 2022

Abstract: The delivery of science, technology, engineering and mathematics (STEM) learning to improve an individual's competence and future career interests has become a critical scientific undertaking for teachers and researchers alike. A plethora of research has proposed various hands-on robotics activities built on constructivist theories, thereby facilitating the development of knowledge based on reality for scientific and non-scientific stakeholders. Robotics may become an essential focus point within technology provision, which is an essential underlying characteristic for the seminal development of computational thinking (CT). However, despite the potential benefit of CT in developing an individual's problem-solving skills, strategies for improving this ability through hands-on robotics activities largely remain underexplored. This paper highlights the constructs drawn from hands-on robotics activities in a STEM workshop designed for pre-service teacher students. The qualitative research design involved eight participants to investigate the responses of pre-service teachers to a hands-on robotics activity intended to provide STEM material. The research findings emphasise the correlations between the CT principles and STEM learning phases and underscore the roles played by educational robotics to enhance previous literature on learning experience.

Keywords: *Computational thinking, educational robotics, hands-on activities, STEM learning cycle.*

To cite this article: Budiyanto, C. W., Fenyvesi, K., Lathifah, A., & Yuana, R. A. (2022). Computational thinking development: Benefiting from educational robotics in STEM teaching. *European Journal of Educational Research*, *11*(4), 1997-2012. https://doi.org/10.12973/eu-jer.11.4.1997

Introduction

The delivery of science, technology, engineering and mathematics (STEM) learning to improve an individual's competence and future career interests has become an important scientific endeavour for teachers and researchers (Kopcha et al., 2017). A plethora of research has suggested various robotics hands-on activities built on theories of constructivism (Elkin et al., 2014; Kandlhofer & Steinbauer, 2016; Kucuk & Sisman, 2020). The research has considered the use of robotics to facilitate knowledge development among people with minimal to negligible technological background. The use of robotics in education has largely been advocated as a means of developing technical skills in areas such as programming activities (Alvarez & Larrañaga, 2016; Chaudhary et al., 2016; Falloon, 2016; Kong et al., 2020; Korkmaz, 2016; Ohnishi et al., 2017), science teaching and learning (Chu et al., 2019; El-Hamamsy et al., 2021; Ibrahim et al., 2020) and control and engineering (Castro et al., 2021; Ibrahim et al., 2020). However, it has also become apparent that robotics offers opportunities to develop social skills through engaging activities such as collaboration (Demetroulis & Wallace, 2021; Lee et al., 2013; Nemiro, 2021), leadership (Morgan et al., 2019) and educational robotics. Therefore, in an innovative learning environment, robotics can enhance students' higher order thinking skills and enhance their ability to solve complex problems (Atmatzidou & Demetriadis, 2016). Research in the context of educational robotics has, therefore, highlighted the prominent development of various areas of computational thinking (CT) skills (Aristawati et al., 2018; Castro et al., 2021; Jaipal-Jamani & Angeli, 2017).

This paper investigates the development of CT during a STEM activity in the context of pre-service teacher students. As a fundamental understanding of CT development should be taught at an early age, research on the use of educational robotics for CT development has tended to over-emphasise the involvement of early-age children (Angeli & Valanides, 2020; Hamilton et al., 2020; Li et al., 2020; Saxena et al., 2020; Shen et al., 2020) or secondary schools (Ardito et al., 2020; Durak et al., 2019; Zhang et al., 2021). While teachers need to develop an advanced understanding of how to

---

* **Corresponding author:**
Cucuk Wawan Budiyanto, Universitas Sebelas Maret, Surakarta, Central Java, Indonesia ✉ cbudiyanto@staff.uns.ac.id

deliver STEM material using hands-on as well as technology-based learning modules, further attention has to be directed to this pertinent subject due to the limited number of existing studies on pre-service teachers' use of robotics to teach STEM content (Papadakis, Vaiopoulou, Sifaki, Stamovlasis, & Kalogiannakis, 2021; Tsakeni, 2021). Although robotics has mainly been advocated as a tool in STEM learning, only a limited number of studies have discussed its potential contribution to the development of learners' CT skills in the context of STEM (Ioannou & Makridou, 2018), let alone the intersection between STEM and CT (Sun et al., 2021). Consequently, it is necessary to explore how robotics plays a vital role in STEM.

This research posits the following two research questions, namely:

1) What is the correlation between CT and STEM within the context of pre-service teacher students?

2) What is the role played by robotics in STEM learning?

Literature Review

Hands-on Design in CT Instruction

Computer scientists recognise CT as a problem-solving skill (Angeli & Giannakos, 2020; Eguchi, 2016; Kale & Yuan, 2021). Bocconi et al. (2016) stated that CT skills are underpinned by the ability to develop regular patterns based on real-world problems and design, develop, refine and explain how computing technology works. Natural scientist argued that CT approaches are broadly similar with mathematical problem-solving abilities (Aminah et al., 2022). This can be interpreted as a type of analytical thinking that refers to fundamental concepts in computer science and provides an approach to problem-solving, designing systems and understanding human behaviour, which needs to be developed in the twenty-first century (Wing, 2006). Despite not necessarily being a specialisation within computer science, literature appears to over-conceptualise CT teaching as the delivery of computer science courses (Kong et al., 2020; Montiel & Gomez-Zermeño, 2021). As a result, the instruction to encourage CT development has become dominated by the delivery of computing ability as opposed to the conception of critical thinking (Li et al., 2020), thereby hindering the adoption of CT in any discipline.

It has been argued that hands-on application provides an active way of learning in a tactile environment (Hamzeh et al., 2017). Moreover, the use of hands-on learning objects has a profound impact on the development of problem-solving skills, understanding of computation and interest in engineering professions (Fidai et al., 2020). Students' active participation determines their exploration of CT principles (Bers et al., 2014). In light of the theory of constructivism (Piaget, 1954), hands-on educational tools may serve as an appropriate medium for active learning, as children construct their knowledge by manipulating artefacts (Budiyanto et al., 2021). Indeed, even though Kotsopoulos et al. (2017) outlined a pedagogical framework for CT with which one can interpret four pedagogical experiences – 1) unplugged, (2) tinkering, (3) making and (4) remixing – into a practical worksheet, it remains a critical issue for course developers. Thus, it appears that the challenges pertaining to instruction design relate to the precise determination of the type of hands-on material that could help stimulate students' involvement in the activities.

Robotics in STEM Learning

Literature highlights that students' interaction with robotics facilitates learning and enhances students' positive interest in STEM (Ioannou & Makridou, 2018), both of which are crucial for engaging students in the STEM fields (Shen et al., 2020). The use of robotics in learning provides a comprehensive education and supports the teaching of subjects that are distinct from robotics per se (Benitti, 2012). Educational robotics, therefore, offers potential as a learning and teaching tool and facilitates the education of students who do not display an immediate interest in academic disciplines related to science or technology. Hence, educational robotics creates the scope for an integrated, multi-disciplinary approach that incorporates technical and social topics (Anwar et al., 2019). However, a sophisticated design of the delivery and learning evaluation remains the utmost necessity, as a positive perception of the robot neither guarantees successful learning achievement (Nasir et al., 2020) nor significantly improves students' STEM attitudes (Zhang et al., 2021).

At the outset, STEM learning helps students understand concepts or knowledge (science) before deepening that knowledge by utilising technology. This technology can then be developed by building or designing something (engineering) to produce something else, which, in turn, can then be communicated and understood (art) based on data calculations (mathematics) to find a solution to a problem (Holbrook et al., 2020; Jurado et al., 2020).

Gülhan and Şahin (2018) argued that the practice of integrating art into STEM in elementary school children's education positively impacted the learning process through five learning phases: Engagement, Exploration, Explanation, Elaboration and Evaluation. These five elements are highlighted as key elements in the constructivist approach to enhancing learning outcomes (Bybee, 2019; Omotayo & Adeleke, 2017). Despite the proposed strategies, the use of robotics as a learning medium to deliver STEM, which simultaneously contributes to CT development, remains a challenging endeavour for course designers.

Methodology

Research Procedures

The research was designed as a case study approach to gather and analyse data (Simons, 2009; Yin, 2018). In this instance, the case study involved the implementation of an educational robotics activity in STEM teaching designed for pre-service teachers. The researchers administered the project to explore participants' perceptions and behavioural patterns within the scope of the activity. Following the protocol elaborated in the research conducted by Budiyanto et al. (2020), the researchers administered a five-stage procedure employing Lego Mindstorms EV3 to encourage the students to assemble and program the Lego robotics. In this instance, the five stages were preparation, introduction, assembly, completion and result testing and closing and reflecting. Thereafter, each participant spent around four hours on the procedure.

The details of each stage have been elaborated in the subsequent sections.

Stage 1: Preparation

The preparation stage began with the participants filling out a pre-test questionnaire, wherein they recorded their previous experience of using robotics, programming or algorithms. Once the schedule had been determined, a time slot was assigned to the eight participants to undertake the robotics activities in the laboratory. Soon afterwards, the participants were introduced to the Lego Mindstorms robotics assembly, Lego Mindstorms programming and an overview of STEM teaching and learning. A set of learning materials, including a practicum handbook, reading materials and short videos, were also delivered for the session.

Stage 2: Introduction

The participants were introduced to the instructions on using the Lego Mindstorms EV3 tools and software in the form of a presentation file. In this step, they were expected to understand the concept of abstraction and generalisation to derive an overview of the learning activities that would be carried out.

Stage 3: Assembly

The participants were directed to conduct exploration activities using Lego Mindstorms EV3 by following the given module. The learning material module contained information on the learning objectives, required components, instructions for assembling the robots and the designated test. During this stage, the focus was on ensuring that the participants were familiar with the management of all Lego bricks and other parts required to assemble and produce a robot model that would demonstrate their decomposition abilities. Figure 1 shows the research participants during the assembly stage.

Figure 1. Research Participants assembling the Robotics Model

Stage 4: Completion and Result testing

In this step, the participants were challenged to solve problems by providing detailed answers. The emphasis was on the participants' understanding of the concepts of abstraction, generalisation, algorithm and development (modularity), as exemplified through their answers. The activity also increased the participants' familiarity with the programming environment.

Stage 5: Closure and Reflection

This session comprised an interview that was carried out by referring to the indicators. It was hoped that the participants would be able to use their abstraction and generalisation abilities to provide their reflections on the learning activities that had been carried out.

Data Collection

Data collection was performed through interviews (Jentoft & Olsen, 2019) with the eight participants and observations (Ary et al., 2018; Fry et al., 2017) derived from the eight participants. As depicted in Table 1, the participants included pre-service teachers who had been purposively nominated for their teaching experience as interns at schools and those who were capable of developing ICT-based learning instructions. However, none of them had experience with robotics modules or had acquired any credits from previous robotics courses. During the activity, the participants were isolated to ensure they could not share their participation experience. During the research, for example, each participant was assigned to perform robotics activities in separate rooms or perform the activities at different time slots so that they could not imitate others' responses to the inquiry. With their consent, the participants' responses were video-recorded or taped for further confirmation, if required. The verbatim data were coded and analysed using the Qualitative Thematic Data Analysis technique (Braun & Clarke, 2006). Data collection and analysis were conducted in Bahasa Indonesia to preserve the meaning and prevent any loss of language richness in translation (Vanmassenhove et al., 2019).

Table 1. Profile of the Research Participants

Participants	Semester	Gender	Robotics Course	Experience in Developing Learning Media
P 1	Semester 8	Female	No	Video and Still Pictures
P 2	Semester 8	Female	No	Video, Still Pictures Presentation
P 3	Semester 8	Female	No	Still Pictures and Presentation
P 4	Semester 8	Female	No	Still Pictures
P 5	Semester 8	Female	No	Still Pictures
P 6	Semester 8	Female	No	Still Pictures and Presentation
P 7	Semester 8	Male	No	Still Pictures and Video
P 8	Semester 8	Male	No	Still Pictures

Code Development

In accordance with the thematic analysis tradition (Maguire & Delahunt, 2017), the data were interpreted using a set of codes developed from the theories related to STEM and CT presented in the previous section. In this case, a code was a characteristic that represented the indicators or parameters of each theory. The observable behaviour comprised one or all of a set of visible or sensed expressions, as detected by the researchers. The codes related to STEM were expressed as 'En', whereas those derived from the CT literature were described as 'CTn'. The codes, observable behaviours and their representations have been outlined in Table 2.

Table 2. List of Codes and Their Representations

Code	Behaviour / Expression	Representation Sign
Engagement	• Expressing interest in the topic • Asking related questions • Having thoughts on learning outcomes	E_1
Exploration	• Thinking freely about activities • Making predictions and hypotheses • Testing the predictions and hypotheses made • Starting to build understanding	E_2
Explanation	• Referring to previous experience • Observing • Explaining obtained knowledge or experience	E_3
Elaboration	• Defining a novel definition, explanation and new skill • Proposing a new solution derived from previous information • Deducing new conclusions	E_4
Evaluation	• Responding to problems with an evident or acceptable explanation • Demonstrating an understanding or skill to a certain level • Evaluating new conceptual understanding and/or conceptual skills • Posing a new question or opinion for further investigation	E_5

Table 2. Continued

Code	Behaviour / Expression	Representation Sign
Abstraction	• Separating unnecessary information • Analysing pattern behaviour in the context of programming between different scripts • Identifying abstractions across contexts, that is, different programming languages	CT_1
Generalisation	• Making connections to abstraction patterns • Constructing ideas on the given problems to extend the same into broader cases • Using variables in solutions	CT_2
Algorithm	• Stating the algorithm steps in detail • Analysing different algorithms for a given problem • Producing the appropriate algorithm	CT_3
Modularity	• Using the previous programming code • Developing parts of code for use against the same or different problems • Producing easy-to-organise programming code	CT_4
Decomposition	• Deconstructing the overall problem into smaller, solvable segments • Dividing a solvable segment based on a specific function • Recombining so that the complex problem can be resolved	CT_5

During the analysis, the codes were employed to interpret a piece of text by sensitising each expression within that text and assigning the relevant sign to it. Table 3 provides a sample from the data interpretation in the original language as an illustration of the text from when the data analysis was performed. Complete interview translations for all the participants have been provided in the Appendix section.

Table 3. Example of Data Interpretation

Interpretation of Participant 1's Response	Code Found
This is a new thing (E1) for me, as typical elementary schools still use simple and conventional equipment. For me, robots and the problems that were given on this designated topic. However, *I needed time to understand the inner workings of the robot itself* (E5). I made mistakes the first few times I tried *implementing into the programming block* (CT3). I finally managed to *successfully run the program because I looked at the first problem's programming block, before I made tweaks and changes in the following problems, and by then I could solve the problem unassisted* (CT1) (CT4) (E4). Firstly, *the assembly. It required a high degree of focus in combining all the components. Other than that, there is also the programming,* (E2) which proved to be tricky, as *when the program was run, it still didn't form the shape of a two-dimensional figure that I hoped for* (E3). *I learnt a lot about making mistakes when at times it turned out that the robot didn't run as it was expected to* (E3). I had to look it up in the manual and ponder back on how to solve the fault in the programming. In my opinion, *this type of learning that has been carried out is very interesting for me* (E1) as a prospective educator--let alone for students. In-class learning with the help of robotic mediums such as this will make for *innovative learning* (E1). *Once a thorough preparation is commenced* (E5), then perhaps the learning objectives that were sought can be achieved. In fact, this learning *can be applied to every subject* (E5), especially since thematic learning—which incorporates a few subjects together at one time, save for physical ed—is now a complementary subject in elementary schools.	CT1 CT3 CT4 CT5 E1 E2 E3 E5

Results

Once the mapping had been completed for all of the interviewees' responses, the identified expressions were coded and interpreted to construct themes. Subsequently, the data interpretations were categorised based on the similarity of the facts and their relevance to the research questions. Some of the themes extracted from the procedure have been presented in Tables 4 and 5. Table 4 summarises the themes that can be categorised under the CT topic, whereas those that can be categorised under the STEM topic have been outlined in Table 5.

Table 4. Data Categorisation of CT Themes

Generated Theme	Code	Interpretation of Data
Correlation with the experience	CT1	Seeing the same or a different pattern in the problem
	CT2	Performing general thinking skills
		Providing a hypothesis of an answer
	CT3	Writing down the steps for solving the problem
	CT5	Answering problems by highlighting the important points
Active learning using hands-on media	CT3	Creating a programming block code
	CT5	Sorting out the components of the robot
Scaffolding learning	CT1	Fixing a wrong programming block
		Developing a programming block code
	CT4	Using a programming block previously

Table 5. Data Categorisation of STEM Themes

Generated Theme	Code	Interpretation of Data
Correlation with the experience	E1	A new and fun kind of learning
	E2	The ability to predict an answer
	E5	Limited knowledge about the use of robotics
		Application to a wide range of subjects
Active learning using hands-on media	E1	Practice by using real or hands-on media
	E2	Design of a robot model
	E3	Observation of how a robot works
		The ability to explain knowledge gained based on evidence
Scaffolding learning	E4	The use of information from previous observations to provide answers
	E5	A gradual understanding of the process

A similar procedure was carried out for each participant's interview. Thus, from the eight participants' interview texts, the researcher constructed eight pairs of tables of text interpretation for both categories. While the themes constructed in both data categorisations were congruent, we determined that the interpretation codes corresponding to similar themes were interchangeable. Figure 2 illustrates the expression of CT principles in the various phases of STEM learning. The quotes derived from the interviews and observations have been presented in the associated sub-sections.

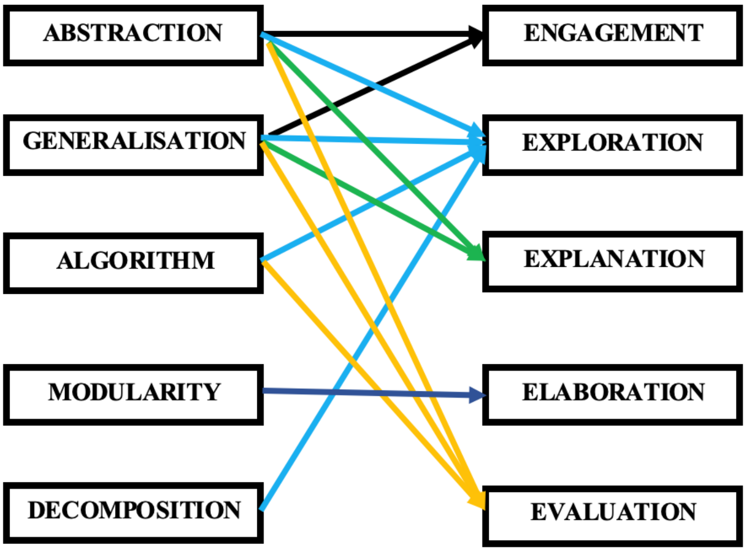


Figure 2. Correlations between CT Principles and STEM Learning Phases

Abstraction and Generalisation

Abstraction and generalisation correspond to one another during learning processes (Yadav et al., 2016). In this regard, the two components could be employed in tandem to resolve a particular issue. Drawn from the analysis, as snipped in Table 6, abstraction and generalisation are expressed in similar STEM phases, whereas engagement, exploration, explanation and evaluation are shown separately.

Table 6. Quote from Observation and Interview Data correspond with Abstraction and Generalisation

Abstraction	**Observation**	**Interview**
Engagement	Participants provide an opinion about the activities to be carried out. P3	"This learning uses a tangible model, giving it the feel of a 'real' learning. On top of that, it's also among one of the newest in technology. I really felt a hands-on learning experience." P3.
Exploration	Participants plan and investigate the robot model. They encounter error on some steps. P1	"The assembly. It required a high degree of focus in combining all the components. Other than that, there is also the programming." P1
Explanation	Participants analyse the results of robotics activities. P5	"Prior to this, I have not yet delved deep into programming, so from this experience here I gained lots of info on programming. During the activity, I continued to improve my mistakes after observing how the robot runs, and when it does, whether it forms the two-dimensional figure that I program it to do." P5
Evaluation	Participants assess their understanding and ability that robotics activities require more time. P6	"The duration needs to be accounted for, as actual activities are usually time limited, so it's unfortunate if the learning objectives are not achieved due to poor time calculation." P6
Generalisation		
Engagement	Participants relate their previous learning experiences. They consider connecting with the mathematical experience they possess. P4	"An innovative learning method, there is still a scarcity of those using this medium." P4
Exploration	Participants employed the model that already exists in the module. They did not separate components. P2	"I immediately followed through the steps of designing the robot, and then went to solving the problems. I observed a pattern within the given problems, that is, that there's a difference in the angles with a repetition of three and four-fold. I copied the code for the programming block, so that once I'm done writing the steps for the solution and implementing it into the programming block, I just simply needed to tweak the angles and repetition." P2
Explanation	Participants gain knowledge based on learning outcomes. They observe the outcome of the robot test. P8	"Yes, I got the knowledge of building and programming the robot. There were quite a lot of components in order to build a robot, so it requires gentleness to handle them all. Understanding the module is the key to build the robot and successfully program it." P8
Evaluation	Participants changed their thoughts about the learning they encountered. P7	"Fun, and it gave me an understanding of something new to me. Cognitive, effectiveness, can be learnt through this learning. I felt like I've gained the knowledge of creativity and responsibility when building this robot." P7

The participants exhibited behaviour consistent with the abstraction and generalisation components from the beginning of the learning or the engagement phases. They expressed their thoughts about the learning process to be carried out and believed that the learning they were about to undertake was different from the learning they had experienced before. Robotics learning was considered interesting and fun learning.

During the exploration phase, the participants also demonstrated the use of abstraction components and their generalisations. Before answering the problem, they identified patterns of similarities or differences in the questions. The questions related to topics that the participants had already encountered, which meant that they could use their prior experience to solve problems. As a result, the participants were able to generate solutions to problems.

The participants also highlighted the components of abstraction and generalisation at the end of the learning (evaluation phase). They identified the abstraction of the learning that had been administered, which, in turn, changed their mindset towards the concept of learning. They obtained a broad overview of the understanding of the knowledge and skills carried out during the learning process using robotics. This assessment by the participants was useful in terms of encouraging further self-investigation in the future.

Algorithm

The algorithm principle was explicated during the exploration and evaluation phases. During the exploration phase, the participants constructed an algorithm in response to the guidelines provided for the robotics activity.

Table 7. Quote from Observation and Interview Data Corresponds with Algorithm

Algorithm	Observation	Interview
Exploration	Participants planned and explored the robotics model that will be built. P5	“My robot had an objective to draw the shape of a two-dimensional figure, so I had to really understand the workings, motion, and movement of a robot. This in turn challenges my critical thinking, trains my patience, accuracy, as well as teamwork, if this activity was executed in a group.” P5
Evaluation	There was a mindset change in the participants after their encounter with the project. P6	“This method encourages us to learn by the process of doing, and if that is the case, aid for more profound understanding is needed.” P6

As quoted in Table 7, during the exploration phase, the participants wrote algorithms based on their thoughts. Descriptive algorithms were written as a means of helping the participants when implementing them into programming blocks. Every participant wrote this descriptive form of algorithm, as it employed the language used in everyday life or human speech. The participants’ prior experiences influenced how they wrote their answers to the questions. As such, they were accustomed to writing sentences and their explanations in sequence, and some even used signs or symbols to provide clarifications.

The descriptive algorithms created were implemented in the form of programming to produce a programming algorithm. When undertaking programming activities, the participants showed distrust due to their lack of previous experience. They felt they needed time to properly understand the function of each programming block. However, the participants who encountered problems, even after receiving support and guidance, re-attempted the programming.

The results also showed that even though the participants initially failed in the first experiment, they were able to run the robot based on the program they had developed. This is relevant to the algorithm indicators derived from Atmatzidou and Demetriadis (2016), owing to the analytical process involved in making improvements to arrive at the correct algorithm.

Modularity

Modularity is the ability to decompose a complex object into smaller modules or components while maintaining limited controlled interactions amongst the components (Avigad, 2018). In this research, the modularity principle was merely expressed during the elaboration phase of the robotics STEM activity. As depicted in Table 8, once the participants realised the similarities across the block of codes, they were able to reproduce the codes applied in the previous block. As such, the activities had already been completed during the elaboration phase when the participants were working on the programming blocks. The programming process is related to the components of the algorithm. The development of an algorithm to create a more efficient programming algorithm encapsulates behavioural patterns that are found in the modularity component. Modularity behaviour is usually exhibited after the observation process, and it can help participants to further develop their knowledge and skills.

Table 8. Quote from Observation and Interview Data Corresponds with Modularity

Modularity	Observation	Interview
Elaboration	Participants gain a deeper understanding and skills developed based on previous experience. P7	“I learnt that by figuring out how to make the robot to work in the first trial successfully, would then make the following problem easier.” P7

In this study, almost all participants used the answer from a particular question to resolve the subsequent question. Having successfully tested the program to answer question one, they realised that there were similarities in the programming code blocks. This, in turn, led them to transfer the code blocks used in the program to address the following question. Subsequently, they fixed the erroneous programming block until it was resolved.

Another behaviour indicating modularity was demonstrated by the fact that multiple participants developed more efficient and organised pieces of code. Participants 1 and 4, for example, used looping blocks when creating their programming code blocks. This behaviour indicated the ability to generate simpler and more organised code, which, in turn, potentially increased the modularity component of each participant.

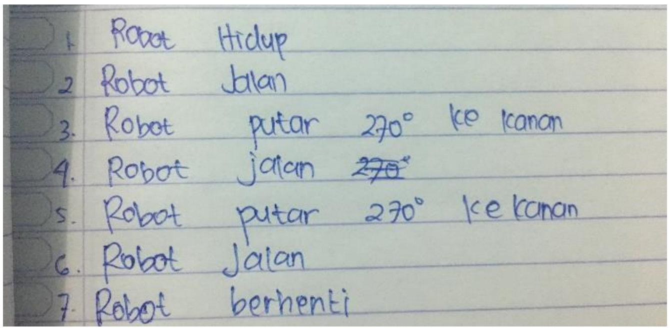
Decomposition

During the exploration phase in robotics STEM, as depicted in Table 9, the participants tended to detach and re-assemble the robotics components based on similarities in their shape, size or colour. This ability to uncouple and re-attach the robotic components into a particular function represented the decomposition principle (Shute et al., 2017).

Table 9. Quote from Observation and Interview Data Corresponds with Decomposition

Decomposition	Observation	Interview
Exploration	Participants think freely about activities and start building new understanding. P7	"There are many steps to go through in order to build a robot. In the beginning, I immediately set off to build my robot, but I realized that there were many components, so I decided to sort them out first. For solving the problems and working on the programming, they are all a matter of reasoning, as by seeing the instructions of either 'go forward' or 'turn that way' from within the problem, I already had an idea of how to create the programming block." P7

During the exploration phase, the participants separated the robot components based on either their shape, size or colour. This type of separation based on a certain function is a behaviour that supports the decomposition components. Separating the problem into different parts made it easier for the participants to undertake a complex job. Every participant made several errors while assembling the robot components; however, those who separated the components first avoided mistakes during the installation of the robot, and their result reflected the guidelines.



1. Robot Hidup
2 Robot Jalan
3. Robot putar 270° ke kanan
4. Robot jalan ~~270°~~
5. Robot putar 270° ke kanan
6. Robot Jalan
7. Robot berhenti

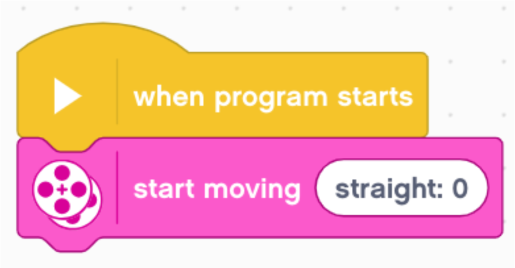
1. Robot turn on
2. Robot forward
3. Robot rotate right 270^0
4. Robot forward
5. Robot rotate right 270^0
6. Robot forward
7. Robot stop

a) b)

Figure 3. Pseudocode written by a Participant. a) Sample of the Pseudocode written by the Participant; b) Translated Pseudocode

During the assembly stage, the participants tended to write the algorithm in their everyday language as opposed to the programming syntax. The descriptive algorithms they wrote helped them break the problem down into smaller, solvable chunks (Looi et al., 2018).

The algorithm shown in Figure 3 comprises lines of descriptive activities that represent a set of instructions. When transferred into a programming language, the instructions become more detailed. For example, executing the instruction on the second line, *'Robot Jalan'*, which means 'Robot is moving (forward)', requires two blocks of code in Scratch – 'Start' and a movement block – as shown in Figure 4.



```
when program starts
start moving straight: 0
```

Figure 4. Block of Code representing the 'Move' Instruction in Scratch

This division of the problem into smaller tasks indicates the decomposition ability, as suggested in CT. This also includes the suggestion of the ability to break the problem down into smaller pieces to enable the participant to work on more accessible objects.

Discussion

This paper sheds light on the constructs drawn from robotics activities in a STEM workshop designed for pre-service teacher participants. Along with the data analysis, the close correlation between STEM and CT is becoming clearer. On the one hand, the participants expressed the abstraction and generalisation components of the CT concept during the STEM phases. On the other hand, the STEM exploration phase combined every CT component into one set of activities. The following discussion highlights the influence of the adoption of robotics in STEM on the participants' learning experiences.

Role of Robotics as a Hands-on Media that facilitates Active Learning Experience

The integration and use of educational robotics in the teaching–learning process at the pre-school, primary and secondary levels can become visible and be a turning point, as a resource for addressing the diversity of the classroom (Negrini & Giang, 2019) as well as keeping students actively engaged (Budiyanto et al., 2021) and motivated (Daher, 2022). Active learning is defined as an approach to instruction that encourages students to become actively engaged with the course material through discussions, problem-solving, case studies, role plays and other methods. While robotics represents a hands-on learning platform (Bravo et al., 2021; Selby et al., 2021), the combination of robotics and an active learning strategy plays a vital role in generating synergy, and it is more effective when it is well harmonised (Lopez-Caudana et al., 2020).

Different from previous literature, this paper emphasises that educational robotics triggered pre-service teachers to actively participate in STEM learning. The research participants were actively involved in performing all activities, especially during the exploration phase. The activities directly related to the robotics media enabled the participants to explore diverse forms of knowledge. This understanding underscores Papert's statement (Solomon & Papert, 1976) that support provided by learning activities will be more practical if the students construct their own knowledge through a hands-on object related to that knowledge.

During the explanation phase, the participants actively communicated the problem-solving process in creative and imaginative ways. Participant 4 expressed the manner in which the assembly would be more effective if it had been undertaken by grouping the robotics components: *'In the beginning I got the components mixed up frequently. I feel like it might be much easier if the robots' parts are assorted according to their shape. We also have to imagine a depiction of how the robot will move so that when we run the program later it moves accordingly.'* The robotics activities encouraged the participants to make essential learning decisions and take responsibility for assessing or determining the progress of the acquired understanding. In addition, robotics media are usually sufficiently flexible to relate to real problems or issues that are easily found in everyday life (Jung & Won, 2018).

Robotics Activities establishes correlations with Previous Life Experience

It is widely understood that the hands-on characteristics of educational robotics bring about a real-life experience for learners of all ages (Kucuk & Sisman, 2020; Papadakis, Vaiopoulou, Sifaki, Stamovlasis, & Kalogiannakis, 2021; Papadakis, Vaiopoulou, Sifaki, Stamovlasis, Kalogiannakis, & Vassilakis, 2021). As such, robotics enables learners to employ all their senses when they construct, code and play with robots during the activity. Robotics also provides learners with a topic for discussion and further develops their understanding of the world.

While experience is an ongoing process, which encompasses an individual's previous experiences and the new experiences they gain, people's unique life experience shapes how they perceive and understand the world around them (Manikutty, 2021). It is relevant with the literature that the presence of previous experience influenced participants' decisions concerning how they carried out the robotics activities in STEM learning (Budiyanto et al., 2020). This is because the participants continually compared their prior experience with their newly constructed understanding to determine their course of action throughout the various STEM learning phases of this research. This research enhances the knowledge by elaborating the details of the correlations between previous life experiences during each phase of STEM learning.

In the engagement phase, the participants encountered fun activities that combined the use of robotics media with STEM learning. They compared the learning concepts involved in how to build the robot with their previous understanding. The difference was perceived in the complexity of the robotics activities in the learning process. In addition, it also increased the participants' interest in terms of triggering the initial motivation to perform well in terms of the learning activities.

In the exploration phase, the participants faced various problems in a series of activities involving robotics. When given a task, they tried to solve the problem. The mathematical material used in the study prompted the participants to recall the experiences or knowledge they had gained. The participants' prior knowledge, in turn, helped them deal with the new learning environment. Therefore, when the participants faced problems related to the material, they could provide hypothetical answers, as demonstrated by Participant 2: *'I observed a pattern within the given problems, that is, there's a difference in the angles with a repetition of three and four-fold. I copied the code for the programming block, so that once I* *was done writing the steps for the solution and implementing it into the programming block, I just simply needed to tweak the angles and repetition.'*

The participants tended to alter their thinking and behaviour patterns when faced with learning conditions that they had encountered either very recently or had never experienced before. During the evaluation phase, for example, the participants identified a shortcoming in the form of their programming capability. Ultimately, however, at the end of the lesson, they demonstrated that both the research circuit and robot were functioning according to the guidelines.

More importantly, STEM learning using robotics provided a new experience for the participants. The experiences they went through helped them adapt so that they could gain the relevant knowledge and develop the pertinent skills. Any level of adventure that an individual goes through, regardless of whether large or small in scale, can still become knowledge that aids in their intellectual development (Amineh & Asl, 2015).

Robotics Intervention facilitates Scaffolding of Learning

The scaffolding of learning helps to facilitate a strategy to deliver technology-based curricula (Sentance & Csizmadia, 2017). A scaffolding strategy aligns with the concept of decomposition in CT (Angeli & Valanides, 2020; Zhang, 2021), especially with regard to incorporating educational robotics as a modular learning tool. As highlighted by previous literature, the robotics-based STEM learning in this research apparently resulted in the development of deep understanding and meaningful knowledge due to its scaffolding (staged) design. In line with the research conducted by Angeli (2022), the participants carefully built their robotics model and subsequent program scripts to obtain the targeted outcome. The participants, in turn, indicated that they scaffolded the learning of algorithmic thinking skills from sequencing to debugging, wrote the pseudocode and computer code and finally tested the program. In our case study, Participant 5 expressed: *'… I have done the programming for assignment number 1, then, I can easily answer (assignment) number 2…'*

The participants did not stop until they had either correctly solved the problem or found no other errors. This provided an opportunity for them to build their knowledge and skills to continue growing, even though they increased only slightly from their previous positions. During the elaboration phase, the participants become independent individuals on their journey towards achieving higher levels of knowledge and skills.

The researchers argue that Lego Mindstorm EV3 enables scaffolding learning due to its modular characteristics. In this approach, participants' understanding is gradually developed and can be maintained through trial-and-error activities. Participants will immediately try and fix any errors. Subsequently, these errors are evaluated to obtain a report that can subsequently be used to overcome the problems.

Robotics activities can provide an alternative way for participants to build long-lasting knowledge. The learning phase applies the principles of constructivism. Robotics media, which can provide activities associated with everyday life, also apply the principles of constructivism. Therefore, Chu et al. (2019) stated that STEM is structured with constructivist activities and supported by constructivist media in the learning process. This, in turn, can help build understanding and skills. In addition, STEM learning using robotics encourages participants to be directly involved in scientific thinking, generating ideas and collecting evidence.

Conclusion

CT indicators were reflected in certain aspects of the STEM learning processes. Characteristics of CT aspects were subsequently indicated in the exploration, evaluation, engagement, explanation and elaboration phases. However, the elements of CT were lacking in the modularity related to programming due to the need for advanced programming skills to perform the activities. Meanwhile, abstraction and algorithm were the principal aspects of CT, as indicated by the participants during the discourse. The participants' variety of critical thinking skills and behavioural patterns, as exhibited during problem-solving, was likely to be driven by the extent to which they acquired CT aspects.

This paper contributes to the literature in two ways. First, it extends Dass' (2015) argument on the correlations between the CT principles and STEM learning phases by demonstrating that almost all the CT principles were represented in all five STEM learning stages. Second, it emphasises the important role played by educational robotics in enhancing the scope of previous literature focused on learning experience. The use of educational robotics in STEM learning ascertains active learning experience. Furthermore, it underscores learners' previous knowledge and facilitates scaffolding learning.

Recommendations

As the focus on the role of CT and its interplay with STEM is relatively new, inquiries may be further examined or even tested in empirical research settings. For example, the lack of CT elements in modularity means that in-depth investigation is required into the reason behind why programming skills were essential to carry out the activities.

The use of commercial off-the-shelf educational robotics in this research sheds new light on the correlation between CT and STEM. However, the question of whether the robotics caused such interplay, or whether it could be replicated with other technological tools, demands further exploration. Moreover, research is needed to investigate whether such correlation in longitudinal design potentially captures the knowledge dynamic associated with participants' knowledge over a particular period of time.

Limitations

This research was conducted in line with the case study tradition that examines a case in its real-life setting. The data and findings extracted from the data analysis, therefore, reflect the understanding in the context of conducting this particular research and may not represent the entire dynamics of a person's or people's knowledge outside that context.

Funding

The research was funded by *RKAT PTNBH Universitas Sebelas Maret 2021* under the scheme of *Penelitian Unggulan (PU-UNS)* contract number 260/UN27.22/HK.07.00/2021.

Authorship Contribution Statement

Budiyanto: Conceptualisation, design, supervision, analysis, writing. Fenyvesi: Editing/reviewing, critical revision. Lathifah: Data acquisition, analysis, drafting. Yuana: Material support, supervision

References

Alvarez, A., & Larrañaga, M. (2016). Experiences incorporating Lego Mindstorms robots in the basic programming syllabus: Lessons learned. *Journal of Intelligent & Robotic Systems, 81*(1), 117–129. https://doi.org/10.1007/s10846-015-0202-6

Aminah, N., Sukestiyarno, Y. L., Wardono, W., & Cahyono, A. N. (2022). Computational thinking process of prospective mathematics teacher in solving diophantine linear equation problems. *European Journal of Educational Research, 11*(3), 1495–1507. https://doi.org/10.12973/eu-jer.11.3.1495

Amineh, R. J., & Asl, H. D. (2015). Review of constructivism and social constructivism. *Journal of Social Sciences, Literature and Languages, 1*(1), 9–16.

Angeli, C. (2022). The effects of scaffolded programming scripts on pre-service teachers' computational thinking: Developing algorithmic thinking through programming robots. *International Journal of Child-Computer Interaction, 31*, 1–20. https://doi.org/10.1016/j.ijcci.2021.100329

Angeli, C., & Giannakos, M. (2020). Computational thinking education: Issues and challenges. *Computers in Human Behavior, 105*, 1–3. https://doi.org/10.1016/j.chb.2019.106185

Angeli, C., & Valanides, N. (2020). Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy. *Computers in Human Behavior, 105*, 1–13. https://doi.org/10.1016/j.chb.2019.03.018

Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A systematic review of studies on educational robotics. *Journal of Pre-College Engineering Education Research, 9*(2), 19–42. https://doi.org/10.7771/2157-9288.1223

Ardito, G., Czerkawski, B., & Scollins, L. (2020). Learning computational thinking together: Effects of gender differences in collaborative middle school robotics program. *TechTrends, 64*(3), 373–387. https://doi.org/10.1007/s11528-019-00461-8

Aristawati, F. A., Budiyanto, C. W., & Ariyuana, R. (2018). Adopting educational robotics to enhance undergraduate students' self-efficacy levels of computational thinking. *Journal of Turkish Science Education, 15*(Special Issue), 42–50. https://bit.ly/3c7dzNq

Ary, D., Jacobs, L. C., Sorenson, C., & Walker, D. (2018). Introduction to research in education. *Cengage Learning.*

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. https://doi.org/10.1016/j.robot.2015.10.008

Avigad, J. (2018). Modularity in mathematics. *The Review of Symbolic Logic, 13*(1), 47–79. https://doi.org/10.1017/s1755020317000387

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education, 58*(3), 978–988. https://doi.org/10.1016/j.compedu.2011.10.006

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. https://doi.org/10.1016/j.compedu.2013.10.020

Bocconi, S., Chioccariello, A., Dettori, G., Ferrari, A., & Engelhardt, K. (2016). *Developing computational thinking in compulsory education: implications for policy and practice*. Publications Office of the European Union.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Bravo, F. A., Hurtado, J. A., & González, E. (2021). Using robots with storytelling and drama activities in science education. *Education Sciences, 11*(7), 1–16. https://doi.org/10.3390/educsci11070329

Budiyanto, C., Fitriyaningsih, R. N., Kamal, F., Ariyuana, R., & Efendi, A. (2020). Hands-on learning in STEM: Revisiting educational robotics as a learning style precursor. *Open Engineering, 10*(1), 649–657. https://doi.org/10.1515/eng-2020-0071

Budiyanto, C. W., Shahbodin, F., Umam, M. U. K., Isnaini, R., Rahmawati, A., & Widiastuti, I. (2021). Developing computational thinking ability in early childhood education: The impact of Karin programming toy to parent–children engagement. *International Journal of Pedagogy and Teacher Education, 5*(1), 19–25 https://doi.org/10.20961/ijpte.v5i1.44397

Bybee, R. W. (2019). Using the BSCS 5E instructional model to introduce STEM disciplines. *Science and Children, 56*(6), 8–12. https://doi.org/10.2505/4/sc19_056_06_8

Castro, L. M. C., Magana, A. J., Douglas, K. A., & Boutin, M. (2021). Analyzing students’ computational thinking practices in a first-year engineering course. *IEEE Access, 9*, 33041–33050. https://doi.org/10.1109/ACCESS.2021.3061277

Chaudhary, V., Agrawal, V., Sureka, P., & Sureka, A. (2016). An experience report on teaching programming and computational thinking to elementary level children using Lego robotics education kit. In V. Kumar, S. Murthy & Kinshuk (Eds.), *Proceedings of 2016 IEEE Eighth International Conference on Technology for Education (T4E 2016)* (pp. 38-41). IEEE. https://doi.lorg/10.1109/T4E.2016.016

Chu, H. -E., Martin, S. N., & Park, J. (2019). A theoretical framework for developing an intercultural STEAM program for Australian and Korean students to enhance science teaching and learning. *International Journal of Science and Mathematics Education, 17*(7), 1251–1266. https://doi.org/10.1007/s10763-018-9922-y

Daher, W. (2022). Students’ motivation to learn mathematics in the robotics environment. *Computers in the Schools, 39*, 1–22. https://doi.org/10.1080/07380569.2022.2071227

Dass, P. M. (2015). Teaching STEM effectively with the learning cycle approach. *K-12 STEM Education*, *1*(1), 5–28. https://doi.org/10.14456/k12stemed.2015.17

Demetroulis, E. A., & Wallace, M. (2021). Educational robotics as a tool for the development of collaboration skills. In S. Papadakis & M. Kalogiannakis (Eds.), *Handbook of Research on Using Educational Robotics to Facilitate Student Learning* (pp. 140–163). IGI Global. https://doi.org/10.4018/978-1-7998-6717-3.ch005

Durak, H. Y., Yilmaz, F. G. K., & Yilmaz, R. (2019). Computational thinking, programming self-efficacy, problem solving and experiences in the programming process conducted with robotic activities. *Contemporary Educational Technology, 10*(2), 173–197. https://doi.org/10.30935/cet.554493

Eguchi, A. (2016). RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition. *Robotics and Autonomous Systems, 75*, 692–699. https://doi.org/10.1016/j.robot.2015.05.013

El-Hamamsy, L., Bruno, B., Chessel-Lazzarotto, F., Chevalier, M., Roy, D., Zufferey, J. D., & Mondada, F. (2021). The symbiotic relationship between educational robotics and computer science in formal education. *Education and Information Technologies, 26*(5), 1–31. https://doi.org/10.1007/s10639-021-10494-3

Elkin, M., Sullivan, A., & Bers, M. U. (2014). Implementing a robotics curriculum in an early childhood Montessori classroom. *Journal of Information Technology Education: Innovations in Practice, 13*(1), 153-169. https://doi.org/10.28945/2094

Falloon, G. (2016). An analysis of young students' thinking when completing basic coding tasks using Scratch Jnr. On the iPad. *Journal of Computer Assisted Learning, 32*(6), 576–593. https://doi.org/10.1111/jcal.12155

Fidai, A., Capraro, M. M., & Capraro, R. M. (2020). “Scratch”-ing computational thinking with Arduino: A meta-analysis. *Thinking Skills and Creativity, 38*, 1–14. https://doi.org/10.1016/j.tsc.2020.100726

Fry, M., Curtis, K., Considine, J., & Shaban, R. Z. (2017). Using observation to collect data in emergency research. *Australasian Emergency Nursing Journal, 20*(1), 25–30. https://doi.org/10.1016/j.aenj.2017.01.001

Gülhan, F., & Şahin, F. (2018). Activity implementation intended for STEAM (STEM+ Art) education: Mirrors and light. *Journal of Inquiry Based Activities, 8*(2), 111–126. https://www.ated.info.tr/ojs-3.2.1-3/index.php/ated/article/view/29

Hamilton, M., Clarke-Midura, J., Shumway, J. F., & Lee, V. R. (2020). An emerging technology report on computational toys in early childhood. *Technology, Knowledge and Learning, 25*(1), 213–224. https://doi.org/10.1007/s10758-019-09423-8

Hamzeh, F., Theokaris, C., Rouhana, C., & Abbas, Y. (2017). Application of hands-on simulation games to improve classroom experience. *European Journal of Engineering Education, 42*(5), 471–481. https://doi.org/10.1080/03043797.2016.1190688

Holbrook, J., Rannikmäe, M., & Soobard, R. (2020). STEAM Education—A Transdisciplinary Teaching and Learning Approach. In B. Akpan & T. J. Kennedy (Eds.), *Science Education in Theory and Practice* (pp. 465–477). Springer. https://doi.org/10.1007/978-3-030-43620-9_31

Ibrahim, M. F., Huddin, A. B., Hashim, F. H., Abdullah, M., Rahni, A. A. A., Mustaza, S. M., Hussain, A., & Zaman, M. H. M. (2020). Strengthening programming skills among engineering students through experiential learning based robotics project. *International Journal of Evaluation and Research in Education, 9*(4), 939–946. https://doi.org/10.11591/ijere.v9i4.20653

Ioannou, A., & Makridou, E. (2018). Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work. *Education and Information Technologies, 23*(6), 2531–2544. https://doi.org/10.1007/s10639-018-9729-z

Jaipal-Jamani, K., & Angeli, C. (2017). Effect of robotics on elementary preservice teachers' self-efficacy, science learning, and computational thinking. *Journal of Science Education and Technology, 26*(2), 175–192. https://doi.org/10.1007/s10956-016-9663-z

Jentoft, N., & Olsen, T. S. (2019). Against the flow in data collection: How data triangulation combined with a 'slow' interview technique enriches data. *Qualitative Social Work, 18*(2), 179–193. https://doi.org/10.1177/1473325017712581

Jung, S. E., & Won, E.-S. (2018). Systematic review of research trends in robotics education for young children. *Sustainability, 10*(4), 1–24. https://doi.org/10.3390/su10040905

Jurado, E., Fonseca, D., Coderch, J., & Canaleta, X. (2020). Social STEAM learning at an early age with robotic platforms: A case study in four schools in Spain. *Sensors, 20*(13), 1–21. https://doi.org/10.3390/s20133698

Kale, U., & Yuan, J. (2021). Still a new kid on the block? Computational thinking as problem solving in Code.org. *Journal of Educational Computing Research, 59*(4), 620–644. https://doi.org/10.1177/0735633120972050

Kandlhofer, M., & Steinbauer, G. (2016). Evaluating the impact of educational robotics on pupils' technical- and social-skills and science related attitudes. *Robotics and Autonomous Systems, 75*, 679–685. https://doi.org/10.1016/j.robot.2015.09.007

Kong, S.-C., Lai, M., & Sun, D. (2020). Teacher development in computational thinking: Design and learning outcomes of programming concepts, practices and pedagogy. *Computers & Education, 151*, 1–19. https://doi.org/10.1016/j.compedu.2020.103872

Kopcha, T., McGregor, J., Shin, S., Qian, Y., Choi, J., Hill, R., Mativo, J., & Choi, I. (2017). Developing an integrative STEM curriculum for robotics education through educational design research. *Journal of Formative Design in Learning, 1*(1), 31–44. https://doi.org/10.1007/s41686-017-0005-1

Korkmaz, Ö. (2016). The effect of Lego Mindstorms Ev3 based design activities on students' attitudes towards learning computer programming, self-efficacy beliefs and levels of academic achievement. *Baltic Journal of Modern Computing, 4*(4), 647-660. https://doi.org/10.22364/bjmc.2016.4.4.24

Kotsopoulos, D., Floyd, L., Khan, S., Namukasa, I. K., Somanath, S., Weber, J., & Yiu, C. (2017). A pedagogical framework for computational thinking. *Digital Experiences in Mathematics Education, 3*(2), 154–171. https://doi.org/10.1007/s40751-017-0031-2

Kucuk, S., & Sisman, B. (2020). Students' attitudes towards robotics and STEM: Differences based on gender and robotics experience. *International Journal of Child-Computer Interaction, 23-24*, Article 100167. https://doi.org/10.1016/j.ijcci.2020.100167

Lee, K. T., Sullivan, A., & Bers, M. U. (2013). Collaboration by design: Using robotics to foster social interaction in kindergarten. *Computers in the Schools, 30*(3), 271–281. https://doi.org/10.1080/07380569.2013.805676

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2020). Computational thinking is more about thinking than computing. *Journal for STEM Education Research, 3*(1), 1–18. https://doi.org/10.1007/s41979-020-00030-2

Looi, C.-K., How, M. -L., Longkai, W., Seow, P., & Liu, L. (2018). Analysis of linkages between an unplugged activity and the development of computational thinking. *Computer Science Education, 28*(3), 255–279. https://doi.org/10.1080/08993408.2018.1533297

Lopez-Caudana, E., Ramirez-Montoya, M. S., Martínez-Pérez, S., & Rodríguez-Abitia, G. (2020). Using robotics to enhance active learning in mathematics: A multi-scenario study. *Mathematics, 8*(12), 2163. https://doi.org/10.3390/math8122163

Maguire, M., & Delahunt, B. (2017). Doing a thematic analysis: A practical, step-by-step Guide for learning and teaching scholars. *All Ireland Journal of Teaching and Learning in Higher Education, 8*(3), 3351–3354. https://bit.ly/3d6leeN

Manikutty, G. (2021). *My Robot can tell stories: Introducing robotics and physical computing to children using dynamic dioaramas*. In *Proceedings of 2021 IEEE Frontiers in Education Conference (FIE)* (pp. 1-9). IEEE https://doi.org/10.1109/FIE49875.2021.9637460

Montiel, H., & Gomez-Zermeño, M. G. (2021). Educational challenges for computational thinking in K–12 education: A systematic literature review of "Scratch" as an innovative programming tool. *Computers, 10*(6), 1–15. https://doi.org/10.3390/computers10060069

Morgan, K., Barker, B., Nugent, G., & Grandgenett, N. (2019). Educational robotics as a tool for youth leadership development and STEM engagement. In A. Sahin & M. J. Mohr-Schroeder (Eds.), *STEM Education 2.0* (pp. 248–275). Brill Sense. https://doi.org/10.1163/9789004405400_014

Nasir, J., Norman, U., Bruno, B., & Dillenbourg, P. (2020). When positive perception of the robot has no effect on learning. In *Proceedings of the 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN2020)* (pp. 313–320). IEEE. https://doi.org/10.1109/RO-MAN47096.2020.9223343

Negrini, L., & Giang, C. (2019). How do pupils perceive educational robotics as a tool to improve their 21st century skills? *Journal of e-Learning and Knowledge Society, 15*(2), 77–87. https://doi.org/10.20368/1971-8829/1628

Nemiro, J. E. (2021). Building collaboration skills in 4th-to 6th-grade students through robotics. *Journal of Research in Childhood Education, 35*(3), 351–372. https://doi.org/10.1080/02568543.2020.1721621

Ohnishi, Y., Honda, K., Nishioka, R., Mori, S., & Kawada, K. (2017). Robotics programming learning for elementary and junior high school students. *Journal of Robotics and Mechatronics, 29*(6), 992–998. https://doi.org/10.20965/jrm.2017.p0992

Omotayo, S. A., & Adeleke, J. O. (2017). The 5E instructional model: A constructivism approach to enhancing students' learning outcomes in mathematics. *Journal of the International Society of Teacher Education, 21*(2), 15–26.

Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D., & Kalogiannakis, M. (2021). Attitudes towards the use of educational robotics: Exploring pre-service and in-service early childhood teacher profiles. *Education Sciences, 11*(5), 1–14. https://doi.org/10.3390/educsci11050204

Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D., Kalogiannakis, M., & Vassilakis, K. (2021). Factors that hinder in-service teachers from incorporating educational robotics into their daily or future teaching practice. In B. Csapó & J. Uhomoibhi (Eds.), *Proceeding of the 13th International Conference on Computer Supported Education* (Vol.2, pp. 55–63). SCITEPRESS. https://doi.org/10.5220/0010413900550063

Piaget, J. (1954). *The construction of reality in the child* (M. Cook, Trans.). Basic Books. https://doi.org/10.1037/11168-000

Saxena, A., Lo, C. K., Hew, K. F., & Wong, G. K. W. (2020). Designing unplugged and plugged activities to cultivate computational thinking: An exploratory study in early childhood education. *The Asia-Pacific Education Researcher, 29*(1), 55–66. https://doi.org/10.1007/s40299-019-00478-w

Selby, N. S., Ng, J., Stump, G. S., Westerman, G., Traweek, C., & Asada, H. H. (2021). TeachBot: Towards teaching robotics fundamentals for human-robot collaboration at work. *Heliyon, 7*(7), 1–9. https://doi.org/10.1016/j.heliyon.2021.e07583

Sentance, S., & Csizmadia, A. (2017). Computing in the curriculum: Challenges and strategies from a teacher's perspective. *Education and Information Technologies, 22*(2), 469–495. https://doi.org/10.1007/s10639-016-9482-0

Shen, J., Chen, G., Barth-Cohen, L., Jiang, S., & Eltoukhy, M. (2020). Connecting computational thinking in everyday reasoning and programming for elementary school students. *Journal of Research on Technology in Education, 54*(2), 205–225. https://doi.org/10.1080/15391523.2020.1834474

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review, 22*, 142–158. https://doi.org/10.1016/j.edurev.2017.09.003

Simons, H. (2009). *Case study research in practice*. SAGE Publications. https://doi.org/10.4135/9781446268322

Solomon, C. J., & Papert, S. (1976). A case study of a young child doing turtle graphics in LOGO. In *Proceedings of the 1976 National Computer Conference and Exposition (AFIPS '76)* (pp. 1049–1056). AFIPS Press. https://doi.org/10.1145/1499799.1499945

Sun, L., Hu, L., Yang, W., Zhou, D., & Wang, X. (2021). STEM learning attitude predicts computational thinking skills among primary school students. *Journal of Computer Assisted Learning, 37*(2), 346–358. https://doi.org/10.1111/jcal.12493

Tsakeni, M. (2021). Preservice teachers' use of computational thinking to facilitate inquiry-based practical work in multiple-deprived classrooms. *EURASIA Journal of Mathematics, Science and Technology Education, 17*(1), 1-23. https://doi.org/10.29333/ejmste/9574

Vanmassenhove, E., Shterionov, D., & Way, A. (2019). Lost in translation: Loss and decay of linguistic richness in machine translation. In M. Forcada, A. Way, B. Haddow & R. Sennrich (Eds.), *Proceedings of Machine Translation Summit XVII: Research Track* (pp. 222–232). European Association for Machine Translation. https://aclanthology.org/W19-6622/

Wing, J. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35. https://doi.org/10.1145/1118178.1118215

Yadav, A., Hong, H., & Stephenson, C. (2016). Computational thinking for all: Pedagogical approaches to embedding 21st century problem solving in K-12 classrooms. *TechTrends, 60*(6), 565–568. https://doi.org/10.1007/s11528-016-0087-7

Yin, R. K. (2018). *Case study research and applications: Design and method*. SAGE Publications, Inc.

Zhang, D. (2021). STEM education through making: What are affordances and challenges of making out of school club? *Open Journal of Social Sciences, 9*(9), 572–583. https://doi.org/10.4236/jss.2021.99042

Zhang, Y., Luo, R., Zhu, Y., & Yin, Y. (2021). Educational robots improve K-12 students' computational thinking and STEM attitudes: Systematic review. *Journal of Educational Computing Research, 59*(7), 1450–1481. https://doi.org/10.1177/0735633121994070