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Research Article

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Educational Robotics: Evaluating the Role of Computational Thinking in Attaining 21st Century Skills

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Abstract: Educational Robotics (ER) has gained prominence in the literature on Computational Thinking (CT) because of its modularity, a feature that potentially facilitates the development of abstract thinking through complex robotic parts. The field of robotics encompasses the characteristics of technology, intelligence, embodiment, and interaction, and these characteristics can serve as means of instruction for CT. Essential 21st Century Skills include decomposition, pattern recognition, abstraction, and the use of algorithms; which are fundamental to effective problem-solving skills. Although CT is believed to be the key to developing 21st Century Skills, its role in doing so is significantly underexplored. This paper investigates the influence of CT ability on students' efficacy in imbibing 21st Century Skills. The study implemented a qualitative case study design, in which students of an Indonesian vocational-education school were engaged in ER activities. CT skills and the associated 21st Century Skills were evaluated through several phases of observation and interviews. The findings reveal that CT paves the way for the development of 21st Century Skills. Analysing the development of CT can be a major way in which individuals are empowered to take full advantage of the developments brought about by rapid changes in technology.

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1 Introduction

Robotics has become a prominent topic in the computational thinking literature. The modularity of Lego robotics, for example, allows students to build their understanding of the abstraction of complex robotics components (Atmatzidou & Demetriadis, 2014). Computational thinking is a prominent skill of the 21st century (Hutamarn et al., 2017; Mohaghegh & McCauley, 2016; Wing, 2008; Yadav, Hong, & Stephenson, 2016). There is considerable agreement about computational thinking's benefits as the primary skill in various aspects of our society. According to Hutamarn et al. (2017), members of the workforce – from doctors and engineers to managers and researchers – are trained in solving computational problems, and this ability enhances their efficiency and economic benefits, as well as the development of further technological advances (Mohaghegh & McCauley, 2016). Chen et al. (2017) predicted that, similar to the traditional skills of reading, writing, and arithmetic, computational thinking would become a valuable and fundamental skill in the mid-21st century (Wing, 2006). The development of computational thinking skills can increase an individual's interest in choosing a career in the fields of science, technology, engineering, and mathematics (STEM) or computer science (CS). As such, it is essential to offer learning activities that meet a variety of student interests (Burleson et al., 2018; Chen et al., 2017). Robotics is considered a tool that can foster computational thinking because it meets requirements such as providing technology to support learning, includes aspects of intelligence and tangible media (embodiment), and allows for interaction between learners and learning media (Catlin & Woollard, 2014).

A study of Organization for Economic Cooperation and Development (OECD) countries in 2009 formulated definitions and conceptual frameworks reflecting the importance of and correlations between 21st Century Skills and individual competencies (Ananiadou & Claro, 2009). Further, the study proposed a new three-dimensional framework comprising the aspects of information communication, ethics, and social impacts. The results showed that most OECD countries had included 21st Century Skills and competencies in their regulations as either guidelines or recommendations for compulsory education.

Although the discussion of computational thinking as a primary skill has become increasingly popular, relatively few studies address the role of computational-thinking skills in the operationalization of 21st Century Skills by students. Therefore, it is essential to devise methods through which students can develop the computational-thinking component of 21st Century Skills. Also, according to Binkley et al. (2012), these skills must continually develop through this century.

Indonesia's vocational education system aims to prepare students for the job market by helping them develop professional attitudes (Wibowo, 2016) relevant to the 21st Century Skills (Binkley et al., 2012). This study was, therefore, conducted in the context of efforts to impart 21st Century Skills to vocational secondary education students studying software engineering. The research aimed to evaluate the students' computational-thinking abilities for the operationalization of 21st Century Skills using robotics-based media to identify the role of computational thinking in students' ability to master 21st Century Skills in vocational higher education.

2 Theoretical Foundation

2.1 Importance of 21st Century Skills

We live in an era in which almost all of our activities are connected with various technologies, many of which are supported by computer programs. As a result, many people are required to become professionals in the information and communication technology (ICT) business sector (Manovich, 2013). Significant changes have occurred in advanced economies in terms of moving from manufacturing to information and knowledge services. Knowledge itself is expanding exponentially. Information and communication technology has changed the meaning of social relationships and the nature of how work is done. Decentralized decision-making, information sharing, teamwork, and innovation are essential in today's market (Binkley et al., 2012), and students can no longer look forward to middle-class success through manual labour or using basic skills, as these can now be performed by machines. Instead, success now lies in the ability to communicate, share, and use the information to solve complex problems, adapt and innovate in response to new demands and changing circumstances, structure and expand the power of technology to create new knowledge, and in developing human capacity and productivity (Binkley et al., 2012). As a result, it has become common for countries with high unemployment rates to start spreading knowledge about information technology and digital literacy from the start of an individual's development (Bers, Flannery, Kazakoff, & Sullivan, 2014; Cejka, Rogers, & Portsmore, 2006; Kazakoff & Bers, 2012) through high school. Allan, Barr, Brylow, and Hambrusch (2010) emphasised the need to integrate these skills with critical competencies such as writing, reading, and maths. Modern devices (Alonso de Castro, 2014; Ramírez-Montoya & García-Peñalvo, 2017; Sánchez Prieto, Olmos Migueláñez, & García-Peñalvo, 2014) – from smartphones to educational robotics – allow these skills and competencies to reach new audiences, especially young people (Fonseca, Conde, & García-Peñalvo, 2018; Jung & Won, 2018; Toh et al., 2016).

Interest groups such as teachers, educational researchers, policymakers, politicians, and business people believe that this century demands a unique set of skills and competencies (Dede, 2007; Kalantzis & Cope, 2012). Initiatives such as the collaboration for assessment and teaching conducted by Cisco/Intel/Microsoft in 21st Century Skills projects (www.atc21s.org) conducted between 2009-2012 also demonstrate how vital these skills are, not only to researchers, practitioners, and policymakers but also to the private sector.

These interest groups state that there is a need for reforms in schools and education to respond to the current social and economic requirements of students and society. They stress that the education system needs to equip young people with skills and competencies that allow them to benefit from new forms of socialization, values, social attitudes, and formative experiences and to actively contribute to the new social spaces and economic developments appearing in systems where the most critical asset is knowledge (Ananiadou & Claro, 2009). The use of the term '21st Century Skills' is intended to show that these skills are related to the needs of models of economic and social development that are different from those of previous centuries, as well as skills that are compatible with the modes of industrial production proliferating in the 21st century.

According to Anderson (2008), young people growing up in the information age are the original digital generation, meaning their skills and abilities must be developed to advance the development of learning through the use of technology. Software development tools for creating programs and solving problems using robotics can help students develop 21st Century Skills (Ramírez-Benavides, López, & Guerrero, 2016; Rativa, 2018). The skills acquired through programming and robotics are critical aspects for students to develop to enhance their future careers (Binkley et al., 2012). Also, computer science requires more than just the ability to operate computers; computational thinking is also an integral aspect (Wing, 2006). Citing an article written by Curzon et al. (2009), Mohaghegh and McCauley (2016) claimed that computational thinking is a skill of the 21st century in itself, but they give no more detailed explanation regarding their arguments for this statement.

2.2 Computational Thinking as a Key Aspect of 21st Century Skills

The understanding that computational thinking is an important 21st-Century Skill (Hutamarn et al., 2017; Mohaghegh & McCauley, 2016; Wing, 2008; Yadav et al., 2016) has encouraged researchers to undertake in-depth research and explore existing literature relevant to how learning experiences and the practice of computational thinking using robotics impacts the development of 21st Century Skills. According to García-Peñalvo and Mendes (2018), for 21st Century Skills development, computational thinking is one of the components of intuitive and critical education that is needed to help students to answer problems using technology based on robotics. Weintrop et al. (2016) claim that computational thinking in the form of a taxonomy consists of four main categories: (a) data practice (collecting, creating, manipulating, analysing, and visualizing data); (b) modelling and simulation practices (using computational models to understand a concept, find and test solutions, assess, design, and build computational models); (c) problem-solving practice (preparing problems for computational solutions, programming, selecting effective computing tools, assessing different approaches/solutions to a problem, developing modular computational solutions, creating computational abstractions, troubleshooting, and debugging); and d) systems thinking practice (investigating complex systems as a whole, understanding the relationships within a system, thinking in stages, communicating information about a system, and defining systems and managing complexity) (Oliveira et al., 2019). Wing (2006) expresses computational thinking as a way of "using heuristic reasoning to find solutions". This could involve coding an algorithm, but it's really about embracing the way computers interact with information and adopting the methods used by computer scientists (e.g. working iteratively). Wing's argument is that computer science as a discipline demonstrates skills and ways of thinking that can benefit how humans use the information that they gather to solve problems. This can involve using the computing power of a computer, but it doesn't have to. According to Binkley et al. (2012), the achievement of problem-solving ability potentially reinforces the importance of 21st Century Skills as solutions to prepare children for the challenges of the new millennium (Salpeter, 2003) in the digital information age (Eshet, 2004, 2012) and the global economy (Caperna, Tracada, Minervino, Alatalo, & Cerreta, 2019).

2.3 Educational Robotics for Computational Thinking

Educational robotics is an expression widely used to explain the application of robotics as a learning medium in teaching and learning activities in schools (Eguchi, 2017). Interest in using robotics has increased in recent years along with the extraordinary level of development of technology not only among the general public but also in the educational community (Benitti, 2012). According to Burleson et al. (2018), learning using educational robotics, in which students design, build, program and document aspects of robotics, enables students not only to use technology as consumers, but also provides meaningful and exciting opportunities (Eguchi, 2017) for them to apply skills and narrate questions, thoughts, and knowledge about current content. Robotics-based learning can also develop other academic skills, increase children's interest in engineering, and engage them in interactive learning experiences (Toh et al., 2016).

In the last decade, several robotics competitions have been held and have popularized so-called informal and productive learning activities with various potential to foster student interest in mathematics and science (Witherspoon, Schunn, Higashi, & Baehr, 2016), as well as motivate students to pursue careers in the fields of science, technology, engineering, and mathematics (STEM) (Eguchi & Almeida, 2013; Wahyuningsih et al.). Training in programming (Lye & Koh, 2014; Wong & Jiang,

2018) can improve skills and ideas, motivate students, and improve their fluency in computational thinking (Aristawati, Budiyanto, & Yuana, 2018), all of which are essential in K-12 education (Catlin & Woollard, 2014). Robotics activities can place the learning of abstract computational concepts and problem-solving techniques and processes into more concrete experiences, with which students can create, observe, and interact with physical objects for experiential learning (Petre & Price, 2004). Learning activities involving robotics in schools enable students to become familiar with the concept of computational thinking, integrate the problem-solving process (Atmatzidou & Demetriadis, 2014) in various types of problems and multiple fields of knowledge (Figueiredo & García-Peñalvo, 2017; Wing, 2008), maximize their understanding of 21st Century Skills (Rativa, 2018), and improve competencies such as teamwork, resilience, and communication (Peixoto et al., 2018). Diego-Mantecón, Arcera, Blanco, and Lavicza (2019) argue that educational robotics drive students to start raising questions, generating debates, suggesting ideas, and providing examples, letting the students see possible ways of finding the solution.

The concept of computational thinking has become prominent in terms of the use of robotics in education. Several researchers have also used robotics programming instruments and everyday reasoning in assessing students' application of computational thinking and in explaining the transferable aspects of computational thinking (Chen et al., 2017). Moreover, robotics can foster computational thinking because it meets the requirements of such thinking (technology, intelligence, embodiment, and interaction) and is a technology that supports the learning and development of intelligence via a tangible medium that allows interaction between learning media and learners (Catlin & Woollard, 2014). Computational thinking and robotics have a naturally symbiotic relationship and can work together to promote attractive educational opportunities for K-12 education. Activities with robots bring practical maturity that can help computational thinking theory become successful in practice (Catlin & Woollard, 2014). Robotics provides opportunities for students to engage in spatial programming, creating improvised and sequential programs that mediate interactions among the environment, robots, and humans in responsive and creative ways, demonstrating the innovative potential for advancing activities involving computational thinking (Burleson et al., 2018).

2.4 21st Century Skills and Vocational High School in Indonesia

The most recent regulation on the Indonesian Education System is Law Number 20 of 2003 concerning the National Education System. The type of education in Indonesia consists of general education, "kejuruan", "vokasi", academic, professional, religious, and special education (Estriyanto, Kersten, Pardjono, & Sofyan, 2017). "Pendidikan Kejuruan" and "Pendidikan Vokasi" are two terms that have the same meaning in English as "vocational education" (Estriyanto et al., 2017). "Pendidikan Kejuruan" is a type of vocational education in secondary education (The Republic of Indonesia, 2003), while "Pendidikan Vokasi" refers to vocational education in higher education (The Republic of Indonesia, 2012b). While both "Pendidikan Kejuruan" and "Pendidikan Vokasi" are types of vocational education, they are different levels of education. In this paper, the term "vocational education" refers to students studying in Vocational High Schools, which are vocational schools at the secondary education level. In Indonesia, Vocational High Schools are commonly referred to as "Vocational High Schools (VHS)" or in Bahasa Indonesia, "Sekolah Menengah Kejuruan (SMK)". Law Number 20 of 2003 states that secondary vocational education aims to prepare students for work in a particular field (The Republic of Indonesia, 2003). VHS in Indonesia is a workplace-oriented education at the second level of education in the national education system. Vocational High School graduates are skilled workers who can handle every task in the appropriate field of work. The success of the educational program is measured by the level of acceptance of workers in the industry or related workplace.

In addition, SMK graduates are also equipped with entrepreneurial skills, where students can use 21st Century Skills to take advantage of new forms of socialisation, social values and attitudes, and constructive experiences so that they can actively contribute to new social spaces and economic developments under systems in which the most important asset is knowledge (Ananiadou & Claro, 2009). Meanwhile, Binkley et al. (2012) suggest that schools must be transformed in a way that will enable students to acquire sophisticated thinking, flexible problem-solving, and the collaboration and communication skills they need to succeed in work and life.

3 Research Methodology

3.1 Research Procedures

The qualitative case study method of this study was designed to collect and analyse data by evaluating students' behaviour and perceptions while carrying out activities. This study employed the Lego Mindstorm EV3 as a module for students' activities.

The qualitative approach helps researchers to find out the characteristics of an entity, phenomenon, or person. According to Ary, Jacobs, Sorensen, and Razavieh (2010), qualitative research investigates the quality of relationships, activities, situations, and materials, focuses on understanding context, and attempts to explain behavioural intentionality. The goal of qualitative inquiry is the ability to describe the complex pattern of what is being studied in sufficient depth and detail, so that even people who have not experienced the phenomena are expected to understand it. When qualitative researchers interpret or explain the meaning of events, actions, and so on, they generally use one of the following types of interpretation: (1) pattern construction through analysis and resistance of constituent parts; (2) understanding of the social meaning of events; or (3) study of the relationship between events and external factors. This study uses the first of these approaches: pattern construction interpretation through the analysis and resistance of the constituent parts. Interpretation of data in qualitative research can lead to theory generation, be guided by existing theories or concept maps, or attempt to better explain or elaborate on theory (Ary et al., 2010). Researchers can be oriented towards complexity through qualitative methods that connect ordinary practices in everyday life with problems in academic disciplines (Denzin & Lincoln, 2011).

For this study, an invitation to participate was sent out to all the students at a vocational high school in Surakarta, Central Java, Indonesia. Eight students voluntarily registered to participate, aged 16–18 years old, and had passed algorithm and programming courses. There was neither gender preference nor any incitement to their participation, and they were free to choose to continue or quit at any time during the data collection. However, the requirement of age and previous programming skills were mandatory since the participants were to be involved in the programming of Lego Mindstorm EV3 for computational thinking learning, as was adopted by previous researchers (Aristawati et al., 2018; Atmatzidou & Demetriadis, 2014). The procedure was carried out in five sessions, with a total session length of 3 hours and varying durations between sessions, described as follows.

3.1.1 1st Session: Preparation

The eight participants joined the sessions in the computer lab on the designated schedule at different times, and the researcher met once with the students, that is, during participant selection. At the beginning of the activity, the students were given a briefing and explanation by one of the researchers about the robotics project activities to be carried out. In this session, the group work took about 10–15 minutes.

3.1.2 2nd Session: Introduction

The students were introduced to the Lego Mindstorm EV3 kit. They were given a brief description of the components' names and functions, including ultrasonic sensors, colour sensors, bricks, driving motors, and so on. In the second session, a video was shown on how robotics function, move, and carry out their activities following the objectives of the project and its problems. Furthermore, the session explained the software used to program the Lego Mindstorm EV3, as installed on the computers being used. This session aimed to understand how the participants' first perception of something new was created and/or their impressions from previous experiences. For this session, the group work took about 10–15 minutes.

3.1.3 3rd Session: Assembly

Each group worked on the robotics projects independently, assisted by modules presented on laptops and in print. During this session, the researchers focused on observation instruments, especially indications of participant behaviour starting from the second session when the students met with Lego Mindstorm EV3. From the researchers' perspective, the third session was the most complex stage. The researchers observed the participants' activities in relation to operational 21st Century Skills and computational thinking instruments. For this session, the group work took an average of 1 hour.

3.1.4 4th Session: Completion and result testing

This session involved the programming of the robotics model and subsequent testing. After the participants had finished assembling the Lego robots, they were faced with how to program the robot to carry out firefighting activities. In this programming session, the participants programmed the robot from scratch without the help of modules because the module is only available for assistance and direction to assemble Lego Robotics. Furthermore, the participants were allowed to test the results of the robot project. In the session, the participants emphasized the achievement of computational thinking and operationalization of 21st Century Skills by designing, analysing, building, programming, simulating, and evaluating their desired robotics project in a working group. In this session, group work on average took about 1–1.5 hours. During the observation, the researchers took notes on the group members' tendency to either follow or disregard the provided module to carry out the assembly.

3.1.5 5th Session: Closing and reflecting

In the previous session, the activity was summarized, and a semi-structured interview (unwritten) was initiated with each participant individually before they left the room. The interview session was of great importance since the interview protocol could be extended to include follow-up questions once a lead was identified. During the interview, the participants tended to express their new thought patterns through the answers to the interview questions presented regarding their experiences during the robotics projects. The interview sessions took about 10–15 minutes.

3.2 Data Analysis

This study conducted a thematic analysis to extract knowledge from interviews and observation data. Data analysis was carried out once all the activities were completed. The researchers identified and analysed the themes in the data and reported patterns. The process required inspection of verbatim data line by line while applying initial codes to the dataset. Texts indicating similar content were grouped to construct their respective themes. The next step involved reviewing and refining the main themes and identifying theme sections, and in the final step, the theme titles were revised and refined (Raufelder et al., 2016). The data obtained through observation and interviews were transcribed. Interview transcripts and field notes were then organized and categorized in accordance with patterns or categories.

4 Results and Discussion

Analysis of interview and observation data reveals the insights of computational thinking in students' attainment of 21st Century Skills. The researcher's interest is in evaluating student behaviour and perceptions during engagement in an educational robotics project. An overview of the themes is presented in the following subsections. The topic profile then tests the suitability of the indicators for achieving computational thinking against the indicators for 21st Century Skills.

Table 1: Profile and experience of participants.

Student	Programming experience	Robotics experience
Student A	Yes	No
Student B	Yes	No
Student C	Yes	Yes
Student D	Yes	No
Student E	Yes	No
Student F	Yes	No
Student G	Yes	No
Student H	Yes	No

4.1 The role of using robotics in the learning of computational thinking skills in vocational students

Table 2: Series of stages of achieving computational thinking - Student A.

Milestone	Activity	60'I	60'II	60'III
M-01	Students get acquainted with the robotics project that will be carried out, namely building a firefighting robot.	2		
M-02	Students get acquainted with the robotics medium Lego Mindstorm EV3 kit, including the names and functions of the parts.			
M-03	Students work on robotics projects starting from understanding the project, designing, determining the parts or tools needed, and building the project.	2, 3		
M-04	Students program the robotics and test the results of the robotics project functions.			2, 5, 3, 4

Components: 1. Decomposition 2. Abstraction 3. Algorithms 4. Modularity 5. Generalization

Mapping data shows that students' enthusiasm for robotics-based learning can facilitate the five components of computational thinking skills. Furthermore, the interview data mapping results concerning the components of computational thinking skills were confirmed, which can then be used to review the level of learning achieved pertaining to computational thinking skills. An overview of the components is described in the following sub-sections.

4.1.1 Decomposition

In the context of learning computational thinking using robotics-based media, students carried out activities independently with the help of an introductory module when assembling the Lego Mindstorm EV3 model, while the students carried out the programming of the robot without the help of modules. Research (Barr & Stephenson, 2011; Weese & Feldhausen, 2017) shows that decomposition is the process of breaking a problem down into smaller parts that may be easier to solve. Li, Hu, and Wu (2016) identified that decomposition skills were assessed when students were able to solve problems. The following are some confirmations that show the results of learning computational thinking using robotics-based media when the participants decomposed a robotics project to make it easier to work on. For example, the following views were expressed by Students E and F when asked to speak about learning to use Lego Mindstorm EV3:

> *Assembling there are two parts, assembling small components into a large component, now that's the first part, the second assembles the large components into one ... (Student E)*

> *Construction of Lego, continuing to install the cables and the coding process, and the Lego continues to be made into a robot ... (Student F)*

Students broke down the robot components and projects into several parts for peer assignments (Observations of Student C, Decomposition). Student F and their colleagues broke down the robot's components to make it easier to divide them among the group members, thereby improving time efficiency (Observations of Student F, Decomposition). Student E divided up the robot's parts for their colleagues to divide the work amongst themselves (Observations of Student E, Decomposition). This is an indicator of the decomposition component of students' computational thinking skills where they break down problems into small or simple parts that are easier to manage. Wing (2008) also argues that computational thinking uses decomposition when splitting or designing complex tasks. Similar arguments are expressed by Yadav et al. (2016), who state that decomposition involves breaking down complex problems into more familiar or manageable sub-problems.

4.1.2 Abstraction

Barr and Stephenson (2011) state that abstraction is a process of simplifying the concrete to general as a developed solution. Weese and Feldhausen (2017) identified abstraction skills using different intensity settings of red, green, and blue, and then giving students time to see what colours they could produce using a series of microcontrollers. General representation of complex problems, ignoring foreign information, simplifying problems by ignoring unnecessary details, and looking for patterns in problems were the main abstraction skills identified by Weese and Feldhausen (2017). The following are some statements that confirm the results of learning computational thinking using robotics-based media, in which students use abstraction skills when working on robotics projects. For example, when asked about the presence or absence of different experiences to those described in the module when building robotics, Student A stated

> *I added a number of parts or series, I added some of it, I lost it because it had no function in my opinion ... (Student A).*

Student A's explanation shows that they ignored parts that were not important by eliminating them because they did not consider these parts to be relevant to the robotics project. This is reinforced by the results of observations in which Student A was seen to immediately build a robot while sorting out the required parts of the robot, using the module (Observations of Student A, Abstraction). Student D separated the parts needed to complete the robotics project (Observations of Student D, Abstraction). This is an indicator specified by Atmatzidou and Demetriadis (2016) regarding abstraction capabilities, namely separating important information from existing information, analysing and determining general behaviour or programming structures between different scripts, and identifying abstractions between different programming environments. Student H also expressed the same thing by describing the general behaviour of robots:

> *The movement goes back and forth, moves the fan, detects the color sensor, and the ultrasonic sensor will turn ... (Student H)*

Student H observed how the robot performed its activities and analysed the robot's steps (Observations of Student H, Abstraction). Although, when asked to describe what was done when carrying out a robotics project, Student G said the following:

> *Yes, when the coding is the most difficult when it comes coding, how is it, all the coding is the same, but it seems like the implementation is a bit different. (Student G)*

Student G's statement is relevant to the findings of Yadav et al. (2016) regarding abstraction abilities reflecting that students review how solutions are transferred to similar problems.

4.1.3 Algorithmic ability

Yadav et al. (2016) argue that algorithmic ability is one of the key components of computational thinking, in which actors are involved in using a sequence of steps regularly to solve a problem or complete a task. Weese and Feldhausen (2017) identified algorithmic skills by seeing whether participants can find ways to grow crops fast enough to sustain life; according to them, making a list of steps to solve a problem, executing a sequence of commands step by step, and performing mathematical operations such as addition and subtraction are the main aspects of algorithmic skills. The following are some confirmations that show the learning of computational thinking using robotics-based media, in which students use algorithmic abilities when working on robotics projects. Students C and B expressed the following when asked to describe the general behaviour of a robotics model:

> *The robot can advance; when there is an object in front of the sensor, it will know and will turn in the desired direction ... (Student C)*

> *When the robot is walking, it detects if there is an obstacle in front of it, then uses a red sensor and extinguishes the fire ... (Student B)*

This is an indicator of the algorithm component in the computational thinking skills, as put forward by Atmatzidou and Demetriadis (2016). Students state the steps of the algorithm explicitly and identify various effective algorithms for a given problem and find the most efficient one. The mapping of interview data on Students C and B was also strengthened by the results of observations which show that Student C identified several algorithms, such as moving forward and turning (Observations of Student C, algorithm). Student B conveyed the stages of the robot carrying out its activities based on videos (Observations of Student B, algorithms). Student H described and explained to the colleagues their findings in the form of information about the function of each program block code for the robot (Observations of Student H, algorithms). The results of observations of Student H are in agreement with the opinion of Astrachan and Briggs (2012) regarding algorithmic components being tools for developing and expressing solutions to computational problems. In addition, Wong and Jiang (2018) believe that students learn to change algorithms for computer programs through finding and combining correct blocks.

4.1.4 Modularity

Barr and Stephenson (2011) and Atmatzidou and Demetriadis (2016) explain modularity to be the development of an automatic process that summarizes a series of commands that are often used to perform certain functions and can be used for the same or different problems. Atmatzidou and Demetriadis (2016) identified modularity skills by looking at how students worked on control structures to use ultrasonic and block sensors and how students practiced the conversion of numbers to text to show numeric values on the screen. According to Atmatzidou and Demetriadis (2016), developing autonomous code sections for the same or different problems is a major aspect of modularity skills. The following are some confirmations that show the results of learning computational thinking using robotics-based media in which students use modularity when working on robotics projects. For example, when asked to express what they did when working on the robotics project, Student A said

> *Adding it, inserting the switch tool with the loop for running, most of them use a switch ... (Student A)*

> *From the stationary robot, it starts moving; then we added a switch and loop so it can keep moving ... (Student B)*

The statements made by Students A and B show that students developed autonomous robot motion using switch and loop functions. The observations made regarding Student H were different from the other participants, in that Student H developed advanced motion using the loop function (Observation of Student H, Modularity). Moreover, Student A's statements are supported by the results of observations. Student A evolved from a one-step walking program to using looping and directions using switches (Observations of Student A, Modularity). Student B changed the motion of one step with a loop so that the movement could be repeated (Observations of Student B, Modularity). This is an indicator of modularity described by Atmatzidou and Demetriadis (2016), according to which, students develop parts of an autonomous code that may be used for the same or different problems.

4.1.5 Generalization

According to Atmatzidou and Demetriadis (2016) and Barr and Stephenson (2011), generalization is the transferring of the problem-solving process to a variety of problems. In their research, these authors identified generalization skills by seeing how students were able to program robots to dance and present them to other groups and asking them to reflect on the role of the concept of generalization in solving their problems. Atmatzidou and Demetriadis (2016) believe that transferring the problem-solving process to various problems is the main assessment of generalization skills. The following section shows the results of students using generalization skills when learning computational thinking using robotics-based media. When asked about the future projects they would consider after the robotics project and what happened when working on the project, Student A stated the following:

> *Like a robot in a restaurant that's cooking, then maybe there's no delivery person, so hopefully, we can make it ... (Student A)*

> *Adding it, inserting the switch tool with the loop for running, most of them use a switch ... (Student A)*

From these comments in the context of the generalization component, it can be seen that the students tried to transfer solutions from problems they had previously encountered at school, namely using switch and loop functions, to enable them to complete the robot program to fulfil the needs of the robotics project. In addition, Student A also planned to transfer the solution to a robotics project, specifically a food delivery robot in a restaurant. To strengthen the mapping of interview data, the results of observations made in relation to Student A show that they used the switch and loop functions when programming the robot (Observations of Student A, Generalization). In addition, Student D used ultrasonic sensors to detect objects in front of the robot (Observations of Student D, Generalization). These are indicators of generalization (Atmatzidou & Demetriadis, 2016), in that students expand the solution of a problem to reach more possibilities/cases. When Student B was asked whether there were special points they wished to make about robotics and the programming projects carried out, they made the following statement:

> *Yes, the method of sequencing the flowchart from being still to moving is like that, because in school the flowchart lessons only get a little and here you can add more, from a stationary robot starting to move, then adding a switch and loop so that it can keep moving ... (Student B)*

> *Maybe it can be used to filter rubbish, yes in the rivers if there is rubbish it can be picked up using a robot, the hand can filter and then lift the trash so that the river can be clean ... (Student B)*

This is also in agreement with the opinion of Selby and Woollard (2014) that generalization is a step in recognizing how small skills can be reused and applied back to the same or new situations. Curzon, Dorling, Ng, Selby, and Woollard (2014) and Csizmadia et al. (2015) state that generalization is a way of quickly solving new problems based on previously solved problems, namely by taking an algorithm that solves some specific problem and adapting it so that it solves all classes of the same problem.

Table 3: Summary of computational-thinking achievement analysis results.

	Decomposition	Abstraction	Algorithm	Modularity	Generalization
Student A	x	√	√	√	√
Student B	√	√	√	√	√
Student C	√	√	√	x	x
Student D	√	√	x	x	√
Student E	√	√	x	x	√
Student F	√	√	√	x	√
Student G	x	√	√	x	x
Student H	x	√	√	x	x

The data analysis shows that only Student B was confirmed to have achieved all five components of computational thinking (Atmatzidou & Demetriadis, 2016). Students A, C, D, E, F, G, and H did not achieve one or more of the components of computational thinking. For example, Student A did not show any achievement in the decomposition component. The difference between Student B and the others is Student B's success in designing, building, and programming the robot until the final stage, but further research is needed to ascertain the causes of variations in the levels of achievement of the computational thinking components. Every student had different tendencies, enthusiasms, and motivations when designing, building, and programming the robots. Student A was more active and interested in the robot designing and building session but tended to be passive in the programming session as compared to Student B. This study revealed that the use of robotics has a strong influence on the learning of computational thinking skills in the abstraction and algorithm components, an intermediate level influence on the components of decomposition and generalization, and a weak influence on the achievement of the modularity component.

While carrying out data analysis, as well as based on the literature, we realised that different definitions of computational thinking skills have been introduced. Shute, Sun, and Asbell-Clarke (2017) introduced iteration as the sixth skill potentially making our endeavour seem to be incomplete or lacking. In this regard, the researchers recommend that future research consider iteration to be a component of computational thinking skills worth exploring.

4.2 Effect of learning computational thinking skills using robotics on mastery of 21st Century Skills

Mapping the interview data using the operational indicators for 21st Century Skills reveals several points that can be used to deliver an overview of 21st Century Skills mastery, as follows.

4.2.1 Creativity and innovation

Certain statements made by the participants show the effect of learning computational thinking skills using robotics in operationalizing students' creativity and innovation skills. When asked to express how a robotics project can solve other present-day problems, Student B stated the following:

> *Maybe it can be used to filter rubbish, yes in the rivers if there is rubbish it can be picked up using a robot, the hand can filter and then lift the trash so that the river can be clean ... (Student B)*

This is an indicator of the generalization of computational thinking skills described by Atmatzidou and Demetriadis (2016), through which students expand the horizon of solutions to problems. When students try to find multiple solutions to a problem, it triggers them to create new ideas, as in this case, the robot's hand being used for filtering. This is an indicator of creativity and innovation skills described by Binkley et al. (2012), in that students create new and useful ideas, both little by little and regularly (incremental), and basically down to the principle (radical), a step which is basic to the principle of generalization. Students can also describe, refine, analyse, and evaluate their own ideas to enhance and maximize creative endeavours. In addition, students also develop innovative and creative ideas into forms that have an impact and can be adopted. In agreement with the results of the interviews, the observations show that Student B presented the idea of robot motion to colleagues and added to the robot's function (Observations of Student B, Generalization) by developing, implementing, and communicating new ideas to others effectively (Binkley et al., 2012). In contrast, Student A exhibited modularity skills through creativity and innovation skills. When asked to express what was done when trying to complete a robotics project, Student A stated the following:

> *Adding it, inserting the switch tool with the loop for running, most of them use a switch ... (Student A)*

Student A's explanation is an indicator of the modularity of computational thinking skills described by Atmatzidou and Demetriadis (2016), through which students develop parts of autonomous code that may be used for the same or different problems. Student A developed a part of the autonomous code, which is an indicator of creativity and innovation skills described by Binkley et al. (2012), according to which, students can describe, improve, analyse, and evaluate their own ideas to increase and maximize their creative efforts. The observations showed that Student A progressed from a one-step walking program to using repetition and directions using switches (Observations of Student A, Modularity), thus developing innovative and creative ideas into forms that have an impact and can be adopted (Binkley et al., 2012). The results show that students' abstraction, modularity, and generalization skills play a role in the operationalization of their creativity and innovation skills. As for students' decomposition and algorithm skills, no findings confirm or indicate their role in the operationalization of students' creativity and innovation skills.

4.2.2 Critical thinking, problem-solving, and decision-making

Confirmations show the effect of learning computational thinking skills using robotics on the operationalization of students' critical thinking skills, problem-solving, and decision-making ability. Student A provided an example of this when asked to speak about the differences in things done that were not in accordance with the module:

> *I added a number of parts or a series that I added, some that I removed because they had no function in my opinion ... (Student A)*

Student A's explanation is an indicator of the abstraction component of computational thinking skills described by Atmatzidou and Demetriadis (Atmatzidou & Demetriadis, 2016), according to which, students try to separate important information from existing information. Student A's separation of important information is a reflection of problem-solving, decision-making, and critical thinking skills, through which students can interpret information and draw conclusions based on the best analysis through categorizing, decoding, and explaining information. Reinforcing the results of the interviews, the observations show that Student A built a robot while sorting out the required parts using the help provided by the module (Observation of Student A, Abstraction). In contrast, Student F exhibited algorithmic skills as an indicator of their critical thinking, problem-solving, and decision-making ability when asked about how they overcame problems encountered in the robotics project:

> *Yes, keep trying, yes try it later, yes later apply it again, try, try, try, replace, replace, replace, take input from colleagues, if a colleague gives this input, try to follow it first ... (Student F)*

Student F's explanation is an indicator of the algorithmic ability of computational thinking skills described by Atmatzidou and Demetriadis (2016), through which students try to identify various effective algorithms for a given problem. Student F's response is an indicator of critical thinking skills, problem-solving, and decision-making, according to Binkley et al. (2012), through which students synthesize connections between information and arguments. Reinforcing the interview results, the results of observations show that Student F evaluated the program block code to stop and move the robot's claws (Observations of Student F, algorithm). The data analysis and observations show that students' abstraction skills, algorithms, and modularity play a role in the operationalization of their critical thinking skills, problem-solving, and decision-making. As for students' decomposition and generalization skills, there are no findings that confirm or indicate their role in the operationalization of students' critical thinking skills, problem-solving, and decision-making. However, Lockwood and Mooney (2017) claim that identification and decomposition are related to problem-solving skills, and in their research, these were carried out using robotic assistance. In addition, Weese and Feldhausen (2017) state that computational thinking is not a problem-solving component but rather a component of cognition.

4.2.3 Learning-to-learn and metacognition

Confirmations from the students show the effect of learning computational thinking skills using robotics on the operationalization of learning skills for student learning and metacognition. When asked to talk about what they dream of in the future after working on the robotics project, Student A said

> *If I make a robot that is useful, so it makes human work easier, maybe now there are a lot of robots in a restaurant, yes, that's cooking, so maybe there isn't one that delivers, so hopefully, it can be made ... (Student A)*

Student A's explanation is an indicator of the generalization component of computational thinking skills given by Atmatzidou and Demetriadis (2016), through which students devise multiple solutions to problems. When Student A put forth multiple possibilities, it triggered critical reflection on learning objects and objectives, which are indicators of learning-to-learn and metacognition skills described by Binkley et al. (2012). In agreement with the interview results, the results of student observations show that Student A tried to change the shape of the robot not according to the module but according to the needs of the robot's motion based on their own analysis (Observation of Student A, Generalization). In contrast to Student A, Student H exhibited abstraction skills with learning-to-learn and metacognition skills when asked about how to solve problems encountered while working on a robotics project:

> *Getting to know more deeply so I can know more, right, I was with my friend, I exchanged ideas, thought together ... (Student H)*

Student H's explanation is an indicator of the abstraction component of computational thinking skills described by Atmatzidou and Demetriadis (2016), through which students identify abstractions between different programming environments. Students' ability to identify and understand more deeply is an indicator of learning-to-learn and metacognition skills described by Binkley et al. (2012), through which students dedicate time to learning, autonomy, discipline, persistence, and information management in the learning process. Reinforcing the interview results, the results of the observations show that Student H found that static forward movement would not be applicable because it needed a conditional when the robot met a barrier object (Observation of Student H, Abstraction). The results of the analysis of interview data and research observations show that students' abstraction, algorithm, generalization, and decomposition skills play a role in the operationalization of learning skills for student learning and metacognition. However, there are no findings that confirm or indicate the role of student modularity skills in the operationalization of learning skills for student learning and metacognition.

4.2.4 Communication

Here are some statements that confirm the effect of learning computational thinking skills using robotics on the operationalization of students' communication skills.

> *The discussion about having to fix the problem, such as having to turn but the robot keeps going straight; maybe it's a lot of trouble ... (Student A)*

Student A's explanation is in accordance with the indicators of the abstraction component of computational thinking skills, as described by Atmatzidou and Demetriadis (2016), through which students analyse and determine general behaviour or programming structures between different scripts. Student A discussing how to fix problems and analysing and determining general behaviour is an indicator of communication skills described by Binkley et al. (2012), according to which, students can communicate in written or oral form and understand or make others understand, various messages in various situations and for different purposes. The observations show that through trying out solutions and encountering errors when programming the robot, Student A could create a program that matched the robot's function to robot activity (Observations of Student A, Abstraction). In contrast, Student E expressed a different relevance, namely decomposition skills, when asked about the processes that took place between him and his colleagues when working on the robotics project:

> *Cooperation, dialogue Bro, I build part number 26, your number 28 ... (Student E)*

Student E's explanation is in accordance with the indicators of the components of the decomposition of computational thinking skills described by Atmatzidou and Demetriadis (2016), according to which, students break down problems into small/simple parts that are easier to manage. Student E handled the dialogue part and divided the problem into several parts, which was an indicator of communication skills described by Binkley et al. (2012), through which students can communicate, in written or oral form, and understand or make others understand, various messages in various situations and for different purposes. The observations show that Student E divided the parts of the robot to do certain things while other parts of the work were being done by their colleagues (Observations of Student E, Decomposition). The data analysis shows that students' abstraction, decomposition, and algorithm skills play a role in the operationalization of their communication skills. Meanwhile, there are no findings that confirm or indicate the role of students' modularity and generalization skills in their communication skills' operationalization.

4.2.5 Collaboration and teamwork

Here are some statements that confirm the effect of learning computational thinking skills using robotics on the operationalization of student collaboration and teamwork skills. When asked to express the role of fellow students when working on a robotics project, Student A stated

> *It is beneficial to correct problems with coding and design, for having the wrong code also correcting the wrong position when building the robot. (Student A)*

Student A's explanation relates to the indicators of the abstraction component of computational thinking skills, according to Atmatzidou and Demetriadis (2016), in which students separate important information from existing information. This separation of information is an indicator of collaboration and teamwork skills, according to Binkley et al. (2012), in which students use others for achieving common goals. Reinforcing the interview results, the results of the observations show that Student A builds a robot while sorting out the required parts of the robot, using the module (Observations of Student A, Abstraction). In contrast, Student B expressed a different relevance, namely the decomposition skills indicated through collaboration and teamwork skills, when asked about the activities they performed with colleagues for solving problems when working on the robotics project:

> *The first stage is discussion, and this is how to install it, continue to be installed together, connect to the computer for the robot program, yes together, keep trying, yes together ... (Student B)*

This explanation given by Student B is in accordance with the component indicators of the decomposition of computational thinking skills described by Atmatzidou and Demetriadis (2016), in which students break the problem into small/simple parts that are easier to manage. Breaking the problem into smaller parts is an indicator of collaboration and teamwork skills, according to Binkley et al. (2012), through which students can utilize the strengths of others to achieve common goals and inspire others to achieve their best through examples and self-expression. Observations show that Student B breaks down several parts of the robot into large and small parts (Observations of Student B, Decomposition). Student B provides directions and input in a polite manner (Observations of Student B, Collaboration and Teamwork). Data analysis shows that the students' decomposition and abstraction skills play a role in the operationalization of their collaboration and teamwork skills. As for algorithmic skills, modularity and generalization, there are no findings that confirm or indicate their role in the operationalization of student collaboration and teamwork skills.

Table 4: Summary of the role of computational-thinking skills achievement in 21st century skills operationalization.

Student	CT	21st century skills
B, D, E, F	Generalization	Creativity and innovation
A, B	Modularity	
A, G	Abstraction	
A, B, C, D, E, F, G, H	Abstraction	Critical thinking, problem-solving and decision-making
A, B, F, G, H	Algorithm	
B	Modularity	
C, H	Abstraction	Learning-to-learn
F, H	Algorithm	
F	Decomposition	
A	Generalization	
A, B, E, F, G, H	Abstraction	Communication
B, E, F	Decomposition	
B	Algorithm	
B, C, E, F	Decomposition	Collaboration and teamwork
A, F, G	Abstraction	

From the discussions presented in Sections 4.1 and 4.2, it can be seen that students' ability to learn computational thinking skills plays a role in the operationalization of 21st Century Skills, predominantly in the components of abstraction, generalization, decomposition, and algorithmic ability but weakly in the component of modularity. The foundation of this study is the belief that computational thinking skills motivate students to operationalize 21st Century Skills. However, we also found other trigger factors, such as the involvement of robotics devices. As a confirmatory review, the comparison of statements made by Student B and Student A shows that they managed to operationalize all the components of 21st Century Skills despite having different levels of achievement of computational thinking components. From the previous explanations, it can be concluded that this study is in agreement with the general opinion established in the relevant literature (Hutamarn et al., 2017; Mohaghegh & McCauley, 2016; Wing, 2008; Yadav et al., 2016). However, the results of this study have underlined that there is a possibility that the type of material content, learning media, and the learning approach used will affect the level of development of computational thinking skills and the role of achieving computational thinking in the operationalization of 21st Century Skills.

4.3 Learning computational thinking using robotics-based media enhances enthusiasm for choosing a career in the STEM field

In the context of learning computational thinking using robotics-based media, students carry out activities independently with the help of introductory modules when assembling the Lego Mindstorm EV3 robot model. In contrast, in the study program sessions, students do so without any assistance. The following are some confirmations that confirm that computational thinking learning using robotics-based media fuels the students' enthusiasm for choosing a career in STEM fields. For example, when asked to speak about plans after doing the robotics project, Students C and F stated the following:

> *I want to explore robotics and coding in the future. I can make robots that are useful for society ... (Student C)*

> *Yes, I want to explore the science of robotics as well as its use and understanding of its application; also, I want to know more about robotics ... (Student F)*

The statements of Students C and F show that the students became more interested in activities that involved robotics and programming after learning computational thinking through the robotics project. The project-based learning focus essentially fostered the enhancement of mathematical competence and science, technology, and engineering (Diego-Mantecón, Blanco, Ortiz-Laso,

& Lavicza, 2021). This is in agreement with the opinion of Chen et al. (2017) and Tran (2018), who stated that developing computational thinking skills can fuel the enthusiasm for choosing a career in the fields of STEM or CS via the opportunity to gain experience through pursuing learning activities meeting various student interests.

4.4 Creating programs using program development tools and solving them using robotics can help students understand and operationalize 21st Century Skills

Learning computational thinking using robotics-based media was divided into several sessions. At the final stage, the students were directed to make and run programs on robotics media. Some findings confirm that learning involving robotics media can help students understand and operationalize 21st Century Skills. An example of this was expressed by Student G when asked to explain what they had learned when creating programs with robot-based media:

> *Like a human part, like a hand, for example, this hand, well we have to program it first, what do we want to do, then if I use the switch, the switch is for selecting, if you eat your right hand or your left hand, if it's the right hand, it means that the correct switch will be true later ... (Student G)*

This explanation shows that, when making the program, students looked for evidence to confirm what they had made was what they wanted, namely by looking at the motion response of the robot. By looking at the response and evidence, the students could decide about developing the next program needed. In another case, Student B mentioned, as a special note, about robotics and programming projects:

> *Yes, the method of sequencing the flowchart from being still to moving is like that, because in school the flowchart lessons only get a little and here you can add more, from a stationary robot starting to move, then adding a switch and loop so that it can keep moving ... (Student B)*

From Student B's explanation, students created ideas so that the robot could continue to run according to their needs. In this section, the students were helped in understanding and operationalizing creativity and innovation skills.

> *The propeller in the module is only up and down, but I did it for 360 degrees, so I took two hands, I took off one hand, so if two hands 360 degrees, the robot will hit the body, it will crash - I keep crashing, that's why I took off one and the right one. I tried to design it so that it could be 360 degrees ... (Student G)*

From the explanation of Student G, the students applied their creativity in designing their robot claws or propellers. This is in agreement with the opinion of Ramírez-Benavides et al. (2016) and Rativa (2018), who revealed that software development tools used to create programs and solve problems using robotics could help students to develop their 21st Century Skills.

4.5 Robotics-based activities place learning of computational concepts and problem management techniques into more concrete experiential processes

The following are some statements by the students that confirm that computational thinking learning using robotics-based media can place learning of computational concepts and problem-solving techniques and processes into more concrete experiences. For example, when asked to express what things were discussed with their group colleagues about the robotics project, Students B and F stated the following:

> *From the start, how do I make the robot with the program, keep trying it, try the robot can run as desired or not, if not try again ... (Student B)*

> *Yes, try to keep going, yes, try it later, yes, it will be applied again, try to try, change, change, take input from colleagues, if a colleague gives this input, try to follow it first ... (Student F)*

From the explanations of Students B and F, it can be seen that the students were experimenting when trying to solve problems by seeing directly whether the robot's motion was as desired or not, and this provided an opportunity for the students to have a more concrete experience of the program they had made. This is also in agreement with the opinion expressed by Petre and Price (2004) that robotics activities can place learning of abstract computational concepts and problem-solving techniques and processes into more concrete experiences in which students can create, observe, and interact with physical objects.

5 Conclusion

The use of robotics can facilitate all the components of computational thinking skills in vocational school students, ranging from decomposition, abstraction, algorithms, modularity, and generalization. This can be seen from the results of the analysis of observational data and interviews that show conformity with achieving computational thinking skills. Another supportive aspect is that robotics devices place computational learning concepts and problem-solving techniques and processes into more concrete experiences. Students can create, observe, and interact with physical objects as part of a learning experience. From this research, it can be seen that the use of robotics shows a strong influence in helping students learn the abstraction and algorithm skill components of computational thinking. The use of robotics for learning also has an intermediate level of influence on the components of decomposition and generalization and a weak influence on achieving the modularity component of computational thinking skills. The development of computational thinking skills using robotics plays a role in the achievement of 21st Century Skills. This is based on the analysis results of observational data and interviews that conform with the operational indicators of 21st Century Skills. Learning computational-thinking skills using robotics occurs strongly in the generalization component that triggers participants to use creativity and innovation skills, in the decomposition component of collaboration and teamwork skills, and in the abstraction component in communication skills, critical thinking, problem-solving, and decision-making. Meanwhile, the achievement of computational thinking skills using robotics occurs at a weaker level in the components of modularity and algorithmic ability, which trigger participants to use learning-to-learn skills, metacognition, communication, collaboration, and teamwork. This was evident from the participants who achieved computational thinking components and in whom the operationalization of 21st Century Skills was triggered.

The exploratory study purposefully delved into a limited number of participants' perspectives to clarify certain specific concepts rather than examining a random population sample. This study generates a plausible understanding of the case through in-depth interviews and observation of knowledgeable participants. However, future researchers are encouraged to formulate hypotheses and test them in explanatory settings to explain why a particular phenomenon occurs, or they must predict future occurrences.

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