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FOSTERING COMPUTATIONAL THINKING PRACTICES OF HIGH SCHOOL LEARNERS THROUGH CODING AND ROBOTICS WORKSHOP

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Abstract

This study reports on high school learners' experiences in a coding and robotics workshop and how participation in the activities enhanced their computational thinking practices. Guided by the constructivist and social cognitive theory, an embedded mixed-method research design was utilized. Data was generated from lesson observations, field notes, and focus group discussions conducted. Participants were twenty-one Grade 10 and 11 female science learners from a rural community in a Northeastern province of South Africa. The qualitative responses were interpreted and analyzed using content analysis, and quantitative responses were analyzed using descriptive statistics. It was observed that learners developed a foundational understanding of robotic components such as input, processor, and output. This understanding helped foster their knowledge of abstraction, which is a key aspect of computational thinking. Additionally, learners acknowledged how working together enhanced their ability to break down the problem they were given collectively. They were also able to create a series of repetitive actions that helped in developing a logical sequence of instructions, which guided them in programming the problem. However, some learners expressed frustration with the engagement levels of their group members, which hindered their learning experience. Learners also expressed concern about the limited resources available in their schools, which can restrict the types of activities and learning experiences they can engage in, especially when teachers lack the necessary knowledge and expertise to embed coding and robotics activities into foundational subjects like physical sciences. The study recommends providing comprehensive training for educators in both robotics and effective teaching strategies. This training should equip educators with the skills to facilitate teamwork, pay attention to details, and promote active engagement among all participants.

Keywords: *Coding, computational thinking, female students, robotics, science education.*

1. Introduction

Computational thinking (CT) is a vital 21st-century educational skill, emphasizing algorithmic thinking and design applicable across subjects (Günbatar & Bakırcı, 2019). CT is a problem-solving method for computer execution and automation (Barr & Stephenson, 2011). It involves breaking down problems, identifying key concepts and patterns for efficient solution planning (Yadav et al., 2016). Developing CT skills, especially in STEM (Günbatar & Bakırcı, 2019), enhances problem-solving, creativity, adaptability, learning, and understanding. Schools globally integrate CT via unplugged and plugged activities (Angeli 2022; Umutlu, 2022), benefiting both students and teachers.

Like other countries, South Africa has recently introduced coding and robotics as an additional subject in the Grade R to 9 curriculum. The introduction of coding and robotics as a subject in the South African curriculum is essential for functioning effectively in a digital and information-driven society; it facilitates the application of digital ICT competencies and the transference of these competencies to address everyday challenges in the development of learners. Coding and robotics as a subject encompasses the various interconnected domains of Information Technology and Engineering, focusing on solving problems through the application of logical reasoning and computational thinking processes (DBE, 2024). Teaching and learning coding and robotics can also enhance learners' conceptual understanding of mathematics or physics. Despite the introduction of coding and robotics as a stand-alone subject in the South African curriculum, many schools across the country still lack the technological infrastructure and teacher expertise to effectively teach the subject (Tshidi & Dewa, 2024). These challenges could result in students not being able to engage with the subject practically, hindering their development of technical competencies like programming and computational thinking, which could significantly impact their ability to thrive in a technology-driven environment (Storte et al., 2019). One way to address this challenge is through the continuous support provided by various higher education institutions and organizations. They equip learners and teachers across the country with the necessary skills by offering coding and robotics workshops. These workshops are considered effective in raising awareness and technology literacy among teachers and learners. Furthermore, they provide valuable hands-on experience and exposure to coding concepts while fostering the development of crucial computational thinking skills. Against this backdrop, this study is guided by the following research questions:

- How does participation in a coding and robotics workshop enhance the learners' computational thinking skills?
- What are high school learners' overall experiences in a coding and robotics workshop?

2. Theoretical framework

The constructivist learning theory and social cognitive theory are the underlying theoretical basis underpinning this study. The constructivist learning theory highlights that learners build knowledge through their experiences and reflections. This theory is often linked to methods like task-based learning, collaborative activities, and group projects, where learners engage in problem-solving and learn through teamwork and sharing ideas (Petraki & Herath, 2022). In the context of coding and robotics, this approach promotes understanding through active and iterative learning that allows learners to design algorithms, build models (solutions) to tackle challenges and apply their understanding to the science context.

The social cognitive theory introduced by Bandura (1986) examines how individuals develop or acquire new skills and behaviours. According to Bandura, people learn through personal experiences, by observing the actions of others, and through social support that fosters expectations, self-efficacy, and various reinforcements to facilitate behaviour change. In the context of coding and robotics, learners build their own models by observing and adhering to the facilitator's instructions as well as working together with other learners in groups, which allows them to explore and discover computational thinking concepts in a practical way. Learners will have to believe in their ability to plan, design, test and refine their algorithms or models.

3. Methodology

This research explored how secondary school learners enhanced their computational thinking abilities through a coding and robotics workshop. By employing an interpretive approach, the study utilized an embedded mixed-method research design in which qualitative and quantitative data are applied together (Behmanesh et al., 2022). This design effectively integrated a primary qualitative dataset with a secondary quantitative dataset, with both types of data gathered concurrently during the workshop. The study followed a cohort of 21 female secondary school students from a rural community in a Northern South African province. Participants were purposefully selected and willingly participated in the study. The Robotics Activity Attitudes Scale (RAAS) instrument (Cross et al., 2016) was adopted as the questionnaire used in this study and consisted of 41 closed-ended questions.

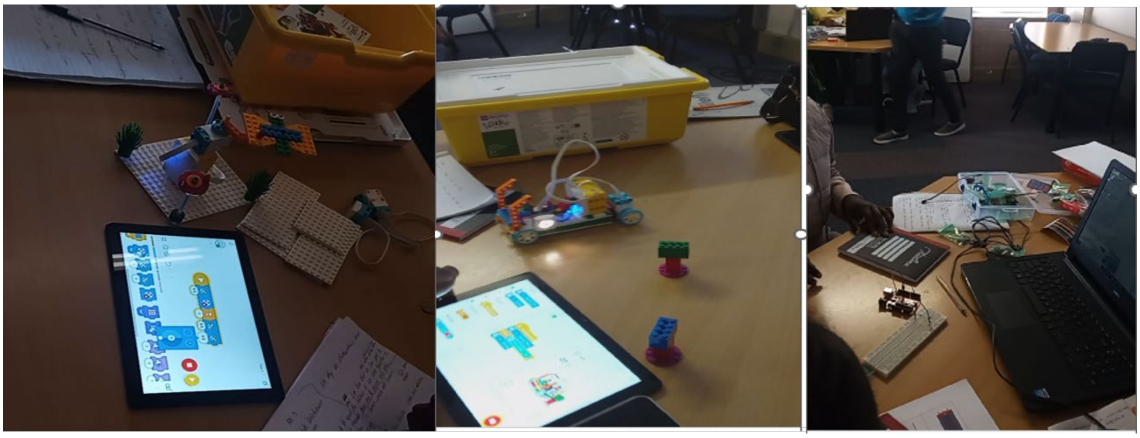
3.1. Context and participants

This study included twenty-two grade 10 and 11 female learners from a rural community in the Northernmost province of South Africa. The learners engaged in a one-week coding and robotics workshop hosted in collaboration with the Technolab unit at the University of Johannesburg. The workshop was aimed at building solid fundamentals that will help learners develop basic programming skills and other essential 21st-century skills. The one-week workshop integrated hands-on robotics and electronics projects with the development of computational thinking skills. Learners actively applied these skills by building robots using platforms like WeDo 2.0 and SPIKE Essential. One example was a project where students explored plant-pollinator interactions. They were tasked with creating and programming robot models of bees and flowers to simulate this relationship, culminating in presentations and documentation of their diverse creations. Project 2 required learners to think like engineers by designing, programming, and testing race cars. They explored the impact of various factors on speed and integrated sensors to gather data and further refine their designs for maximum velocity. The project explored during the workshop involved two core activities: (1) building a simple blinking LED circuit using an Arduino board and (2) developing a project utilizing an ultrasonic sensor with the Arduino platform. Towards the end of the workshop, learners engaged in a group activity that did not require any technology. In this unplugged activity, one member of each group was blindfolded. The other group members then provided verbal instructions to guide the blindfolded member through an obstacle course. This activity aimed to reinforce learners' understanding of fundamental programming concepts, such as providing clear and concise instructions and debugging errors (when the instructions were unclear or inaccurate). The average age of learners who participated in this study was 16 years, with the youngest being 15 years and the oldest being 19 years

3.2. Data collection and analysis

Data was collected based on learners' work, participation in discussions, and self-reported survey responses. Students' problem-solving processes and computational thinking skills were analyzed through video recordings of their work on coding projects. Additionally, an observational schedule was employed to document students' interactions, behaviours, and problem-solving strategies during the workshop. Learners worked collaboratively in teams. All facilitators and learners were informed of the voluntary nature of their participation in the study and their right to withdraw at any time. Informed consent was obtained, ensuring that all participants agreed to participate in the research. For this paper, data was only analysed qualitatively using content analysis. The analysis was conducted with Atlas.ti, a qualitative data analysis software program. A pictorial representation of learners' activities is shown in Figure 1.

Figure 1. Sample of learners' activities during the workshop.



(a) (b) (c)

4. Findings

4.1. Learners' computational thinking outcomes from a coding and robotics workshop

The focus group discussions revealed that the coding and robotics workshop positively impacted learners' computational thinking abilities, particularly in problem-solving. Participants learned to approach problems creatively, explore multiple solutions, and understand that there isn't just one correct method. This fostered flexible thinking and encouraged them to consider various strategies, as exemplified by a participant's quote about "many ways of doing something" and the facilitator's instruction to visualize solutions.

Analysis of participants' responses and observation of activities also revealed that participating in the workshop also exposed learners to opportunities for engaging in decomposition and paying attention to detail. For instance, learners were observed practicing how to break down the given tasks into smaller, manageable parts (decomposition), which is crucial in computational thinking. Participant H mentioned:

> “When building the motor robot, we had to do a lot of calculations during the design specification stage by breaking down possible angles from which the robot might move. Another thing was that it was not easy to identify the components needed to build the robot. So my group had to do a lot of dissecting of ideas to understand how to go about the design”.

This ability to carefully examine problems in bits allows learners to tackle challenges systematically. One significant skill that appears to be mentioned by almost all the participants during the reflection of their learning was the ability to pay attention to details. For instance, one of the learners mentioned, " I have learned that I have to pay attention to each and every detail to avoid big mistakes. I have learnt to think out of the box. I have learnt programming where I give instructions to a robot, and that will help in future when I give instruction at my workplace” – participant K. This statement was also emphasized by Participant A when she said that participating in the workshop has helped her learn how to follow instructions and pay attention. The workshop activities emphasized the importance of paying attention to details, especially in coding and robotics. This focus on detail is essential for debugging and ensuring that instructions are followed correctly, which is vital in programming. Based on learners' response to paying attention to details, the facilitator also emphasized the importance of these skills on learners' academics. This was observed when he said: "When answering questions in class, particularly in subjects like mathematics and physical sciences, it is crucial to pay close attention to the details provided within the question. Word problems often require careful analysis to identify the key elements and relevant information needed to solve the problem effectively. This is a critical skill that needs to be developed to successfully tackle challenging questions". Another learner reflected on the process of learning how to think systematically and logically, emphasizing planning, precision, and understanding the problem's requirements before attempting a solution.

> During the unplugged activity, we were asked to program our partner as a robot. I had to try as much as possible to read the instructions on where I wanted my robot to go and how it would get there. So, I had to clearly select where I wanted the robot to go so that I would not build the wrong robot; if not, the robot would respond wrong. I think this has to do with my ability to understand the specifications of what I want before programming the robot so that the robot will respond correctly (Learner G).

This response demonstrates learner G's growing awareness of computational thinking principles in relation to algorithm design, where the focus is on identifying the key details needed to focus on solving the problem without unnecessary distractions (abstraction) and devising clear, logical steps to achieve a specific goal. Findings of the study also showed that the workshop fostered collaboration among learners, which is important for developing computational thinking. They learned to communicate their ideas and solutions effectively, as observed during the discussions about their projects and problem-solving approaches. Most of the learners also noted this during their reflection. One participant noted the importance of teamwork, saying, "Teamwork, respecting others and working well with others

4.2. Learners' experiences in the coding and robotics workshop

Learner feedback on the coding and robotics workshop was largely positive, highlighting appreciation for its importance, high engagement with hands-on activities, and understanding of fundamental concepts like input-processing-output and the need for precision in coding and building. Participants connected robotics to real-world applications and saw its relevance to academics and future careers. However, some learners expressed frustration with group member engagement and concerns about limited school resources and teacher expertise in integrating coding and robotics into other subjects.

Figure 2. Learners experiences in the coding and robotics workshop.

> By specifications (design patterns), when we were asked to build the robot used in explaining the concept of pollination, I first had to understand what pollination is, spec under which conditions the robot is going to work, identify the type of plant to be used and understand the size of pollen grains that the robot will pick for the crossbreeding process. Based on all the basic understanding, we were now able to identify the components needed in building our robot for the pollination activity.

> One thing I think I have gained is how robots can be constructed and a better understanding of how they work. I also learnt how to follow instructions when making things and paying attention to details, especially when building the robot

> If there is anything I have learnt again in this one-week workshop, that is to be more patient when doing some activity.

> I learnt about the input, processor and output functionality in operating a robot system. I also learnt a lot about teamwork, respecting others, working well with others and during the block-based coding, I learnt how to give instructions. I think there were also a lot of new terminologies that I did not know, but participating in this workshop has broadened my vocabulary list. Terms like micro-controllers (the brain of the robot).

> I think one thing I appreciate is that the robotics activities make science easier to visualize, create opportunities to engage in more practical activities using technology-related materials, and make it easy for us to understand certain difficulties even in mathematics (cartesian planes using the X and Y axis). Learning was fun and interesting.

> One thing I think I have gained is how robots can be constructed and a better understanding of how they work. I also learnt how to follow instructions when making things and paying attention to details, especially when building the robot

5. Discussion, recommendations and conclusion

The results of the study reveal that the coding and robotics workshop provided a dynamic platform for high school learners to enhance their computational thinking skills. This agrees with existing research that demonstrates that hands-on activities effectively engage participants in problem-solving, decomposition of tasks, debugging, and logical reasoning, which are essential components of computational thinking (Yilmaz Ince & Koc, 2021). This current study also aligns with the perspectives of Mathebula et al. (2024) who assert that the structure of coding and robotics activities encourage learners to think creatively and explore multiple solutions to problems, fostering a mindset that values flexibility and innovation. Additionally, the emphasis on attention to detail and effective communication highlighted the importance of collaboration in the learning process. As learners navigated the complexities of coding and robotics activities, they not only developed technical skills but also critical thinking abilities that are applicable across various academic disciplines. Participation in collaborative coding activities reinforced algorithmic thinking, enabling learners to approach problem-solving in a structured and logical way.

In conclusion, the coding and robotics workshop significantly contributed to the enhancement of learners' computational thinking skills. By engaging in practical, collaborative tasks, students were able to develop essential skills such as problem-solving, decomposition, and logical reasoning. This experience not only provided them with valuable technical skills but also fostered the development of crucial 21st-century skills necessary for success in a complex and technology-driven world. Based on the findings of this study, it is recommended that educators should receive ongoing training in coding and robotics to effectively facilitate workshops and incorporate these skills into their teaching practices. Furthermore, schools need to offer more workshops and extracurricular activities focused on coding and robotics to provide students with additional opportunities to develop their computational thinking skills. More importantly, future workshops should continue to emphasize teamwork and collaboration, as these skills are vital for success in both academic and professional environments.

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