A study exploring the use of LEGO® and Scratch to engage middle school students in programming*

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Abstract

This study presents a one-day outreach workshop designed for middle school students, where the focus was on teaching block-based programming using Scratch alongside LEGO® Education SPIKE™ kits. Using the inherent appeal of LEGO® construction, the workshop aimed to make programming fun and exciting through a hands-on project: building and programming a motorized LEGO® car. A key component of the session involved having students articulate, in their own words, how the car should move in a square—for example, describing that "the car moves 15 cm in the north direction, then makes a 90-degree turn to the east, followed by another 15 cm movement, a 90-degree turn to the south, and finally moves 15 cm before a 90-degree turn to the west." This verbal algorithm was then collaboratively translated into Scratch code that controlled sensor inputs, motor outputs, and sound effects. The experience provided valuable observations on the strengths and challenges of short-duration programming workshops and laid the foundation for future, more extensive outreach initiatives.

1 Introduction

Introducing programming to young learners is most effective when the learning process is engaging and relatable [6]. Middle school students in particular, benefit from methods that combine hands-on activities with abstract thinking. Understanding that LEGO® captivates many students, this study's workshop was designed around this familiar and enjoyable medium. The session started with students describing, in plain language, how a LEGO® car should move in a square. In the workshop, a group of six students initially reached a consensus on a rough description of the car's movement. One student demonstrated the motion visually by holding the car and using hand gestures to show how it would move straight, then turn, then move straight again, and continue in this pattern until it returned to its starting point. To further clarify the motion, the car's movement was traced on a piece of paper marked with the cardinal directions, offering students a concrete visual reference. Building on this demonstration, the group refined their description to a more precise set of instructions: "move 15 cm in the north direction, then make a 90-degree turn to the east, followed by another 15 cm movement, a 90-degree turn to the south, and finally move 15 cm before making a 90-degree turn to the west."

This natural language description served as a foundation for developing algorithmic thinking. Students collaborated to translate their verbal instructions into Scratch code, enabling them to control the car's motors and sensors. They also incorporated sound effects to enhance the overall experience and engagement. The workshop, held over a three-hour session at California State University, Chico, successfully combined LEGO® construction with computational thinking, demonstrating that programming concepts can be introduced in a fun, interactive, and collaborative environment.

2 Literature Review

Research on programming education for middle school students has explored various approaches, including LEGO®-based robotics, Scratch programming, and tangible computing tools. De Lira [2] found that project-based programming camps improve computational thinking, while [11] demonstrated how integrating Scratch with physical computing improved engagement. Paparo [12] analyzed how middle school students engaged in advanced Scratch concepts, such as variables and procedures, through structured challenges.

Jormanainen [5] highlighted the motivational impact of educational robotics. Their large-scale empirical study (n=1440) showed that students at the age of 9-10 years (Grades 3-4) are significantly more motivated towards such a learning tool than the students of age 11-12 years (Grades 5-6). Furthermore, they proved that young girls in particular find robotic programming motivating and they are eager to learn more. This indicates that appealing tools play a key role when teaching programming concepts to young school children. Sung [14] introduced Concrete Computational Concepts Programming Environments (3CPEs), using metaphors to simplify computational concepts. Their findings indicate that 3CPEs have the potential to offer elementary students a suitable environment to learn computational concepts. This is accomplished by offering a low entry point, making it easy for students to begin, while also providing a high ceiling that encourages them to take on progressively more challenging projects.

Waldhor [15] developed BrickMusicTable, a LEGO® based music sequencer for creative coding. Their resulting musical instrument is a sequencer that produces sound based on visually tracked bricks placed on a LEGO® ground plate. The prototype recognizes different sizes and colors of bricks and their position on the sequencer as notes. This proved to be an exceptional motivator in student attention to detail and learning. Lott [10] explored LEGO® as a hands-on learning tool, leading to a LEGO® based creative learning space at Rutgers University. Lott's goal was to create an affordable, compact, and easy-to-install space within the Rutgers library that would engage students. The initiative was influenced by the research by Lotts on LEGO®, which showed that hands-on, mind-on learning leads to deeper and more meaningful engagement with concepts and their possibilities. Lotts also believed that active learning workshops could help individuals discover how hands-on experiences, community building, and play can positively impact their organizations.

Korei [8] demonstrated how LEGO® robots promote STEM engagement and interdisciplinary learning. Their findings emphasized how robotic activities in education spark interest in STEM and motivate students to engage with technology. They concluded that Robotics in Education (RiE) serves as a valuable tool to involve students in scientific and technological creativity while creating the development of technological knowledge. Beyond technical skills, RiE also promotes soft skills such as communication and teamwork. Within RiE, educational robotics focuses on improving learning experiences by creating, implementing, refining, and validating pedagogical activities, tools, and technologies in which robots play an integral role. Kolne [7] studied LEGO® robotics for children with disabilities, showing its role in STEM learning, therapy goals, and the development of social skills. The study focused on the activity settings of the HB FIRST® Robotics program; a group-based initiative tailored to meet the needs of children with disabilities. The program aimed to provide opportunities for participants to develop STEM skills while simultaneously working on therapy goals, creating self-confidence, independence, communication, and teamwork, all within a play-centered environment. In general, [7] found that the robotics program facilitated extensive interaction between children and adults, as well as meaningful social engagement with peers in all activity settings. These observations aligned with the program's objective of integrating the teaching of STEM and robotics principles into a social environment that nurtured critical thinking, problem-solving, and teamwork skills.

Likewise, [3] introduced LEGO® Kintsugi, a teaching method that combines LEGO® robotics with emotional intelligence, promoting resilience and creativity. In their study, they explored the impact of the LEGO® Education SPIKE™ environment on children with autism and disabilities. Their results showed that using LEGO® Education SPIKE™ Prime and its structured lesson plans significantly improved students' digital skills, particularly benefiting those with special educational needs. The LEGO® Kintsugi methodology integrates LEGO® robotics with the Japanese art of Kintsugi, emphasizing resilience and the beauty of imperfection in the learning process. By encouraging students to reflect on and rework their robotic creations, the approach positively impacted the development of life skills, especially in managing and coping with emotions. [3] concluded that LEGO® Kintsugi could serve as an innovative teaching method for STEAM disciplines—Science, Technology, Engineering, Art, and Mathematics—which emphasize interdisciplinary learning through creativity, problem-solving, and critical thinking. This approach blends emotional intelligence with technical skills, supporting students in developing competencies relevant to fields such as artificial intelligence.

Korkmaz [9] assessed educational robots' technological integration, identifying LEGO® kits as highly adaptable and user-friendly. Danahy [1] reviewed how universities have integrated LEGO® robotics into engineering curricula, demonstrating its effectiveness in teaching sensor accuracy, motor control, and rapid prototyping. Specifically, [1] highlighted Tufts University, The University of Nevada, Reno, the Arizona State University Polytechnic Campus and The University of Notre Dame which have incorporated LEGO® products into their curricula for over 15 years. The researchers noted the enthusiasm with which students engaged in complex robotics challenges early in their engineering education. They emphasized that LEGO® Mindstorms products enable engineers and nonengineers to explore critical concepts such as sensor accuracy, motor latency, response times, and task prioritization without requiring extensive knowledge of circuit design, assembly-level programming, or artificial intelligence. In addition, these tools provide students with accessible opportunities to investigate product design and prototyping.

Shang [13] found that STEM robotics camps significantly enhanced computational thinking and self-efficacy among rural students. The study also revealed gender differences in participation: girls tended to favor creative activities, while boys preferred structured and competitive tasks. Although boys and girls exhibited similar self-ratings for their ability to learn and their expectations of success in mathematics, girls who participated in the camp expressed a strong interest in pursuing future careers in STEM fields. Francis [4] showed that programming robots to navigate polygons reinforced geometric concepts, incorporating measurement, proportional reasoning, and hands-on role play to strengthen understanding. Notably, [4] creatively engaged students by having them act out and identify the steps needed before beginning programming on the computer.

In contrast to previous work, our study differs in several significant ways. First, it focuses on a short, one-day workshop rather than multi-week programs. Second, it uniquely integrates LEGO® construction and Scratch coding in a single session, bridging physical computing with block-based programming. Unlike [5], who studied long-term robotics education, this approach prioritizes immediate engagement through an interactive LEGO® car project. Although [14] used predefined metaphors, this study relies on student-generated verbal instructions to develop algorithmic thinking before coding. Waldhor [15] explored LEGO® for music-based programming, whereas this research emphasizes robotic movement, sensor integration, and engineering concepts. Inspired by [10], this study highlights the role of LEGO® in promoting creativity and active learning. Unlike [8], who used robotics for mathematical visualization, this approach focuses on real-world movement and problem solving.

Kolne [7] emphasized social engagement and therapy goals, while this study focuses on computational thinking and algorithmic problem solving. Filippone [3] linked LEGO® robotics to emotional intelligence and resilience building, whereas this work emphasizes STEM learning through interactive programming activities. While [9] assessed the suitability of robots for preschool learners, this study explores how LEGO® and Scratch can introduce computational thinking into middle school education. Unlike [1], which investigated the role of LEGO® in university engineering programs, this research focuses on initial STEM education. Shang [13] examined gender differences in robotic STEM camps, while this study emphasizes cooperative, practical problem-solving independent of gender. Finally, while [4] focused on polygon navigation and geometric learning, in contrast, this study highlights algorithmic problem solving through real-world robotics applications.

Future work will expand the workshop to five days, incorporate pre- and post-assessments with statistical analysis, and refine the curriculum to enhance student learning. By integrating hands-on building, computational thinking, and collaborative problem solving, our study provides a novel perspective on how short-term workshops can effectively introduce programming to middle school students.

3 Day of Workshop

During the workshop, a single LEGO® Education SPIKE™ kit was shared among six students. The instructor closely monitored their progress and facilitated the turn-taking as they collaboratively built the LEGO® car equipped with sensors. The initial assembly phase was straightforward as the students were already familiar with reading the instruction manual and following step-by-step instructions. However, occasional guidance was provided to explain unfamiliar components. For instance, when the students connected the wire to the LEGO® motor, the instructor paused to demonstrate its functionality by assembling a simple piece of code. This demonstration helped the students recognize that certain LEGO® components were not merely static but could perform various actions based on programmed instructions. Through this hands-on learning experience, they began to grasp the fundamental concept that connecting wheels to the motor enabled movement. When the motor was activated, it set the wheels in motion, ultimately propelling the car forward.

Following construction, the instructor led an interactive activity to further explore the concept of movement. By manually pushing the car across a sheet of paper, a pen traced its path. The paper had been premarked with the cardinal directions: north, south, east, and west to facilitate the exercise. As the car moved, students were encouraged to describe its motion in their own words, providing directions such as moving a certain distance north, turning 90 degrees east, and continuing with additional movements and turns. This exercise served as the foundation for the next phase of the workshop. Although most of the students had limited prior exposure to programming, they engaged in trial and error, experimenting with various programming constructs in Scratch. Through collaborative problem solving, they successfully matched the appropriate constructs to their verbal instructions. Ultimately, the group developed a program that directed the car's movement as described, effectively transforming everyday language into a functional piece of code. Figure 1 presents the SCRATCH code that was developed collaboratively with the students during the workshop, while Figure 2 shows the LEGO® car they built.

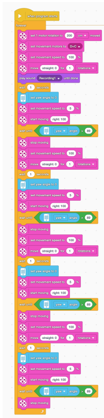

Figure 1: SCRATCH code developed in the workshop to make the LEGO® car move in a square shape.

Figure 2: Actual LEGO® car built in the workshop using LEGO® Education SPIKE™ Kit.

4 Lessons Learned

One key observation from the workshop was that using LEGO® as the primary medium provided significant motivation. The students were excited about the opportunity to build a tangible object that they could relate to, which made the subsequent introduction of programming concepts feel natural and engaging. Another highlight was the development of algorithmic thinking. By asking students to describe the movement of a car in a square using everyday language, for example "moving 15 cm north, then making a 90-degree turn to the east, etc.", the workshop provided a concrete basis for translating these ideas into Scratch code. This exercise underscored the value of starting with natural language descriptions to bridge the gap between real-world instructions and computational logic.

Through a collaborative process to encode the motion of the car, the students shared and experimented with different features of Scratch programming to make the car move. By choosing suitable Scratch programming constructs that reflected their verbal directives, they not only improved their coding abilities, but also promoted teamwork and critical thinking. In addition, incorporating the audio feature of the LEGO® Education SPIKE™ kit, having students record and play back sound effects during specific movements, added an element of fun and creativity to the workshop, further deepening their participation.

Despite these successes, the three-hour session presented some challenges.

Sharing one computer among several students occasionally limited individual participation, particularly for those who were less assertive. This experience has important implications for the design of future workshops, suggesting that adjustments in equipment allocation and session structure might be necessary to ensure that every student has ample hands-on time.

5 Future Work

Building on this experience, several enhancements are envisioned for future iterations of the workshop. Instead of a single-day session, a five-day workshop and each day allocating three hours to the workshop are planned to allow for a more gradual introduction of concepts, with each day dedicated to constructing and programming a new LEGO® artifact that increases in complexity. Furthermore, investing in more LEGO® Education SPIKE™ kits will reduce the student-to-kit ratio, ensuring that each participant enjoys ample hands-on time, a change that will particularly benefit shy or less vocal students by allowing them to engage more fully with the project. Future sessions will also incorporate pre- and post-workshop surveys to collect quantitative data on students' programming knowledge and interest in computer science (CS). The data collected will be analyzed using statistical tests, such as a Welch test, to objectively assess the impact of the workshop. Finally, the curriculum will be refined iteratively based on ongoing feedback and observations, with potential integration of additional multimedia elements and more challenging programming tasks to further enhance student engagement and learning outcomes.

6 Conclusion

This one-day outreach workshop demonstrated that integrating LEGO® construction with block-based programming can serve as an effective and engaging introduction to CS for middle school students. By first inviting students to describe, in their own words, how a LEGO® car should move in a square, the session successfully bridged the gap between natural language and algorithmic thinking. The subsequent translation of these descriptions into Scratch code, complete with sensor inputs, motor outputs, and sound effects, provided a memorable and tangible demonstration of how programming works. Although time constraints and equipment sharing presented challenges, the experience offers valuable insights that will inform future more extensive iterations of the workshop. With extended duration, improved access to equipment, and a focus on empirical assessment, future sessions have the potential to further enhance student engagement and create a sustained interest in CS.

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References

[1] Ethan Danahy et al. "Lego-based robotics in higher education: 15 years of student creativity". In: *International Journal of Advanced Robotic Systems* 11.2 (2014), p. 27.

[2] Carla De Lira, Rachel Wong, and Olusola Adesope. "A systematic review on the effectiveness of programming camps on middle school students' programming knowledge and attitudes of computing". In: *Journal of Computing Sciences in Colleges* 38.1 (2022), pp. 89–98.

[3] Alfonso Filippone and Antonio Bevilacqua. "Lego-Kintsugi: a new teaching and educational methodology to enhance life skills and digital life skills, create well-being and educate happiness". In: *Italian journal of health education, sport and inclusive didactics* 8.3 (2024).

[4] Krista Francis and Michael Poscente. "Building number sense with Lego® robots". In: *Teaching children mathematics* 23.5 (2016), pp. 310–312.

[5] Ilkka Jormanainen and Markku Tukiainen. "Attractive educational robotics motivates younger students to learn programming and computational thinking". In: *Eighth International Conference on Technological Ecosystems for Enhancing Multiculturality.* 2020, pp. 54–60.

[6] Tanja Karp et al. "Generation NXT: Building young engineers with LEGOs". In: *IEEE Transactions on Education* 53.1 (2009), pp. 80–87.

[7] Kendall Kolne, Sunny Bui, and Sally Lindsay. "Assessing the environmental quality of an adapted, play-based LEGO® robotics program to achieve optimal outcomes for children with disabilities". In: *Disability and rehabilitation* 43.25 (2021), pp. 3613–3622.

[8] Attila Körei, Szilvia Szilágyi, and Ingrida Vaičiulytė. "An Educational Robotics Approach to Drawing and Studying Central Trochoids at the University Level". In: *Sustainability* 16.22 (2024), p. 9684.

[9] Özgen Korkmaz et al. "PEDAGOGICAL CLASSIFICATION OF EDUCATIONAL ROBOTS IN PRE SCHOOL TEACHING". In: *International Online Journal of Primary Education* (2023).

[10] Megan Lott. "Playing with LEGO®, Learning about the Library, and "Making" Campus Connections: The Rutgers University Art Library Lego Playing Station, Part One". In: *Journal of Library Administration* 56.4 (2016), pp. 359–380.

[11] Callan J Noak et al. "Introducing Programming to Middle School Students to Increase Knowledge and Interest in Computer Science". In: *Proceedings of the 53rd ACM Technical Symposium on Computer Science Education V. 2*. 2022, pp. 1098–1098.

[12] Giulia Paparo, Marco Hartmann, and Mareen Grillenberger. "A Scratch Challenge: Middle School Students Working with Variables, Lists and Procedures". In: *Proceedings of the 21st Koli Calling International Conference on Computing Education Research*. 2021, pp. 1–10.

[13] Xiaojing Shang et al. "Effects of robotics STEM camps on rural elementary students' self-efficacy and computational thinking". In: *Educational technology research and development* 71.3 (2023), pp. 1135–1160.

[14] Ching-Ying Sung et al. "3CPEs: Concrete Computational Concepts Programming Environments for Elementary Computer Science Education". In: *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*. 2024, pp. 1–7.

[15] Merlin Waldhör, Oliver Hödl, and Peter Reichl. "BrickMusicTable: A LEGO brick-based tabletop sequencer". In: *Proceedings of the International Conference on Mobile and Ubiquitous Multimedia*. 2024, pp. 412–418.