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Designing Robotics Activities to Enable Data-Informed Learning in the Metaverse

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Abstract: This paper presents a technology-enhanced learning activity that integrates educational robotics and the metaverse to promote computational thinking, programming, and collaboration while increasing motivation and engagement. Students solve narrative problems from the real world through tasks of increasing complexity that include route constraints, time limits, and customizable scenarios. The design incorporates systematic data collection to analyze students' problem-solving processes and engagement. This data-driven approach supports continuous refinement of instruction and adaptation to meet the diverse needs of students.

Keywords: Technology-enhanced learning, educational robotics, metaverse, computational thinking, problem-based learning.

1. Introduction

Educational robotics offers hands-on experiences that promote computational thinking and connect abstract concepts with practical applications (Kerimbayev et al., 2023). However, meaningful learning requires well-designed activities (Alshammari et al., 2016). Combining robotics with problem-based learning (PBL) enhances critical thinking, collaboration and motivation (Saygili Yildirim & Sahin Izmirli, 2024; Tengler et al., 2021). Narratives and real-life scenarios further increase engagement and contextual relevance (Liang & Hwang, 2024; Tengler et al., 2025).

The integration of robotics into metaverse environments supports personalized, hybrid learning and increases motivation (Verner et al., 2022; Zhang et al., 2025). Tools such as Ozobot have proven effective in promoting computational thinking through interactive storytelling (Tengler et al., 2025). To continuously improve such activities, learning analytics plays a key role by systematically collecting data on coding attempts, task completion and error patterns (Banihashem et al., 2022; Scaradozzi et al., 2020), providing insights into learning behavior and information for evidence-based instructional design.

This paper presents a hybrid learning activity that combines educational robots and a metaverse platform to engage students in narrative problem solving while embedding planned data collection for learning analytics and instructional improvement.

2. Activity "Robot Delivery Mission"

The *Robot Delivery Mission* aims to develop computational thinking, programming and collaboration skills among K-12 students through hands-on activities with physical robots embedded in realistic, problem-oriented scenarios.

The activity is designed for a hybrid *learning environment* combining physical robotics and a metaverse platform, where students program a wheeled robot to navigate a coordinate-labeled grid of objects in physical or simulated environment. A *narrative framework* gamifies the tasks, motivating students as they solve realistic delivery challenges that promote computational thinking, problem solving and logical planning. In line with the computational thinking framework proposed by Lodi & Martini (2021), the activity targets several core elements of computational thinking. Students engage in algorithmic thinking and problem decomposition by planning delivery tasks and breaking them down into programmable steps. Navigating both physical and virtual environments, they practice abstraction by translating real-world movements into symbolic instructions. The virtual space enables modelling, simulation and supports experimentation before execution in the physical environment. Students test and troubleshoot by revising instructions based on the robot's behavior, developing perseverance and reflection as they compare and refine strategies in different environments.

Students interact with the robot using one of three *programming interfaces*, avatar-based, using voice commands to communicate with a virtual avatar supported by natural language processing, block-based, using visual environments such as Blockly, and code-based, using text-based programming languages such as Python. Students work through *challenges* of increasing difficulty, starting with beginner tasks and progressing to more complex tasks so that they can gradually develop skills and problem-solving strategies.

At the beginner level, students program the robot to deliver a package from the post office to one destination, focusing on simple path planning, navigation, and accuracy. At the intermediate level, they navigate from start to post office, then deliver to multiple destinations, practicing multi-step route planning. At the advanced level, students optimize routes with constraints, apply conditional logic, and adapt strategies to deliver parcels through specific checkpoints efficiently, emphasizing precision and strategic planning in problem solving. Depending on the level of education and the desired learning outcomes, the activity can be integrated into formal education through regular lessons as well as into non-formal and informal education through extracurricular activities.

Data collection systematically gathers student interaction, such as challenge difficulty, number of robot movements, completion time, number of failed attempts and code quality, to understand learning processes, identify challenges and refine instructional design. This data captures both final results and the processes behind them, where tracing paths, code iterations, and time reveals students' computational thinking, spatial reasoning, and debugging skills. By analyzing errors, common challenges and problem-solving methods are identified to support evidence-based improvements in physical and virtual environments. In addition to technical data, collaboration and engagement can be assessed through observations, surveys and reflections, providing qualitative feedback that enriches understanding of student experiences and group dynamics. Data from block-based, code-based, and avatar-based applications will be analyzed through automated logging, visual analytics, and learning analytics tools. Interaction logs and code submissions will reveal patterns in behavior, such as errors, time-on-task, and problem-solving paths. This data will be visualized in dashboards to support instructional refinement and personalized learning.

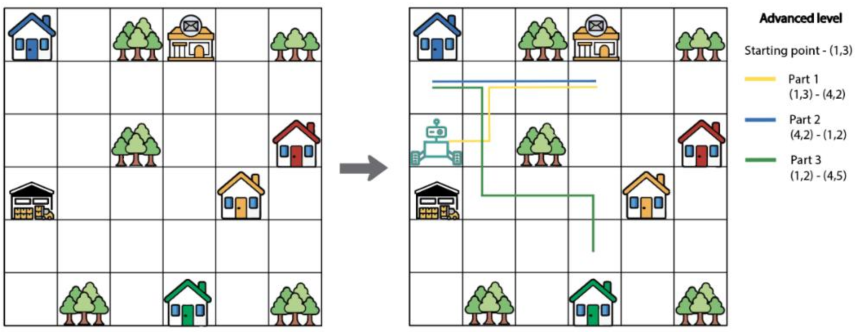

Figure 1. Example of a solution of an advanced activity

Possible extensions to the activity can be used to suit different learning contexts and students' abilities by adding obstacles, time limits and multiple parcels to increase complexity and simulate real-world challenges. Students can work individually or in teams, where teams can challenge each other by creating new rules, promoting creativity and critical thinking.

3. Conclusions and future work

This paper presents the design of the Robot Delivery Mission, which integrates educational robotics and a metaverse environment to support the development of computational thinking, programming, and collaboration skills. The combination of physical robots with a virtual metaverse platform creates a flexible, immersive learning space where students can safely experiment, immerse themselves through playful and interactive scenarios and connect real and virtual experiences. The design incorporates planned data collection to enable learning analytics that can be used to customize instruction and address the diverse needs of learners. The narrative, hands-on format is designed to promote engagement and skill acquisition in hybrid environments. Future work will focus on implementing the activity, collecting and analyzing data, and refining the design. The use of rotating team roles (planner, programmer, tester) is intended to encourage collaboration and skill development while allowing role-specific data analysis to provide deeper insights into individual contributions and team interactions.

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