RE-IMAGINING CLASSROOM TOOLS: MODELING MATHEMATICS IN MICROPROGRAMMING ENVIRONMENTS

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This paper presents an initiative aimed at integrating tailor-made micro-programming environments (MPEs) into middle school mathematics education to foster student learning and enhance computational thinking skills. We examine the effectiveness of MPEs in engaging students in computational thinking, aligning with mathematical practice standards, and usability in promoting interdisciplinary connections between mathematics and computing in the middle school setting. Findings suggest MPEs can advance computational thinking skills and enrich lesson alignment with educational standards. Most participants indicated approval of integrating MPEs into middle school classrooms.

Keywords: Mathematical Representations, Computing and Coding, Computational Thinking

In pedagogy-centered mathematics classrooms, educators encourage students to articulate and demonstrate their mathematical thinking through various representations, including diagrams, graphs, and verbal explanations. Incorporating MPE tools for mathematical modeling can enhance modeling effectiveness while exposing students to computer science. The idea of using programming to help students learn mathematics and science has a long history (Papert, 1980; Mayer, 2004; Hickmott et al., 2018), but few studies (Benton et al., 2017; Calao et al., 2015) explore learning key mathematical ideas through computing (Schanzer et al., 2015; Bråting & Kilhamn, 2021). Programming languages are excellent for externalizing and manipulating thought processes (diSessa, 2001; Schaffer & Kaput, 1998). While paper and pencil modeling or physical manipulatives are typically used to externalize thoughts, programming requires students to use explicit commands for each step in the problem-solving process. This approach can aid students in correcting their thinking and help teachers recognize misconceptions. General-purpose programming languages, or even tools such as spreadsheets, may be too unconfined to be effective for students and require prerequisite knowledge. Our design allows teachers to limit features, tailoring the MPE to the specific purpose of the activity. Through survey analysis, we assess MPEs' ability to engage learners in computational thinking, align with math practice standards, and overall usefulness in the middle school classroom. Findings suggest MPEs advance computational skills, align lessons to standards, garner general approval for classroom integration, and feature intuitive elements requiring minimal learning time, necessitating no expertise from teachers to implement.

Theoretical Framework

This study is grounded in Constructivism, which posits that learners construct their understanding and knowledge through experiences and reflection (Piaget, 1972). Constructivism highlights the importance of learners being active in their learning process, engaging in meaningful tasks (Vygotsky, 1978). The MPE embodies the constructivist approach by providing hands-on, experiential learning in computing. The MPE allows students to visualize and model their step-by-step problem-solving processes, making their understanding and misunderstandings visible. When the program does not perform as intended, students quickly realize mistakes, enabling immediate feedback and correction through debugging, a key aspect of learning in programming (Papert, 1980).

With the intentionality to bridge the gap between computer science and mathematics, the aim of the MPEs in this study is to create a constructivist environment that develops computational thinking and enhances student engagement in the Standards for Mathematical Practice (SMP):

- SMP1 “Make sense of Problems and Persevere in Solving them.”
- SMP2 “Reason Abstractly and Quantitatively.”
- SMP3 “Construct Arguments and Critique the Reasoning of Others,”
- SMP4 “Model with Mathematics.”
- SMP5 “Use appropriate tools strategically.”
- SMP6 “Attend to Precision.”
- SMP7 “Find and make use of structure.”
- SMP8 “Find and make use of repeated reasoning.”

MPE Modeling

Our MPE offers diverse strategies for solving mathematical problems. Consider the example: "A seventh-grade class needs 5 leaves daily to feed 2 caterpillars. How many leaves would the students need daily for 12 caterpillars?" Various mathematical strategies can be represented through operations performed on ratio tables. Teachers can limit available blocks to encourage specific strategies or provide options for students. Figure 1 illustrates four typical strategies, showcasing features of the MPE and its evolution of reasoning from concrete to abstract.

Explicit Copies: Manual Additive reasoning	**Repeat Block:** Automated Repeated Addition	**Avoiding Magic Numbers:** Multiplication by a scale factor, using only starting values	**Abstract Reasoning:** Generalized to calculate with any starting values.
Make a table make column caterpillars with 2 make column leaves with 5 copy row 1 copy row 1 copy row 1 copy row 1 copy row 1 add the last 6 rows together show the table	Make a table make column caterpillars with 2 make column leaves with 5 repeat 5 times do add row 1 to the last row show the table	Make a table make column caterpillars with 2 goal for caterpillars is 12 make column leaves with 5 multiply the last row by 12/2 show the table	Make a table make column caterpillars with 2 goal for caterpillars is 12 make column leaves with 5 divide the last row by caterpillars multiply the last row by goal show the table
row caterpillars leaves 1 2 5 2 2 5 3 2 5 4 2 5 5 2 5 6 2 5 7 12 30	row caterpillars leaves 1 2 5 2 4 10 3 6 15 4 8 20 5 10 25 6 12 30	row caterpillars leaves 1 2 5 2 12 30	row caterpillars leaves 1 2 5 2 1 2.5 3 12 30

Figure 1: MPE block-code is shown above, with the corresponding output table below.

Research Methodology and Design

This study addresses the following research questions:

- RQ1. Do micro-programming environments (MPEs) facilitate and enhance participant engagement in computational thinking skills?
- RQ2. Does integration of MPEs support the alignment with and application of mathematical practice standards in the context of middle school mathematics?
- RQ3. What are the perceptions of pre-service teachers on the usefulness and challenges of integrating MPEs into mathematics education?
- RQ4. Is the MPE tool intuitive enough for participants to make sense of the tool without teacher expertise?

This study employed a mixed-methods research design, combining qualitative and quantitative approaches to explore the effectiveness of integrating micro-programming environments (MPEs) into middle school mathematics education. The qualitative approach allowed for an in-depth understanding of participants' experiences and perceptions regarding the use of MPEs, while quantitative data were collected through surveys to supplement the qualitative findings.

As a preliminary to the in-class implementation detailed in publications to come, this trial was run on college students enrolled in a pre-service teacher program. The participants in this mixed-methods study were eleven pre-service teachers who engaged in a self-guided activity using the MPE. Among the participants, 2 (18%) were males and 9 (82%) were females. In terms of racial demographics, 7 (64%) identified as White, 3 (27%) as Black/African, and 1 (9%) as Asian/Vietnamese. The participants had diverse academic backgrounds, with 8 participants majoring in Biology, and one each studying Math, Physics, and Chemistry.

Data were collected through self-reported surveys administered after the MPE activity. The surveys assessed participants' educational backgrounds, experiences with the MPE tool, perceptions of computational thinking, and the usefulness of the MPE in middle school classrooms. Qualitative data analysis was conducted to identify themes and patterns in participants' responses. Thematic analysis was employed to categorize and interpret qualitative data related to participants' experiences, perceptions, and feedback on the integration of MPEs. Quantitative data from the surveys were analyzed using descriptive statistics to provide additional insights into participants' demographics and perceptions.

Analytical Results

RQ1: Computational Thinking

Survey responses revealed significant insights into participants' perceptions of computational thinking. Participants reported an increase in engagement with computational thinking skills during the MPE activity to 82%, compared to 49% in their previous education experiences. Comments included: “This activity developed my computational thinking skills well because I had to think about what I was doing and it helped me develop skills for computer thinking and problem-solving,” and “It really forced me to think about the meaning behind simple arithmetic.”

RQ2: Alignment to Standards for Mathematical Practice

Participants rated the MPE lessons' alignment with the standards for mathematical practice (SMP) on a scale of 0 (no alignment) to 5 (full alignment). The results showed that participants reported full alignment (5/5) with SMP1 "Make sense of Problems and Persevere in Solving them" and SMP3 "Construct Arguments and Critique the Reasoning of Others." The average alignment rating for the other standards was 4 out of 5, indicating near full alignment. Researchers observed that participants engaged more in discussions and debates when using the MPE (SMP4, SMP5), which required precision commands (SMP6, SMP7), than when modeling their thinking on paper. Quotes from the lesson include: "We can't get there from here," and "Yours is more efficient, but mine more clearly shows my thinking. In this format, the table can be used repeatedly for different numbers of days and different numbers of caterpillars."

RQ3: Usefulness of the MPE

Participants rated the usefulness of the MPE on a scale of 0 to 5. Analysis showed that 73% of participants considered the tool generally useful (rating of 3 or higher) in a middle school setting. Comments included: "I think that tools like this would be useful for introducing coding concepts for use in problem solving," and "For students that struggle to solve stepwise problems, this could be a useful tool to outline their thinking. Middle school is a good age to develop these skills." Thematic analysis revealed that participants appreciated the hands-on and experimental nature of the MPE activity, which made their thought processes visible. Some initially struggled with block coding but found it easier once they understood the process. Comments included: "The restriction of having to show every single step forced us to figure out how to solve every step using the program." Participants who rated the MPE "low" (0-1) reported 80% less PBL in their middle school experiences than those who rated it "high" (4-5), and half as much PBL as those who rated it "moderate" (2-3). This suggests that participants with less exposure to similar challenges in their own education found the tool less suitable for middle school settings, while those with more exposure found the tool more suitable. One participant commented: "I don't think I've done project based learning in my entire K-12 schooling, especially in math."

RQ4: Intuitive Design

Although students initially engaged in a productive struggle, all 11 participants were able to quickly deduce the mechanics of the tool without prior knowledge, teacher guidance, or intervention. One participant commented: "It took a while to model my step-by-step process on the block coding, but once I did, it was easy to see the process visually."

Conclusion

This study underscores the potential of Micro Programming Environments (MPEs) to transform middle school mathematics education by fostering computational thinking and aligning with mathematical practice standards. The integration of MPEs facilitates an active, constructivist learning environment where students can model and visualize their problem-solving processes, receiving immediate feedback and opportunities for correction through debugging. Participants reported significant engagement in computational thinking skills and observed near-full alignment with the Standards for Mathematical Practice.

The findings suggest that MPEs are effective tools for enhancing mathematical modeling and computational thinking skills among middle school students. Most participants indicated a positive reception towards integrating MPEs into classrooms, highlighting the tool's usefulness and ease of adoption without requiring extensive teacher expertise. This study contributes to the growing body of research advocating for the integration of computational tools in education, suggesting that MPEs can enrich the learning experience and bridge the gap between mathematics and computer science.

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