Supporting Elementary Students to Develop Mathematical Models Within Design-Based Integrated Science and Mathematics Projects

Sarah Lilly, University of Virginia, scl9qp@virginia.edu
Sarah J. Fick, University of Virginia, sjf9pn@virginia.edu
Jennifer L. Chiu, University of Virginia, jlc4dz@virginia.edu
Kevin W. McElhaney, Digital Promise, kmcelhaney@digitalpromise.org

Abstract: This study explores how upper elementary students develop mathematical models within an integrated science and engineering unit. We collected and coded student explanations from two fifth-grade classrooms. Results indicate that many students used mathematical reasoning to create mathematical models of science phenomena. However, some students struggled and instead created descriptive models. These findings highlight the role of mathematical concepts and reasoning associated with science processes in supporting mathematical modeling in upper elementary science instruction.

Introduction and background

This paper describes how modeling can be used to integrate science and mathematics in an upper elementary science and engineering unit. Developing models is a central scientific and mathematical practice: research demonstrates benefits of modeling in both science and mathematics (Lesh & Lehrer, 2003; Schwartz et al., 2009). Relatively few studies examine the concurrent development of scientific and mathematical models, especially with elementary students (Suh & Seshaiyer, 2019). We argue that upper elementary students can construct mathematical models of scientific phenomena, developing and using mathematical models to explain and predict aspects of a phenomenon. A modeling approach can be particularly fruitful to help students integrate disciplines as modeling can help students engage in both scientific and mathematical practices as well as synergistically learn science and mathematics concepts (e.g., NRC 2012). We present a case study of fifth-grade students to address the following questions: (1) To what extent can upper elementary students create mathematical models that represent the scientific phenomenon of water runoff? and (2) What challenges do students face when developing mathematical models of scientific phenomena? We focus on the development of mathematical models as a way for students to develop and integrate understanding between science and mathematics at the elementary level.

Methods

The context is within a five-week science and engineering curriculum unit for upper elementary classrooms (Chiu et al., 2019), and analysis focuses on lessons where students created mathematical models of science processes as part of an engineering challenge. In each lesson, students engaged in hands-on activities targeting different aspects of water runoff, including observing the effect of hourly rainfall and duration on total rainfall (Rate-Based), the absorbency of different materials (Ratio), and the total amount of water runoff (Conservation). After each activity, students were given an opportunity to use actual values to calculate the amount of water absorbed and the amount of water runoff in different scenarios. Students used these ideas to develop conceptual models representing relationships among rainfall, absorption, and runoff. They subsequently developed mathematical models of these relationships that informed the development of a computational runoff model used to test and refine their design solutions. The unit was implemented with fifth-grade students (n=53) in two science classrooms team-taught by two teachers with science degrees. The participating school district exhibited socio-economic diversity, with 43% of students belonging to ethnic groups underrepresented in STEM, 44% eligible for free or reduced price lunch, 14% with disabilities, and 14% language learners. The primary data source for the analysis was scientific explanations from synthesis activities. We coded these explanations for the presence of a mathematical model (e.g., "total rainfall - total absorption = water runoff") or a description of scientific processes or system variable relationships (e.g., "when it rains some of the water gets absorbed," or "the more water the more runoff").

Results

Table 1 summarizes the number of students who generated mathematical models for each lesson. For the rate-based lesson, some responses (32%) included a mathematical model ("total rainfall = hourly rainfall x duration"). None of the responses in the ratio lesson had a mathematical model ("total absorption = absorption ratio x total rainfall"). Instead, the most frequent response for the ratio based lesson (60% overall) had qualitative descriptions of surface absorption. For example, one student wrote, "If the water is absorbed then it is going into the surface.

If it isn't then it will be a puddle or evaporate. Permeability of a surface and the amount of rainfall tells us how much is absorbed and how much is on top.” Another wrote, “Some of the surfaces absorb water and leaves a little water on top but some surfaces don’t absorb as much and leave more water behind.” In the conservation lesson, most students (68%) had an appropriate mathematical model (“total rainfall - total absorption = water runoff”).

Table 1. Number of students with mathematical models, descriptions, or other/blank responses by lesson.

Student Response Types	Rate-Based	Ratio	Conservation
Mathematical model	17 (32%)	0 (0%)	36 (68%)
Description of science process or relationship	10 (19%)	32 (60%)	1 (2%)
Other Response or Blank	26 (49%)	21 (40%)	16 (30%)

Discussion and conclusions

Results demonstrate that many fifth-grade students can create mathematical models of science phenomena, while other students experience challenges when trying to participate in this model-based, integrated STEM approach. Students’ level of success also varied with the type of mathematical concepts inherent to the model. Specifically, students had the most success with the additive conservation model, some success with a multiplicative rate-based relationship, and no success expressing a multiplicative relationship with a dimensionless ratio. Despite the lack of formal mathematical models for the ratio lesson, many students created descriptive accounts and reasoned from tables of values, an important precursor to model development (Lesh & Harel, 2003). Our analysis illustrates the need to carefully consider the level of the mathematics concepts undergirding targeted scientific models.

Our study has implications for the design of experiences that integrate science and mathematics through modeling. We found that a small amount of added complexity to the scientific model regarding absorption ratios placed substantial demands on students’ mathematical reasoning. Because this curricular unit was designed to be implemented in science class, the science phenomenon of absorption drove the inclusion of mathematical concepts (e.g., rate and ratio) within the models. While U.S. guidelines for mathematics place these concepts at the middle school level, the elementary unit introduced these concepts because of their alignment with elementary science standards. Thus, as deeper levels of science understanding often invite connections to more complex mathematics, designers should carefully consider what supports are necessary for students to integrate concepts and practices across science and mathematics. Although students were able to complete tables showing discrete values for different amounts of absorption, abstracting these values to a general mathematical relationship was difficult. This observation is not surprising, as concepts of ratios and proportionality were relatively new for students as was applying mathematical concepts to modeling in science generally. Our findings suggest avenues to further investigate what curricular and instructional supports are needed in contextualized, interdisciplinary model-based instruction for elementary students to engage in developing mathematical models as part of science investigation.

References

Chiu, J. L., McElhaney, K., Zhang, N., Biswas, G., Fried, R., Basu, S., & Alozie, N. (2019, April). A Principled Approach to NGSS-Aligned Curriculum Development: A Pilot Study. Paper presented at NARST Annual International Conference, Baltimore, MD.

Lesh, R., & Lehrer, R. (2003). Models and modeling perspectives on the development of students and teachers. *Mathematical thinking and learning*, *5*(2-3), 109-129.

National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13165.

Schwarz, C.V., Reiser, B.J., Davis, E.A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B. & Krajcik, J., (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632-654.

Suh, J. M., & Seshaiyer, P. (2019). Promoting Ambitious Teaching and Learning through Implementing Mathematical Modeling in a PBL Environment: A Case Study. *The Wiley Handbook of Problem-Based Learning*, 529-550.

Acknowledgements

This work was supported by the National Science Foundation under Grant DRL-1742195. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.