Integrating technology for deep mathematics learning

Technology can enable students to visualize challenging mathematical concepts, giving students opportunities for deeper learning, as Jeremy Roschelle, Philip Vahey, Celia Hoyles, and Richard Noss explain

MATHEMATICS EDUCATORS WANT STUDENTS to develop more than the ability to carry out routine procedures and algorithms; they also want their classes to develop deep understanding of the meaning and application of mathematical concepts. For deep understanding, students must see how familiar ideas connect with formal ideas. They must see how the same mathematical idea is represented in different forms: in a graph, in a table, in an algebraic expression, in a story. They must also see how concepts they learned earlier connect with more advanced concepts.

Technology can help to build conceptual understanding through "dynamic representations" – that is, visual models of mathematics concepts. This approach has a strong research basis, with ample evidence of efficacy. But technology is not enough. Some teachers can take the raw technology for dynamic representations, and fashion from them an appropriate sequence of lessons, but most teachers benefit from guidance in using these capabilities to develop student reasoning across a series of lessons.

Cornerstone Mathematics

Researchers in the US and UK have joined together to create Cornerstone Mathematics, supported by the Li Ka Shing Foundation. This program offers mathematics teachers three integrated elements – software resources, instructional workbooks, and professional development – all needed to leverage dynamic representations effectively in the classroom.

Cornerstone Mathematics builds on the research of James Kaput with a prior technology called SimCalc. The SimCalc approach begins with animations of motion, connecting to students' prior understanding of speed. The motion, for example, could be an animated dog running through a forest. A graphed line controls the speed of the dog, and students can change the length and steepness of the line to see the effect on its motion.

Other key representations are also supported (see Figure 1): students tell stories about motion, examine tables with paired numbers representing distance and time, and express motions mathematically as linear functions. The representations – motion, graphs, stories, tables, expressions – can appear on screen at the same time, and they are "dynamic" in the sense of being responsive to changes made by students; a change in the steepness of a line on the graph results in the dog moving faster. Students benefit from progression from familiar to more formal mathematics, and from the connection of visual representations with more linguistic representations.

The program is currently focused on four modules, for the concepts of linear function, geometric similarity, algebraic expression, and ratio. Each module lasts two or three weeks. Teachers are provided with a sequence of lessons, the appropriate dynamic representations, and professional development. The professional development component has been consistently highly evaluated by teachers. It includes the opportunity to think about how to use technology to build mathematical meaning, and how to present and share their findings with colleagues.

What we know

- Students benefit from progression from familiar to more formal mathematics, and from the connection of visual representations with more linguistic representations.
- Technology can help to build conceptual understanding through dynamic representations.
- Integrating software, curricular workbooks, and teacher professional development enables more teachers to use get results with technology than technology alone.

Research results in the US

In the US, the Cornerstone Mathematics team is based at SRI International, a nonprofit research institute, and led by Jeremy Roschelle and Philip Vahey. The SRI team had the opportunity to conduct "gold standard" research with dynamic representations in Texas in 2005-2007, funded by the US National Science Foundation. In this research, 95 teachers across diverse demographic regions of Texas agreed to implement a three-week module for rate and proportionality in place of their normal teaching on that topic. Of these teachers, half were randomly assigned to make the replacement in a first year, while the others continued with their existing approach in the first year and switched in the second year. Students in both sets of classrooms took a test before and after this topic was taught.

Although the teachers had widely varied prior teaching experience, philosophies, and knowledge, 90% of teachers were able to achieve better student learning results with the modules than with their existing materials. Students were not much better on the simpler, more procedural aspects – however, on items that stress mathematical meaning, such as the types of items found on the PISA international test, students who used dynamic representations performed much better. Results were equitable for boys and girls, and the approach was successful both in lower-income and middle-class regions of the state. Students from ethnic minorities (mostly Hispanic in Texas) had strong gains. Although this study is now more than five years old, it still stands as one of the few rigorous experiments with clear results in the field of technology in mathematics education.

Research results in the UK

In England, Richard Noss and Celia Hoyles of the London Knowledge Lab at the Institute of Education, University of London, have adapted Cornerstone Mathematics to the English context. This included aligning it to the National Curriculum, and providing more opportunities for groupwork. Teachers in England are more empowered to develop their own "schemes of work" than their American colleagues, who are more likely to follow a printed textbook. Cornerstone modules fit nicely with the notion of a scheme of work, as modules do not provide a detailed and exacting script, but rather an overall structure and guidance for the teacher, who is expected to elaborate the modules to fit their classes' needs. In England, many teachers took longer to implement Cornerstone than we anticipated, as they adapted the activities for children with particular needs, for example, for those children with English as an Additional Language.

We conducted initial pilot research in England, with 17 teachers in 9 schools, selected so as to include a wide diversity of school contexts, student prior achievement, and school academic strength. There were 429 children in the sample, distributed across different year groups (according to teacher choice): Year 7 (aged 11-12): 179 children (42%); Year 8: 227 children (53%); and Year 9: 23 children (5%). As the modules had been adapted, it was possible that variation could lead to uneven results – the trade-off of greater teacher ownership. Fortunately, we found a pattern of results very similar to those in the US, with 90% of the teachers experiencing student learning gains above those typically found on the post-test.

Next steps: Scaling up and evaluation

Our focus is now on scaling up Cornerstone Mathematics to more schools, while continuing to strengthen the research base. In the US, the research team has proposed a "validation" project that would test Cornerstone Mathematics at scale in more than 50 Florida schools, and would use assessments aligned to the Common Core standards to measure results. This project is currently under review and, if funded, would go beyond prior research by deploying modules with dynamic representations across three years and measuring the impact on broad, standardized assessments. It is anticipated that children could gain, on average, about a half year of additional learning with this approach.

In the UK, the Li Ka Shing Foundation is sponsoring the implementation of Cornerstone in 100 English schools. For this, the dynamic representation software has been rewritten to run on modern, lower-cost tablets and laptops, and all the materials and the software can be accessed on the web.

We are also in the process of designing ways to provide more informative data on student progress to teachers based on formative assessment, and research on the process of adaptation by teachers continues. We are marshaling evidence from online teacher communities and webinars, teacher interviews, and examples of student work. In addition, once 100 schools are reached, the team plans to look for opportunities to conduct a rigorous evaluation of impacts, as well as ways to make the innovation self-sustainable.

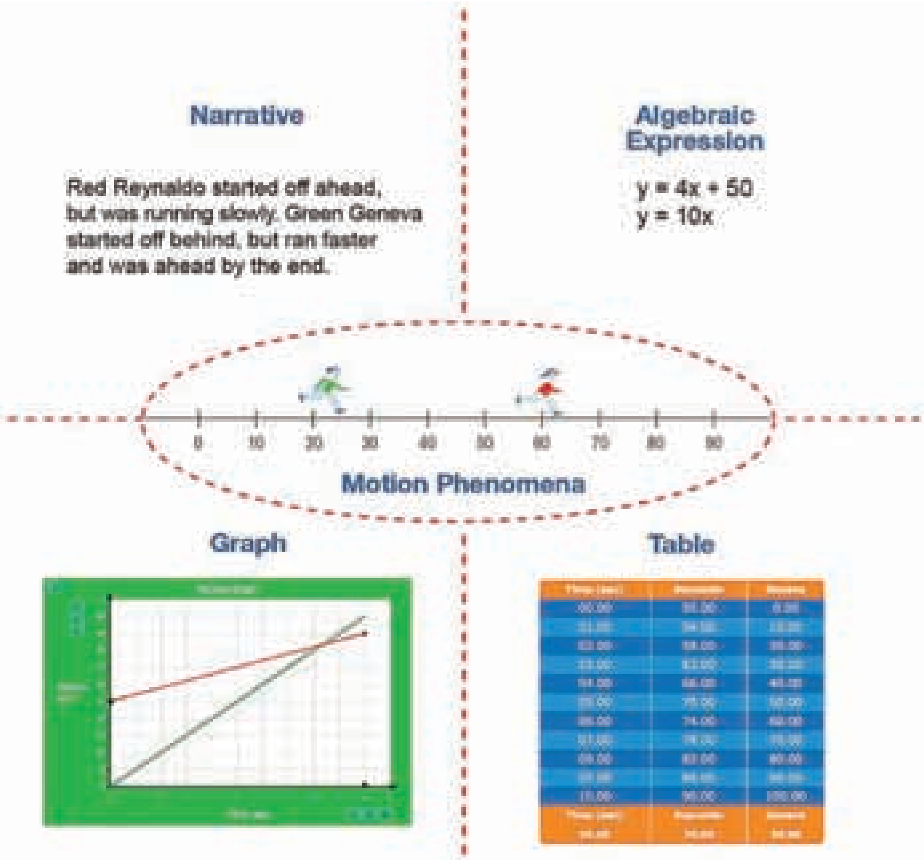

Figure 1: Cornerstone connects animations of motion to narratives, equations, graphs, and tables

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Further reading

Moreno-Armella L, Hegedus SJ, and Kaput JJ (2008), From Static to Dynamic Mathematics: Historical and Representational Perspectives. *Educational Studies in Mathematics*, 68(2), 99–111.

Hoyles C, Noss R, Vahey P, and Roschelle J (2013, in press), Cornerstone Mathematics: Designing Digital Technology for Teacher Adaptation and Scaling, *ZDM* special edition, volume number 7.

Roschelle J, et al. (2010), Integration of Technology, Curriculum, and Professional Development for Advancing Middle School Mathematics. *American Educational Research Journal* 47(4), 833–878.

Roschelle J, and Shechtman N (2013), SimCalc at Scale: Three Studies Examine the Integration of Technology, Curriculum and Professional Development for Advancing Middle School Mathematics. In Roschelle J, and Hegedus S (Eds.), *The SimCalc Vision and Contributions: Democratizing Access to Important Mathematics*. Berlin: Springer, 125–144.