Modeling at the Intersection of Learning and Teaching

The other day, while my six-year-old son Nicholas and I were observing the opposition of Mars in the early night sky, he posed the question, “Dad, why is the moon so much bigger than the stars?” I began trying to explain to him that the farther away something is, the smaller it appears to be. He didn’t quite get it. So back in his room a few minutes later, I demonstrated the idea by asking him to hold up a ruler in front of his eye and measure me as I was standing just a few feet away from him. I then moved back about 10 feet and asked him to “measure” me again. “You shrunk!” he exclaimed. Nicholas was attempting to make sense of the world around him. I was pretty impressed with my demonstration, feeling confident he was getting the idea. But then he said, “So the Sun must be a lot closer to us than the Moon. That’s why it is so hot.” So much for my science lesson at 9 o’clock at night. But in that discussion, my son was demonstrating how we, often intuitively, take a new understanding of a natural phenomenon and apply it to other situations. He was constructing a mental model of the relationship between the distance between our eyes and an object, and the relative size of that object. He then attempted to explain another situation with his new model. While the concept was certainly not mastered, he was learning and progressing towards better understanding. Much like Nicholas, we all make mental models that explain why things behave the way they do. We draw on these internal models to make sense of the world around us. As we apply and subsequently modify these mental models for better fitness to the natural world, we learn and come to understand the natural phenomena around us.

Just as Nicholas, other children and adults often do when attempting to make sense of the world, scientists and applied mathematicians tap into this intuitive process of model construction and deployment in order to promote and support meaningful, deep knowledge construction. This process of building, using, evaluating, and modifying models is a common practice in most, if not all, scientific work. In much the same way, applied mathematicians engage in modeling the real world in order to make accurate predictions of future events through simplifying and mathematizing the phenomenon into a predictive mathematical model that can be tested and modified.

Philosophers of science have now recognized how science has evolved away from being a purely hypothetico-deductive process towards being a theory-building process and, more recently, a model-building process. Model-Based Teaching is an attempt to reframe the process of science and mathematics for students through a models-based discourse. The Next Generation Science Standards (NGSS) and the Common Core State Standards (CCSS) for Math both include a renewed emphasis on the benefits of engaging students in disciplinary practices that approximate the ways scientists and mathematicians engage in their work. Inspired by these calls, teachers are now engaging students in the development and use of scientific models and mathematical models in ways that approximate the work of scientists and applied mathematicians, going well beyond the traditional candy model of a cell in a biology classroom or the long set of word problems in the mathematics classroom.

The rising prominence of scientific and mathematical modeling in both the standards and as a pedagogical strategy has been driven, in large part, by the growing body of research on the characteristics of effective teaching and the cognitive and behavioral aspects of how people learn. Both mathematical modeling and scientific modeling involve an iterative and predictive process of making sense of real world phenomena through the development of descriptive, explanatory, and predictive models that attempt to uncover the underlying and often unseen mechanisms of the natural world. These authentic disciplinary practices that draw on our intuitive curiosity to explain the world around us are now being transformed into powerful pedagogical strategies that are improving student understanding and interest in science and mathematics.

Yet with all of these benefits, modeling is a difficult and ambitious pedagogical practice to successfully enact. For it to be effective, a teacher needs to be well informed about the practices of modeling as it occurs in their discipline, and possess the time and ability to thoughtfully plan a unit of study that draws on and approximates modeling, while not losing the authenticity of the practice. A teacher must also be able to skillfully orchestrate a dynamic classroom environment in which students are empowered to discuss their own ideas (in the form of mental models) and critically examine the ideas of others. All too often, this form of ambitious yet powerful pedagogical practice is very different from how any teacher ever experienced learning in science and math, making its implementation feel uncomfortable. Students and their parents may also feel uncomfortable with this very different approach to teaching and learning. But if we can all recognize the relationship between Model-Based Teaching and our natural mental model building processes, students, teachers and parents can get excited about the deep learning that results from this effective pedagogical practice.

As part of KSTF's goal to develop and support STEM teachers as leaders from the beginning of their careers, the first years of the Teaching Fellows Program focus on building content knowledge needed for teaching (CKT). This includes understanding how practices like posing questions, constructing explanations and using evidence to back up claims play out across different disciplines. In other words, we want our Fellows to think about and experience their disciplines with less distinct boundaries, less separate from other disciplines. Our intention is that this work may help teachers to recognize shared practices, even in the space of non-shared language. Ultimately, we see this as a way to support cross-curricular learning for students but also to support teachers to deepen their own content knowledge and pedagogical content knowledge.

To demonstrate why the sun looks bigger than the moon, I ended up showing Nicholas a 3D digital model of the solar system. As we looked at the model, I could see him wrestling with the ideas of orbits and planets and I was really excited to hear his next question. Was he going to ask about gravity or the phases of the moon? After a second or two he finally asked, "Dad, can I still be a Jedi when I grow up?" At least I have plenty of time. He's only six after all.