Exploring Connections Between Physical and Mathematical Knowledge in Science Museums

By Tracey Wright and Alana Parkes

The designers of the *Math Moves!* exhibits have worked hard to support visitors' qualitative, kinesthetic understanding of the topic of ratio and proportion. How did we, as designers of math exhibits in science museums, attempt to make connections for visitors between embodied understanding of mathematics and more abstract knowledge? How have they come to view what counts as mathematics?

Embodied understanding, or kinesthetic learning, is one of eight types of learning styles defined in Howard Gardner's theory of Multiple Intelligences (Gardner, 2011). Bodily kinesthetic learning styles, or intelligence, refer to a person's ability to process information through hand and body movement, control, and expression. Bodily kinesthetic intelligence entails the potential of using one's whole body or parts of the body to solve problems. It is the ability to use cognitive understanding to coordinate bodily movements, for example, learning to catch a ball. As Rafael Nunez (1999) puts it, "Cognition itself is embodied, and the bodily-grounded nature of cognition provides a foundation for social situatedness, entails a reconceptualization of cognition and mathematics itself, and has important consequences for mathematics education."[1] According to Shelly Weisburg (2006) there is an inclusive role for such a learning style in both formal and informal environments, "Movement as nonverbal communication probes beyond socioeconomic and educational boundaries allowing those who might not be verbal or auditory learners to be integrated into the learning process." Kinesthetic learning invites math/science learners into a new conceptual space, which may provide access to those who might not typically be engaged.

What is Math Core? What is *Math Moves*?

Math Core is an NSF-funded collaboration (DRL-0840320) of four museums working to develop, install, and study a suite of exhibits about ratio and proportion for children ages 6–12 and their families. According to the National Math Advisory Panel Report (2008), facility with fractions, ratios, and proportion is one of three critical foundations for students' success in algebra. Over two years, four museums (Explora, Albuquerque, NM; Museum of Science, Boston, MA; Museum of Life and Science, Durham, NC; and the Science Museum of Minnesota, Saint Paul, MN) articulated a set of principles to guide exhibit development[2] and developed and tested 16 exhibit components. Each of the exhibits includes an opportunity to explore the concepts "twice" and "half" in a variety of contexts, including area, volume, weight, time, and rate. After considerable evaluation and discussion, we selected a core set of seven components (including Partner Motion, which we discuss below) for installation in each of the museums. Each museum added some of the original 16 exhibits, resulting in four unique exhibitions called *Math Moves*. Installation took place in January 2012.

Partner Motion

In this exhibit, two visitors use two motion detectors to explore their rate of travel along a rainbow-colored path. Walking back and forth, slowly and quickly, visitors create distance vs. time graphs. They can match pre-made graphs or create their own motions and graph shapes. The graph lines on screen (one black and one white) display in real-time their position over time, giving them direct proportional slopes. This provides a way for them to think about and feel how their rates compare to each other as well as to their individual motions. It also allows them to create interesting shapes together. This is not as easy as it might seem, because it requires that they move in particular ways in relation to the graph as well as to each other.

In Math Core, one question we were particularly interested in was, "How do you design and study exhibits from the perspective of embodied cognition?" This article explores the connections visitors made between embodied understanding of mathematics and more formal knowledge and the design strategies we employed to support mathematical understanding in the Partner Motion exhibit.

A qualitative understanding of rate is an important way to connect to the numbers. In an informal setting, we wanted to develop people's intuitive, informal notions of ratio. For example, when one middle school math teacher was asked about what was difficult for students in terms of fractions, ratio, and proportion, she immediately said, "Context; kids have no context for thinking about these ideas."[3] By exploring rate and ratio in a variety of physical contexts, we are building a conceptual understanding of rate.

We also hoped to give people a physical memory that involves playing with ratio and proportion so that later when they encounter more formal notions, they could make a connection to this experience. As Annie Murphy Paul (2014) states, "One reason involving the body improves learning is that bodily movements provide the memory with additional cues with which to represent and retrieve the knowledge learned. Taking action in response to information, in addition to simply seeing or hearing it, creates a richer memory trace and supplies alternative avenues for recalling the memory later on."

Preparing to Develop a Bodily-based Exhibit

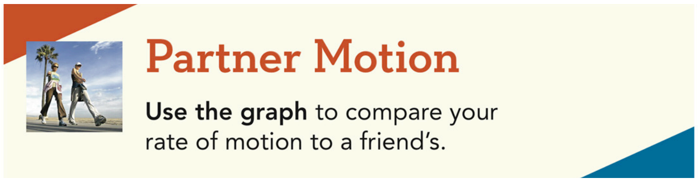
In designing Partner Motion, we first developed our own understanding of rate of change. We read and discussed a lot of literature on ratio and proportion as well as on embodied cognition (Jones, Taylor & Broadwell, 2009; Lamon, 2007; Nemirovsky & Ferrara, 2009: Singer & Goldin-Meadow, 2004; Carraher, 1996). We consulted with a Tufts student (Jason Kahn) who was doing his dissertation on Science Education with a focus on Physical Motion (2010) on exhibit design features. Andee Rubin, Senior Scientist at TERC, shared her experience with change over time representations on the CamMotion project and in the Design Zone exhibit (http://www.designzoneexhibit.org). We led a half-day workshop with a Boston-based dance teacher (Andy Taylor-Blenis) and six experts in the field of body motion and design from formal and informal settings.

We drew on previous experience developing math exhibits, including findings from the *Handling Calculus* exhibit (Gyllenhaal, 2006) that showed that some visitors get anxious if they think they are about to do math, because of previous bad experiences. This is contrasted with our experience at the October 2011 ASTC session (Doing Math with your Body), where we found that people who didn't normally like mathematics felt comfortable and interested in the *Math Moves* exhibition in general. However, they and others wondered if what they were doing was considered "real" math. They wanted us to draw more explicit connection to the more formal mathematics that is valued in schools.

This raises questions for designers of math exhibits regarding how to support the development of mathematical understanding. For example, how important is it for a visitor to know what math topic they are working on? If a visitor does the activity, but is not articulating how they did it, does that "count" in terms of showing evidence of mathematical understanding?

Developing Partner Motion

Historically, in formal education environments, motion detectors permit students to explore the modeling of their own body movement through space by means of real-time graphical displays (Arzarello, Pezzi, & Robutti, 2007; Nemirovsky, Tierney, & Wright, 1998; Robutti, 2006). The area of formal mathematics that Partner Motion addresses is rate of change. Rate of change is a rate that describes how one quantity changes in relation to another quantity, in this case, distance over time. The slope (incline) of the graph line describes its steepness. The greater the slope, the steeper the line and the faster one has travelled. A horizontal line indicates that motion has stopped. This is related to Math Core's goal of focusing on ratios, since a ratio is a comparison between two numbers, or a relationship between two quantities.



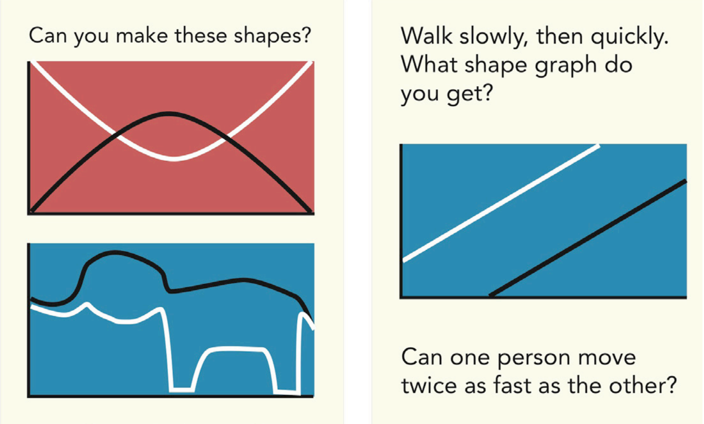


Figure 1 (Top Right): The title graphic for Partner Motion. Photograph courtesy of the Science Museum of Minnesota. Figure 2 (Left): A prototype version of Partner Motion installed at the Science Museum of Minnesota. Photograph courtesy of the Science Museum of Minnesota. Figure 3 (Bottom Right) : Print graphics pose challenges for visitors. Prompts on the screen pose challenge questions such as: Can you make mountains? Can you make an elephant? What other animals can you make? Photograph courtesy of the Science Museum of Minnesota.

Testing with Visitors

At the Museum of Science in Boston, we tested different versions of Partner Motion with about 90 groups of visitors over the course of a year. This allowed us to try out different features including the impact of a second motion detector, rainbow tiles, and even footprints. Our goal was to provide a meaningful physical experience that could lead to a mathematical understanding of rate and to foster conversation among visitors.

From One Motion Detector to Two

Partner Motion was developed at the Museum of Science in Boston, MA. It was inspired by exhibits at the Science Museum of Minnesota and at the Museum of Science in Boston, at which visitors could engage with a single motion detector which measures a visitor's distance from a sensor in real-time and graphs their rate of motion on a computer screen. With a single detector, visitors could ask questions like "What does it feel like to move twice as fast?"

Adding a second motion detector created a more playful experience. One visitor said, "It'd be fun to try to create the pictures, to work together to try to do something" (Wright and Parkes, 2010-2011). It also allowed visitors to explore additional questions comparing their rates, such as, "Can I move twice as fast as you? What would it feel like? How would my motion look compared to yours? What would the graph look like?"

A second motion detector also increased the amount of mathematical conversation. Conversation helped visitors connect their physically embodied experiences to mathematical learning. A mother noted that, "Your [graph line] went up and mine went down. You went backwards and I went forwards." Visitors collaborated more: talking to each other about how they would move, planning their motions, and afterwards, engaging with each other about how successful they were. Talking about the graphs they made together was an important way to develop and solidify understanding of rate. A father making a graph declared, "Oh, I get it. I'm going to start on this and stay on one color each second. I'll back up diagonally? No, straight." Parents on the sidelines often participated by asking questions that were not posed on the surrounding text. "Can you move slow like a turtle?" "How can you make opposite lines?" "Can you make parallel lines that aren't horizontal?" Other conversation from the sidelines offered suggestions of how to move in order to better create the desired pattern. With his wife trying to double their daughter's speed, one dad commented, "Now you're parallel again. One of you slow down."

Ricardo Nemirovsky, co-Project Investigator of Math Core, says, "Fusion of physical action and graphical shapes is a major resource to engage students in conversations around the production and the interpretation of graphs" (Nemirovsky et al., 1998). Partner Motion provides two visitors with an opportunity to see how each of their individual rates of motion create two graphs on one screen. It potentially enables them to have a deeper experience of rate, by comparing their different speeds and thereby experiencing a ratio of rates.

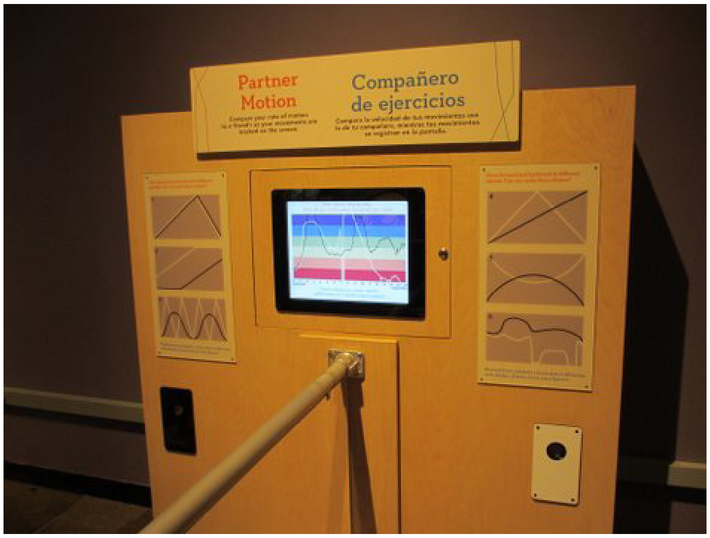


Figure 4 (Above): A graph created by two visitors. Photograph courtesy of the Science Museum of Minnesota. Figure 5 (Below): A pair of visitors using Partner Motion. Photograph by Rich Fleischman.

Adding a Rainbow and Footprints

Early versions of the component used numbers on the floor that corresponded to numbers on screen indicating distance. Visitor feedback showed that these were not noticeable enough, nor was it clear which distance was being measured (from the starting line? from the screen?). We made the switch to a color representation with a rainbow of tiles on the floor that corresponded to color bars on the computer screen. This enabled even our youngest visitors to start to interact with the exhibit and to quickly grasp the relationship between their position on the floor and the line on the screen by simply matching colors. The graph on screen continued to use numbers to indicate the number of seconds passed on the horizontal axis.[4]

Figure 6: Colored floor tiles helped visitors map there position to the line on screen. Photograph courtesy of the Science Museum of Minnesota.

In early tests, some visitors were unclear where to stand. Some started with their backs to the screen. Adding footprints on the tiles and changing the position of the "start" button helped visitors orient themselves and helped them connect their physical motion to the graph more quickly.

How does Partner Motion Attempt to Support Mathematical Understanding?

In the design of the activity itself, we asked visitors to move with their whole bodies and to see how a graph line of distance vs. time would respond in real time. By building in a kinesthetic way to engage with this graphing activity, our hope was that we would allow visitors to access formal mathematical understanding in a new way, through body motion. We also hoped that the visceral appeal of these would make someone want to come back and work with this exhibit again.

Visitor testing was a crucial part of the exhibit development process. We learned early on that this activity was very engaging for visitors and that it had potential for people to develop a qualitative, intuitive understanding of slope. When asked how they had matched a graph, two teen-aged boys replied, "The faster you move forwards, the faster the graph goes up." Our testing focused on improving visitor conversation with each other and with group members watching from outside, as well as developing challenge questions that focused the conversation on the math. We also experimented extensively with the hardware to maximize the clarity of the signals from the two sensors. In addition, the formative evaluation informed the development as well as testing exhibit prototypes with colleagues on the floor at the Museum of Science in Boston, and with colleagues from the Math Core project.

What Did Visitors Think They Were Doing?

In some cases, visitors saw physical connections to math. For example, when an interviewer asked some young visitors, "Would you describe for me what you did at this activity?" one 6-year-old boy said, "I walked and tried to follow the graph." A 5-year-old girl said, "The speed of how the line went." One particularly math literate visitor described what she was doing this way, "It looks like my calculus graphs. … It's helping you figure out rate of change, 2nd derivative."

In other cases, people saw this activity as a chance to move in space, which is related to geometry and proprioception, but not directly to rate. When parents were asked by an interviewer, "What would you say the Museum is trying to show with this activity?" one mom replied, "I'm a massage therapist — [it's about] how we move — the science of how we move." Another mom answered, "Looking at screen and knowing where you are in space. I teach and kids don't know where they are in space." In answer to the question, "What could we do to make this activity better?" one adult replied, "I never considered movement from that perspective. Anything that educates people on how we move (is great…)." One visitor said that the most interesting thing about this exhibit was thinking about how you use your body to make something spatially. Another said they thought this exhibit was about "solving puzzles using your brain and your body."

Is This "Math"?

In what sense can mathematical thinking be a body activity? What actions indicate visitors' understanding of how the graph responds to their motion? What actions indicate understanding of slope or rate? Visitors completed some of the challenges posed without necessarily describing in words how they did this. What does this tell us about their mathematical understanding? In other words, how could a visitor's motion show us that they "knew" the math? Sometimes our bodies have knowledge that may or may not be able to be articulated. At this exhibit, visitors were able to move in such a way that they would match the colors on the floor with the colors on the screen as well as match the general shape of the graph itself. For example, when a visitor completes a challenge such as drawing an elephant with a partner, this type of visitor motion indicates a qualitative, kinesthetic understanding of slope.

When asked about what type of math visitors saw while trying Partner Motion, one said, “The faster you go, the faster the graph changes.” Another said, “Speed; some relationship between motion and the graph being made.” This indicates a basic understanding of a qualitative connection. Yet there were others who said they weren’t thinking about math at all. Perhaps they meant in a quantitative or numerical sense.

In formative evaluation data collected at Partner Motion (Wright & Parkes, 2010–2011), we asked people about discoveries they’d made. Some visitors were able to articulate in words what they learned. For example, one visitor said that the faster they move, the faster the graph changes and that staying in place makes horizontal lines. Another visitor said, “We discovered that the lines on the floor relate to the scale on the graph.” When asked about the kinds of math ideas that they tried, one visitor replied, “Speeding up or slowing down will make the slope steeper or flatter.” This exemplifies a more specific verbal connection between body motion and graphing that we had hoped a visitor would also come away with.

In general, this exhibit was more successful at developing a qualitative type of understanding than a quantitative understanding. Many visitors learned to create and interpret graphs of linear motion, using concepts of rate. They were able to make the graphs they intended to make. At times their understanding was embodied, and in other cases, it was also articulated verbally. According to Goldin-Meadow (2006), “Gesture thus lets speakers convey thoughts they do not have words for and may even play a role in changing those thoughts.”

If a visitor does the activity, but is not articulating how they did it, does that show evidence of mathematical understanding? From our perspective, yes. People experienced an important connection between motion and graphing that had to do with rate of change (for example, when they made an elephant) even when they may not be able to describe how they did it. While we hope that people will become more articulate in their descriptions and even in writing numerical equations, this sense of qualitative, intuitive, kinesthetic understanding of motion is equally important and traditionally left out in school mathematics. In the end, it depends on what one “counts” as mathematical understanding. If *Math Moves* has broadened people’s understanding of what counts as mathematical knowledge, then it has done its job.

End Notes

[1] In this article, we refer to bodily kinesthetic learning, but recognize that others use related terms including embodiment or embodied cognition.

[2] The content focus is the broad topic of ratio and proportion, including fractions and the geometric concept of similarity, with exhibits that are: 1) Open-ended to encompass several ways visitors may interact and often more than one math problem to explore, 2) Conversational to encourage children and adults to talk with each other about the exhibit activity, and 3) Accessible by incorporating audio and written labels in English and Spanish.

[3] All visitor quotations are from our formative evaluation (Wright and Parkes, 2010–2011).

[4] A color version of this paper is available through the CAISE website at informalscience.org under the MathCore project.

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Acknowledgments
The authors would like to thank J. Newlin and Andee Rubin.

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MIDDLE OF THE ROAD: RESPECT OR SELF-CENSORSHIP?

By Jan B. Luth

For science centers and natural history museums, evolution seems like a fitting topic for engaging our audiences. But in a growing number of communities around the country, the subject of evolution is hotly debated and politically polarizing. Is there a way for a museum to find a balance to serve their entire community when some disagree with aspects of accepted scientific thinking, such as evolution? That's what Exploration Place faced in Wichita, Kansas. Would we be able to find a middle ground to be welcoming to families with a different world view?

We had to get our arms around the character of this community and its concerns with the museum. A local elected official, who believed in our museum's pledge to find middle ground, helped immensely. As part of this community group he generalized the character of the individuals as those who do not believe in evolution, extended geologic time, climate change, vaccines, abortion or fluoridated water. He also shared some key museum history that had sparked dissension.

He explained that one of the museum's founding donors was a Wichita doctor who conducted late-term abortions. His name on the founders' wall led to a letter writing campaign and an unofficial boycott of the museum by anti-abortion supporters. Then in 2006, Exploration Place hosted the traveling exhibit *A T. rex Named Sue*. Not all staff stationed in the exhibit had been sufficiently trained to handle visitors who might challenge extended geologic time. There were some contentious interchanges that rippled through this community.

Over the years, staff had tried to reach the very large home school audience in south central Kansas but those efforts fell flat. Equipped with history, insight and the support of an elected official, it was time to try again. We knew we needed buy-in from the community. To be successful, we knew we had to be sincere and they had to believe us. With the help of the elected official, we formed a Home School Advisory Committee, many of whom were leaders and all were aware of the issues described above.