Mathematical Challenges in Science Centers: The Case for Involving Visitors with Data

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Abstract

The Math Momentum in Science Centers Project[1], led by TERC in conjunction with the Association for Science-Technology Centers (ASTC) and thirteen science centers throughout the U.S., is examining mathematical challenges involving visitors in the study of data, measurement, and algebra. Data are ubiquitous at these informal science institutions, yet visitors have rarely had opportunities to engage in mathematical challenges that involve data collection, measurement, representation, and interpretation. This paper explores methods of incorporating mathematical challenges into science center practice, focusing on five dimensions of these challenges: 1) designing engaging and motivating questions; questions that are of interest to a wide range of people;2) prompting inquiry into questions where the answers are not known in advance, and where there is a purpose for finding the answer; 3) involving people in collaborative mathematical problem-solving; 4) making connections to the larger scientific phenomena represented at the center; and 5) engaging people with substantial mathematics, often by integrating a physical challenge with a mathematical one.

Background

The goal of the Math Momentum Project is to help science centers (including children's museums, natural history museums, and aquariums) develop the capacity to incorporate math into their existing exhibits, educational programs, and outreach activities. The project's philosophy is that inquiry-based mathematics ought to permeate the work of science centers, and should reflect the fact that math is a critical part of scientific work.

Much of the project's work involves technical assistance to teams from science centers as they examine their programs, discuss the nature of mathematical challenges, study mathematical interactions of visitors, identify mathematical opportunities that may be just beneath the surface of their programs, and design ways of "mathematizing" their work. Each center is developing a substantial mathematical challenge for visitors. The project is producing a book that describes the ways centers have grappled with incorporating mathematics into their work: The book will be published in the summer of 2006.

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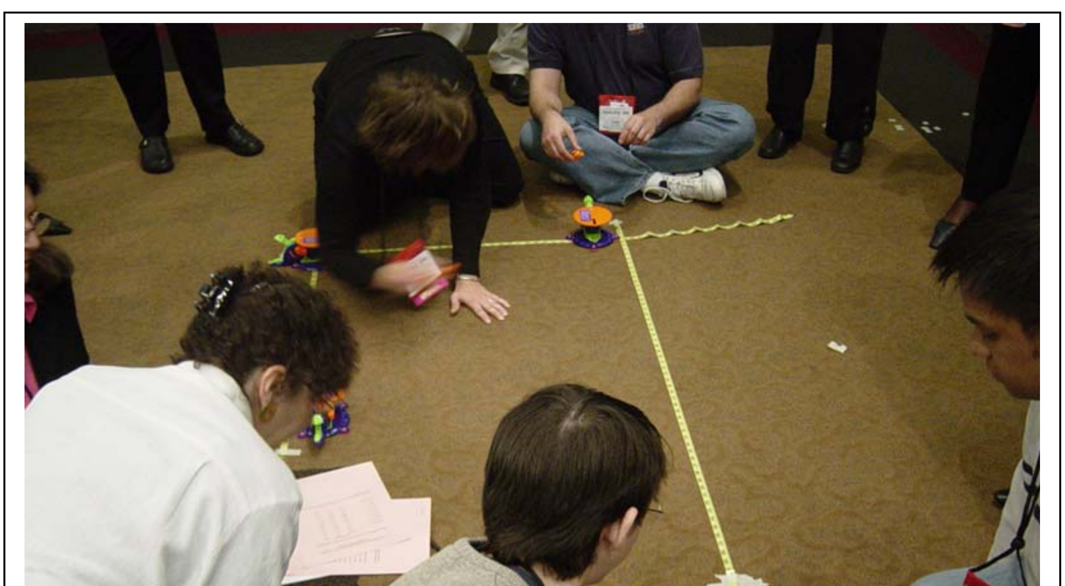
The mathematical challenges of greatest interest to the project involve data and measurement. (Algebra is a third focus, but will not be addressed in this paper.) These content areas were selected because they are mathematically critical and because there is an excellent match between them and the inquiry activities that take place in science centers. The NCTM Standards (2000) as well as educational researchers more generally assert that "the study of data and statistics should be firmly anchored in students' inquiry." (Lehrer and Schauble, 2002). Data and measurement go hand in hand, as measurement is an important means of collecting data. Coincidentally, measurement is one of the areas where U.S. students perform most poorly, and where they need a great deal of practice that they are not getting at school (Clements and Bright, 2000).

We have found that science centers, whose themes range from animal behavior to physics to paleontology, have a plethora of data to work with. But visitors are not often presented with challenging activities involving data. It is widely believed that visitors are not interested in math, and that math does not provide the same kinds of "hands on" inquiry offered by science. Furthermore, many staff members begin with a narrowly-defined conception of math based on their experiences in school. Most have had little experience with real data sets, though several have participated in formal statistics courses.

Involving Science Center Staff in Data Challenges: Catapulting

In order to construct significant data challenges for visitors, staff must first experience such challenges for themselves. Engaging directly in these challenges helps dispel stereotypes about math as pages of worksheets, and convinces staff that mathematical activities, like science activities, can involve exciting inquiry. It also helps staff understand the value of *collectively* undertaking mathematical challenges, and of discussing the mathematics they are doing with each other.

A data challenge that has been particularly effective involves teams of staff in setting up a chain reaction of catapults. Groups of three receive a catapult which has several settings to control a) force, and b) angle of launch of a small rubber cat. Groups work on finding a particular combination of force and angle settings that will result in a readily predictable distance. Finding this distance is critical, because the catapults are subsequently set up in such a way that the landing point of Cat A is the launching point of Cat B, which in turn lands in a place that launches Cat C, etc. Errors in data collection and measurement can easily be compounded and prevent a successful chain reaction.

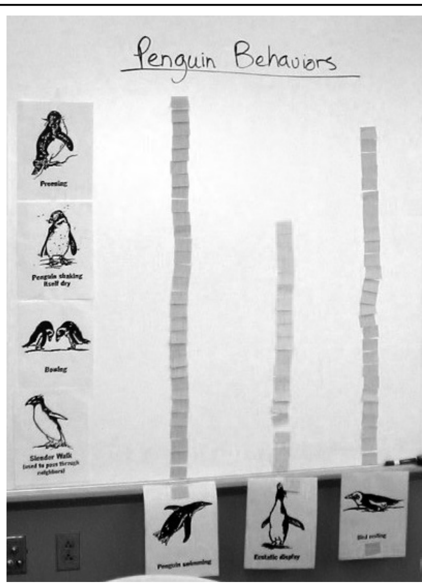


Once each group has taken enough data to establish a reliable setting for their catapult, they work with other teams to form a chain reaction (see above.) Each group uses its data to place its own catapult in relation to the next one in the chain. Success is measured by the number of cats in the chain reaction, or by the ability to make a chain of catapults that eventually launches one of the cats into a particular target (such as a small dish of cream!) In order to do this work successfully, careful measurement is necessary.

Note: We have a couple of brief (20 second) videotape segments showing staff involved in such a chain reaction. These could be shown at the session.

After the chain reactions have been implemented, staff engage in a discussion and analysis of the challenge. They address underlying questions about the mathematics, such as: How did the data that were collected inform the decision of which settings to choose? To what extent is measurement error controllable, and to what extent is there "noise" that cannot be avoided? They also discuss the ways that the challenge involved (or failed to involve) various members of the team, and possible reasons for this. For example, in mixed-gender groups, it is sometimes observed that men take charge of the measurements, while women record data and assist with set up. Individual differences also emerge, with some participants claiming that they are either adept or not adept at mechanical challenges. These discussions lead to an examination of ways of involving a more diverse group of visitors in data challenges.

The catapulting activity has been done in several Math Momentum workshops. Evaluation data show that participants find the activity particularly effective because: 1) It offers an "existence proof" that mathematical challenges can be exciting and involve inquiry; 2) It is based on a physics phenomenon (e.g., catapulting) that is present in nearly all science centers, so that it is easy to envision conducting similar activities with visitors; and 3) It provides opportunities to talk about mathematics in order to solve a real problem. In sum, the activity effectively demonstrates a data challenge for staff.



Involving Visitors in Data Challenges: The Penguin Program

Ultimately, we want to involve visitors in significant mathematical challenges by equipping staff to design such challenges. Staff at these centers are beginning to design such challenges, and many of them involve data. For example, the New England Aquarium in Boston has developed a highly successful version of an animal behavior data challenge for young children who are involved in school visits. The challenge, based on penguin behavior, was designed as an interactive alternative to the Aquarium's traditional demonstration-based program. In the traditional program, children are given many facts about penguins through an engaging "show-and tell" method. In the enhanced program, children were involved directly in collecting data on seven penguin behaviors (slender walk, bowing, swimming, preening, shaking dry, ecstatic display, and resting), which the children learned through role-playing. After enacting these behaviors, children were given observational charts and told about the ways scientists collect data by noting the behaviors they see at regular time intervals. At this point, half of the children were assigned the role of penguins, and half became "scientists" who observed and charted the behaviors of the simulated penguins. They were given the challenge of discovering which of the behaviors were engaged in most and least often. After a few minutes, the groups switched, enabling everyone to have a turn simulating a scientist as well as a penguin.

To analyze their data, each member of the group counted the number of times that they had observed each penguin behavior. Three of these behaviors became the focus of data analysis. Each child selected the number of stick-on notes that corresponded with the number of times s/he had observed the three behaviors. Then, the children built a cumulative graph of their data with stick-on notes, showing the total number of times these behaviors were observed, as shown in the accompanying graphic.

As children examined the graph, they were asked to note which behaviors occurred most and least frequently, and to compare the numbers in each category. Then they were asked, "How do you think the data from real penguins might look?" Children were eager to follow-up!

Note: Videotapes showing children involved in enacting penguin behavior, collecting data, making data representations, and interpreting data could be shown at the proposed session.

For most of the classes, children moved from the program to the penguin exhibit itself. Staff members observed the extent to which children identified the penguin behaviors they had learned about, the length of time children spent at the penguin exhibit, and the kinds of questions they asked about penguin behavior. Staff observed that children who participated in the data-based penguin program were not only highly engaged, they were also spending more time at the penguin exhibit than children who participated in the traditional "show-and-tell" penguin program. They also hypothesized, based on their observations, that children in the new program were more keenly observing actual penguin behavior and were more able to identify the behaviors they had enacted themselves. Moreover, children wanted to collect additional data.

At this point, the results are anecdotal, but reveal that children in the "data rich" penguin program were more likely to identify penguin behaviors than children in the "traditional" program, and spent more time at the exhibit. By focusing on data collection and analysis challenges, children can become more interested in animal behavior itself. The next step is to formally determine what impact the program has on children's understanding of data, as well as of animal behavior.[2]

While other institutions (Brookfield Zoo, Bronx Zoo) have developed interactive animal exhibits, there are few structures or supports for engaging in research on what visitors learn about the mathematics of data through these experiences. Research is needed to show what visitors understand about collecting data, about the collective power of many pieces of data (rather than just one's own), and about representing and "reading" data.

Designing "Layered" Mathematical Challenges: Reaction Time

In many science centers, a popular hands-on activity involves pressing (or releasing) a button as quickly as possible in response to a sound or light. Visitors are often interested in examining and improving their reaction times. Predictably, they are quite interested in competing with each other to see who is fastest. Unfortunately, in most of the reaction time activities we have observed, there are no mechanisms to record or compare data. Mathematical opportunities are being missed.

There are several potential mathematical challenges that could be incorporated into reaction time activities. At the Sciencenter in Ithaca, New York, an enhanced reaction time exhibit is being developed to incorporate different levels of mathematical challenges to match the needs and interests of different visitors. In the basic activity, visitors see bar graphs of up to six successive reaction times. The X axis shows the six trials, and the Y axis represents time. The higher the bar, the slower the reaction time. The first mathematical task is to examine the bars and determine which one is best or fastest. This is a basic level of challenge, but it is difficult for many visitors. Seeing that .4 seconds is *slower* than .3 seconds helps visitors understand that the highest number or tallest graph doesn't correspond to the best outcome.

The second level of challenge involves setting a target reaction time (or target range), then trying to produce a time that gets as close as possible to the target. This challenge integrates a physical task with a mathematical one: Achieving a reaction time close to .5 seconds, which is not an unusually fast time, takes practice. Visitors are challenged to use the feedback from their graphs to get successively closer to the target. In the process, they learn to read graphs more closely than they would otherwise do. They are learning about mathematical representations of data as they respond to this challenge.

The third level of mathematical challenge in the Sciencenter's reaction time activity involves learning about the characteristics of a data set, particularly about where the arithmetic mean is located in a data set and what the mean represents. In this challenge, visitors are asked to come as close as they can to a target (e.g., .5 seconds) over the course of six cumulative trials. If one trial is too fast, they would need to compensate by

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[2] Rebekah Stendahl, of the New England Aquarium in Boston Massachusetts, designed this program and provided information on it for this paper.

going more slowly on one or more subsequent trials. Again, the physical challenge is closely integrated with the mathematical one. But at this level, visitors must also construct a working definition of average, one which involves paying close attention to deviations. What matters is not how far away from the target one is on a given trial, but instead how one can "balance" the deviations over and under the target in order to arrive at an average. This kind of thinking involves visitors in constructing the idea of average for themselves, which is an important piece of mathematical understanding (Mokros and Russell, 1995).

At the time of writing, the Sciencenter was designing the three layers of mathematical challenge for their reaction time exhibit.[3] At the conference, findings concerning visitors' involvement in and learning from these challenges will be presented.

Ingredients of Data Challenges in Science Centers

The project is finding that data challenges, whether for visitors or staff, need to have as many of the following ingredients as possible:

1) They start with engaging and motivating questions; questions that are of interest to a wide range of people;
2) They prompt inquiry into questions where the answers are not known in advance, and where there is a purpose for finding the answer;
3) They involve people in collaborative mathematical problem-solving;
4) They have some connection to the larger scientific phenomena represented at the center.
5) They engage people with substantial mathematics, and often integrate a physical challenge with a mathematical one.

Conclusions

In working with science centers, we are promoting a broader view of mathematics as a discipline that *involves compelling challenges.* Most people have not thought about mathematics in this way. There are concrete ways in which centers can begin building math challenges into their exhibits and programs, particularly challenges that involve data. Comparison of data points over time, and comparison of data contributed by various visitors, motivates visitors to examine data. Visitors are especially interested in the data that they have contributed. Using these interests, it is possible to build "layered" mathematical challenges that involve various degrees of sophistication, ranging from simply reading and comparing data to constructing a data set that results in a given average. The centrality of visitors' own actions in these mathematical challenges cannot be overstated: Science center visitors come with the expectation that they will push buttons and levers and engage in physical activity. We have offered case studies to support the premise that visitors' expectations can be connected with mathematical challenges that are purposeful, collaborative, and integrated with meaningful scientific phenomena.

[3] Dr. Charlie Trautman, President of the Ithaca Sciencenter will provide data concerning the uses of and impact of the reaction time exhibit for this paper.

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