Pacific Science Center
www.pacsci.org
Pacific Science Center

Mathfinder and the Museum

Pacific Science Center is located in the heart of Seattle, Washington. Like many science centers, it serves the local community, school groups, and tourists. With traveling blockbusters supplementing an array of permanent exhibits and two IMAX theaters hosting large-format films, the science center is attractive to locals and tourists alike.

Mathematics has had a long-term presence at Pacific Science Center. It is specified in the museum’s mission statement, and mathematics educators serve on the education advisory committee. During the 1980s Pacific Science Center offered teacher workshops in mathematics, which were focused on problem-solving strategies and provided teachers with hands-on lessons and teaching materials. However, these were phased out as the NCTM Standards became more widely adopted.

Mathematics gained “new life” at Pacific Science Center when Washington adopted the Essential Academic Learning Requirements (EALRs)\(^{17}\). These K–12 educational standards are tied to state-level, high-stakes exams. When the first results in mathematics came in, the scores were abysmal, and Pacific Science Center seized the opportunity to design a new mathematics outreach program.

For this case study, the site-visit team focused primarily on the Science on Wheels program and its Mathfinder van. But the team also “unpacked” the mathematics in floor exhibits, using “a mathematics lens” to explore the different science disciplines presented in the science center exhibits.

Pacific Science Center’s education programs serve more than 162,300 students, teachers, and other adults each year. What makes the education offerings notable is that Washington’s Office of the Superintendent of Public Instruction (OSPI) provides significant funding for these programs through a line item in the state budget. Through its Science on Wheels program, Pacific Science Center demonstrated that it could serve schools beyond the metropolitan area of Seattle. The science center obtained visibility for its programs by notifying legislators whenever the van visited schools in their area. This strategy helped guarantee audience awareness and government support for what the science center could do for schools.

\(^{17}\) The Essential Academic Learning Requirements (EALRs) were developed based on the NCTM Standards and are similar in structure and content. Use of the NCTM Standards for this publication permits more generalized use.
Mathematics at Pacific Science Center

Van-Program Structure

The Science on Wheels van programs are Pacific Science Center’s key strategy for maintaining connections with school districts across the state. Now a high-visibility program, Science on Wheels got off to a modest start in 1973, when, with gasoline in short supply, school districts couldn’t afford to visit the science center. Confronted by declining revenues, staff decided to bring the science center to the schools. They set up a pilot program with one local school district, filled a station wagon with hands-on science lessons and a few floor exhibits, and drove out to a nearby school.

From that initial visit, the program grew in scope and in service area. In the beginning, Science on Wheels staff taught a handful of science lessons in classrooms. Now the van program includes tabletop exhibits, a menu of lessons, and an all-school assembly. The program logs 540 van days each school year, and service is statewide. There are six Science on Wheels programs: Physics on Wheels, Space Odyssey, Teach Every Child How (T.E.C.H.), Blood & Guts (human physiology), Rock and Roll (geology), and, newest of the offerings, Mathfinder.

The basic program structure varies only slightly among the different vans. Generally, there is a 30-minute all-school assembly, an exhibit hall of 20 to 30 tabletop exhibit devices, and a set of 6 to 9 classroom lessons. Programs require two or three Pacific Science Center staff and a number of school-based volunteers.

The school chooses in advance which van it wants and reserves a day or more for the program. Staff arrives an hour before the opening assembly to set up the exhibit hall and train volunteers. Volunteer support is crucial since the staff spends the day teaching lessons in the classrooms. The volunteers help set up the exhibits and learn to do simple maintenance. They are also trained to ask questions of the students and provide simple directions for exhibit use.

The all-school assembly serves as an introduction and stimulates excitement. Each program offers students some challenge to resolve during exhibit visits and in classroom lessons. Some assemblies are done in costume, and one includes teachers from the schools as performers alongside the staff.

Teachers preselect a 45-minute classroom lesson appropriate to their grade level from a menu of options. Class instruction is for a maximum of 32 students, a constraint imposed by the materials available per session. The classroom teacher stays to monitor the students and to observe the instructional strategies—a serendipitous professional development benefit. Each lesson is extended with a leave-behind sheet for the teachers and a take-home sheet for families and children to do together.

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18 The van concept has been replicated in other science centers in the United States and internationally.
19 In addition to the six OSPI van programs, there are two middle school van programs: Waste Busters, funded by King County and Brain Power, funded by the National Institute of Health.

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The Mathfinder Assembly

The purpose of the Mathfinder assembly is to orient the students and staff to the structure of the day and prepare them with conceptually stimulating ideas in anticipation of the classroom and exhibit hall activities. The assembly explores the concept of probability by having students consider the likelihood of reaching a specific phone number (for example, that of the President of the United States) by dialing 10 random numbers, 0 to 9. Students then participate in a demonstration to illustrate the concept. Scale and perspective are introduced by showing the audience a trick photograph of dinosaurs, alive and well and living in Seattle. The program concludes by encouraging students to view mathematics as a powerful tool in daily life.

Mathfinder Classroom Lessons

The blueprint for designing a van program was well established before Mathfinder was created. Historically, the van programs had offered K–3 and 4–8 grade lessons. But for mathematics, the staff established an advisory group of teachers and asked them for recommendations. Following their advice, the team planned and developed three lessons each for grades K–2, 3–5, and 6–8.

To narrow choices down and to build the connection with schools, the development team started with the EALRs. A survey of teachers and administrators helped the team select which of the Learning Requirements needed the most support. Teachers suggested a variety of activities that required too-expensive materials or that were too difficult to do in a hands-on way. Ultimately, the developers chose to focus on five math topics: probability, statistics, geometry, logic and problem solving, and measurement.

Pacific Science Center staff developed the mathematics lessons and then did a pilot test. The first prototypes were tested in three sessions: with school groups, with families, and on the floor of the science center. Observations and feedback allowed the staff to modify products before the van made its debut. The table of Mathfinder lessons that follows denotes both the topics and the NCTM Standards addressed by each.
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<td>3. Standard 7 Reasoning and Proof (item 7.2)</td>
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Tabletop Exhibits

It was a challenge for exhibit developers at a science center to think about mathematics exhibits. To push their thinking about appropriate mathematics exhibits, the Pacific Science Center design team reviewed children's books and brainstormed ideas for interesting exhibits. They also had to think about the EALRs and the developmental appropriateness of concepts. In the following photographs, some of the exhibits are presented, along with the corresponding NCTM Standards.

Standard 1 – Number and Operations

*Big Numbers* is a counting machine that began its count at zero in January 2000. Visitors are asked to press a button to advance the counter. The machine then asks the visitor to consider how long it will take to count to 1,000,000 (1 million). The exhibit addresses

- Standard 1 – Numbers and Operations (items 1.1 and 1.1)

Standard 2 – Patterns, Functions, and Algebra

*Pattern Block* encourages visitors to replicate patterns using the colored blocks. It specifically addresses

- Standard 2 – Patterns and Functions (items 2.1 and 2.1)
Some Mathfinder exhibits address more than one Standard. Here a traditional northeast Angolan activity, Lusona Patterns, invites visitors to draw patterns without lifting the pen from the paper and without crossing lines twice.

*Lusona Patterns* addresses
1. Standard 2 – Patterns, Functions, and Algebra (item 2.1).
2. Standard 3 – Geometry and Spatial Sense (item 3.2)

Square Wheel invites the learner to figure out how to make a square object roll smoothly. The mathematics enters in as visitors analyze characteristics and properties of two- and three-dimensional geometric objects and use different representational systems, including coordinate geometry and graph theory.

- Standard 3 – Geometry and Spatial Sense (items 3.1 and 3.3)
Other well-known science center exhibits or activities, such as *Pentominoes* (below, left) and *Escher Tessellation* (below, right) found their way into tabletop devices for use in schools.

The Pentomino blocks and their puzzles help to develop spatial reasoning. The class lessons provide the experience of creating the 12 Pentominoes, which requires work in spatial reasoning, and trial-and-error problem solving and can reinforce the difference between area and perimeter. It works well for students grade 3 and up. Those as young as 7 or 8 do well at creating the 12 pentominoes by working in groups or working with adults. Middle school and older students can tackle the harder puzzles and work to create their own set of blocks.

- Standard 3 – Geometry and Spatial Sense (items 3.1, 3.3 and 3.4 )
- Standard 4 – Measurement (item 4.1)
- Standard 6 – Problem Solving (items 6.1 and 6.3)

Standard 4 – Measurement

This box filled with tools for making measurements covers many of the Standard 4 – Measurement items.
Standard 5 – Data Analysis, Statistics, and Probability

The normal-distribution exhibit is found in science centers in many guises. Pacific Science Center's *The Way the Ball Bounces* exhibit is miniaturized and made to travel. The following photographs show the exhibit in motion and the resulting distribution. This exhibit corresponds to NCTM Standard 5 – Data Analysis, Statistics and Probability (items 5.2 and 5.4).

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The Way The Ball Bounces

- Tilt the board to move all the balls to the top.
- Tilt it the other way and let all the balls fall to the bottom.

What pattern do they make?

A Pattern from Random Bounces

All the balls start above the center slot. They bounce off the posts to follow a random path down the board. You can't predict the path of a single ball, but you can predict the pattern made by many balls.

- There are many paths leading to the center slots, so most of the balls end up there.
- There are only a few paths to the slots at either side, so fewer balls end up there.

The bell-shaped pattern created by the balls is called a normal curve. It's an important concept in statistics.
In Galton's Board a Normal Curve of Probability can be formed according to PASCAL'S TRIANGLE—which simply counts the number of paths a ball can take.

Even when the balls bounce erratically the result of the accumulated errors will form the Normal Curve.

Additional text from signage of "The way the Ball Bounces" exhibit
Funding

Costs for the Science on Wheels program include development expenses, materials and resupply costs, staff salaries, travel, and indirect costs. OSPI provides approximately two-thirds of the delivery costs of all the programs. The remainder comes from other sources, including Pacific Science Center’s development office, which raises money to defray expenses and keep school fees as low as possible. Schools pay about 20 percent of the cost of a program, depending on how many schools the science center visits while traveling within a specific region.

The budget for the newest van, Mathfinder, was $350,000, split over two years. Two-thirds was spent in the first year to develop lessons, exhibits, and the assembly. The budget for lesson development was $69,000, exhibit development was $122,000; and the assembly development cost was $5,500. The van costs $27,500. The remaining funds will support first-year program delivery, but delivery costs exceed what is provided by OSPI.

Evaluation

As at many science centers, full-scale evaluation is not a high priority at Pacific Science Center, and there are no systematic studies of how or what children are learning, nor any investigation of the ideas that teachers pick up during the visits. However, some effort has been made to find out what teachers and students have to say about the van programs. The staff asks classroom teachers to fill out questionnaires at the end of the lessons, offering comments about the age appropriateness of the lessons, the assembly or exhibits, and what students are saying. The contact person is also asked to fill out an overall evaluation form.

Mathematics Exhibits and Public Programs

Mathematics Found in the Science Exhibits

At the Pacific Science Center, many of the existing exhibits have mathematics connections that are not explicated directly. Mathematics is inherent in virtually every science discipline. The science is articulated in the copy, and made enjoyable in the exhibits. Mostly the mathematics seems obscure, but the connections could be made for the visitor. The following photographs illustrate this point, with the relevant NCTM Standards.
Physical Sciences

In Astro-Physics, the Gravity Well exhibit—found in many centers—invites visitors to drop coins or marbles into the well to observe the elliptical orbits that develop. It addresses

- Standard 3 – Geometry and Spatial Sense (items 3.1 and 3.4).

Mirrors and prisms make connections between geometry and real-world phenomena. The photograph at left is the Parabolic Mirror, where visitors investigate parabolas and foci.

It addresses NCTM Standards

- Standard 3 – Geometry and Spatial Sense (items 3.1 and 3.3)
Below, at the left, is an exhibit on Reflections.

- Standard 3 – Geometry and Spatial Sense (item 3.1)

On the right is an example of Leonard da Vinci’s Anamorphic Art, which relies on curved mirrors to make sense of the image.

The Standards addressed in Anamorphic Art are:

- Standard 3 – Geometry and Spatial Sense (items 3.2 and 3.4)
- Standard 5 – Data Analysis and Representation (item 5.1)
- Standard 6 – Problem Solving (item 6.3)
- Standard 8 – Communication (items 8.1, 8.2, 8.3, and 8.4)
- Standard 10 – Representation (items 10.1 and 10.3)

The Giant Lever illustrates simple mechanics and mathematics concepts of ratio and proportion.

The Standards that correspond are

- Standard 4 – Measurement (item 4.2)
- Standard 6 – Problem Solving (items 6.1, 6.2, and 6.3)
Life Sciences

In Life Sciences, insects provide a great opportunity for including mathematics. The obvious geometric shape of honeycombs built by bees and wasps is a good starting point for mathematical investigations of the natural world. The Wasp Hives (right) show repeats of hexagons, making a strong Standards connection:

- Standard 3 – Geometry and Spatial Sense (item 3.1)

Measurement is frequently used in describing plants or animals. Size, weight, and height are the focus of the wall case at left, which corresponds to

- Standard 4 – Measurement (items 4.1 and 4.2)
Scale and proportion are investigated with fleas and ants, below, and connect to

- Standard 1 – Numbers and Operations (item 1.3)
- Standard 4 – Measurement (items 4.2 and 4.2)

As children move the head, thorax and abdomen sections in *Invent Your Own Insect*, they develop an understanding of finding combinations. Whenever, a head, thoracic, or abdominal section is changed, a new bug is created. This activity is appealing to all ages, but it is fun for older children (ages 8 and up) to try to work out how many possible bugs they can create. They could also discuss the probability of creating a particular bug.

- Standard 1 – Numbers and Operations (item 1.2).
- Standard 5 – Data Analysis, Statistics and Probability Standard (items 5.1 and 5.4)
The Body Works exhibition provides lots of opportunities for visitors to interact with exhibits and measure personal performance on tasks. The visitor can compare his or her best with averages among different age and gender groups.

- Standard 4 – Measurement (items 4.1 and 4.2)
- Standard 5 – Data Analysis, Statistics and Probability (items 5.1, 5.1, and 5.2)
Earth Sciences

Maps illustrate a number of mathematics connections. For example, this computer screen shows a cylindrical projection map. The image raises lots of questions: What happens to shapes undergoing these transformations? Why does Greenland look so big on this map, but not on a globe? If airplanes essentially fly in straight lines, why do the paths appear as curves on a map? Finally, the twilight line appears as a sine curve rather than a straight line. The related Standard items are:

- Standard 3 – Geometry and Spatial Sense (items 3.3 and 3.3)

Oceanography may apply only to science centers near coastal regions, but its concepts have solid mathematics potential. At the Puget Sound Model, visitors have a scaled-down, birds-eye view (not shown here) of the body of the sound. The model is controlled by a tide-generation component (below left), which displays concepts of wave interference (constructive and destructive), while the 11 “rivers” flow into the model at different flow rates (below right).

The Tide Generating Machine connects with

- Standard 2 – Patterns, Functions, and Algebra (item 2.3)

River Flow control panel matches

- Standard 2 – Patterns, Functions, and Algebra (item 2.3)
- Standard 4 – Measurement (item 4.1)
The exhibit copy for the Puget Sound Model describes time and space scales used for the model which correspond to:

- **Standard 1 – Numbers and Operations** (items 1.3)
- **Standard 4 – Measurement** (items 4.1 and 4.2)

**Technology**

Robots are a natural in a science centers, and this robot plays tic-tac-toe. Strategy and logical reasoning are central elements of this exhibit.

- **Standard 2 – Patterns, Functions, and Algebra** (item 2.1)
- **Standard 6 – Problem Solving** (item 6.3)

The Puget Sound Facts includes numbers, statistics, and percents corresponding to:

- **Standard 1 – Numbers and Operations** (item 1.2)
- **Standard 4 – Measurement** (item 4.1)
Mathematica—A World of Numbers and Beyond

Viewing Mathematica—A World of Numbers and Beyond was an unexpected and appreciated opportunity at Pacific Science Center. This venerable exhibit is the one that science center professionals usually talk about when asked if science centers do mathematics. It was created by Charles and Ray Eames approximately 30 years ago, and copies of it were on display at multiple science centers, including the California Museum of Science and Industry, Museum of Science in Boston, Museum of Science and Industry in Chicago, and Pacific Science Center. The exhibit has now been refurbished and copied for traveling.

Mathematica presents a fascinating display of mathematics development, and the visitor is introduced to different topics within the discipline. However, it tends to be a “look and read” exhibition, rather than offering the more experiential approaches science centers now take. It benefits from additional activities presented by staff members. For example, when Mathematica was on display at Pacific Science Center in the late 1960s and '70s, the exhibits were augmented with tabletop mathematics games and puzzles. A discovery room area provided materials for visitors to make bubble wands in shapes like those of the exhibit hall and Tangle pieces to construct different animal shapes.

A timeline of historic events in mathematics can be found on one wall of Mathematica, and throughout the hall there are a number of other interesting exhibits.
The nature of hands-on exhibits at the time *Mathematica* was built required the visitor to push buttons mostly and observe the action. There was little, if any opportunity for the visitor to learn through the manipulation of variables.

The *Calculating-Cube* (above left) provides computed answers by lighting bulbs in the three dimensions of the cube.

The arrow on the *Moebius Strip* (above right) tracks around the surface when the visitor pushes a button.

In the exhibit to the right, visitors push a button to lower different geometric shapes into a tub of soap. The resulting bubbles reflect the science of surface tension and the mathematics of geometric solids.
Lessons Learned

Designing developmentally appropriate products and meeting the needs of a widely diverse audience is challenging.

Designing mathematics exhibits for the *Mathfinder* van was not as simple as anticipated. Even though the primary audience is schoolchildren in grades K-8, the intellectual and developmental levels of the children varies. Not only do different audiences want and need different activities, but a free-choice exhibit area must stand on its own and be inviting. There was deep anxiety among staff about how explicit mathematics exhibits should be. Would mathematics terms and experiences draw the visitor or should the mathematics be embedded in nonobvious and nonthreatening ways?

Developmental issues are major design challenges. On the one hand, children respond differently to concepts according to their developmental levels. They have both individual and developmental differences in attention span and responses to frustration. In a pattern activity, young children may want to do dot-to-dot repeatedly. Older children may try a pattern once and move on to new challenges. Staff spoke of these concerns:

> Mathematics develops sequentially—one concept building on another. Exhibits usually stand alone, or at best, tie topically or conceptually. Rarely do exhibits connect sequentially with one another. Do children “get it” if the experience isn’t comprehensive in developing a concept? How do science center professionals know if and when the visitor does “get it?”

People may not perceive the presence of mathematics when it does not appear in a traditional form they recognize. They ask: Where is the math?

Two different views on this question were found. Much depended on who the audience was. The design team found that volunteers felt uncomfortable if the mathematics was not explicit. Parent volunteers manage the kids in the exhibit hall, and because they are conscientious and want to help kids understand the copy or do the activity, they wanted to see mathematics displayed. They wanted the explanations and the formulas. While piloting exhibits, one volunteer came in and said,

> This isn’t mathematics... where is the math? There is nothing in the label to tell me what the mathematics is.

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The opposing point of view was expressed by one of the site-visit team members—a university mathematics educator. His comment was revealing:

\[ \text{Forty minutes was not enough time to see all the mathematics in the Pacific Science Center. Everywhere I looked -- math! Math! MATH!} \]

The problem of making mathematics explicit is not limited to a mini-exhibit hall that is staffed with volunteers. Even very sophisticated visitors, such as members of the site-visit team, recognized the challenge. In the words of one Pacific Science Center team member:

\[ \text{So, the science center is full of mathematics, and we need not worry, right? Well, unfortunately, most people would not recognize the mathematics in the activities and exhibits. Most of the math was inherent, but not explicit. Some of the mathematics was hidden. How would we get people to see the mathematics in these activities?} \]

**Sometimes mathematical ideas that work as activities do not translate into inviting exhibits.**

Something that works well as a classroom activity, even if it can be represented with objects, may not work as well as an exhibit. For example, Moebius strips are cool and interesting mathematics and give hands-on learning experiences of topology. However, with premade strips people are not inclined to just pick them up. They just don’t seem to stimulate curiosity. According to the developers who crafted them for the Mathfinder van, Moebius strips require an interpreted experience.

**Using Standards to create exhibits and programs benefits teachers (and parents) in utilizing the science center**

Within the Science on Wheels program, which targets schools, making the mathematics connection is aided by linking activities and exhibits to their corresponding Math EALR. In choosing topics, making decisions about copy, and designing lessons, the mathematics framework gave the science-center staff and the teachers who get the program a common ground for understanding. The team found a way to tie the exhibit or activity with specific statements within the Essential Learnings. And for the sake of the children, they sought to tie the exhibit to real-world experiences as often as possible.
While the EALRs frame the components that go to schools, there is no comparable effort to use them or the NCTM Standards within the main exhibit halls. Pacific Science Center does directly state that mathematics is part of its mission and has made an effort to link with mathematics educators in the community. Since most exhibits were developed prior to the EALRs, tagging exhibits to corresponding Standards might be a mutually beneficial activity for both Pacific Science Center and the Washington State Mathematics Council.