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Cambium

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INNOVATIVE K-8 CURRICULUM FROM THE ARBOR SCHOOL OF ARTS & SCIENCES

In this issue

ARBOR SCHOOL
OF ARTS & SCIENCES

EVIDENCE IN ACTION

Each day at Arbor School affords numerous chances to support the idea of using evidence, both in formal lessons and in informal interactions with our students. In fact, while we may associate "evidence" especially with scientific or mathematical thinking, Arbor teachers also ask students to develop and then support their assertions during literature discussions, observations of artwork, and during "recess chat" discussions in which students are engaged in social problem solving.

In order for students to make evidenced claims, their work must grow from careful observation, engaged reading, thoughtful hypotheses, and organized data collection. It is then possible to expect a student to point to the specific sentence in a novel that made her think a character was heroic, to ask him to literally point to the area within a painting that led to the conclusion that it is set in China, or to nudge her to explain why she changed the design of her balloon-powered car after testing and consultation with her lab partners.

While ubiquitous, our requests that students gather evidence are grounded in careful language. Rather than perpetually posing the direct question, "Why?" we ask our students, "What makes you think so?" or "Teach us the thinking behind your idea." Through their own self-assessments as well as assessments of peers, we hope that students will begin to ask themselves and their classmates similar questions. Immersion in a culture that eschews random guesses (or at least identifies them as such) requires that we all support careful thinking by acting as interested and engaged listeners and reviewers of each other's work.

Just as Arbor teachers ask students to consider evidence throughout the day, we also put such thinking at the heart of our curricular planning and assessment. At any grade level, Arbor teachers begin by asking ourselves where we might look for evidence of a child's understanding a particular idea. Will a third grader point to holes or clumps of crystals in a rock he's found at the beach to identify it as an igneous formation? Will a fifth grader draw on observations of the position of the sun at various times of the year to describe the tilt of the earth on its axis? From this point, lessons and projects evolve so that students will necessarily wrestle with, communicate, and potentially improve these sought-for understandings. A chance to create "magma" out of corn syrup and sugar lets the student watch bubbles form and remain as the substance cools. Modeling the path of the sun with a flashlight against a globe helps her see the more diffuse light and shorter day experienced at northern latitudes during the winter.

As students work, teachers must continuously assess whether each student's

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understanding is valid, strong, or in need of further coaching. In preparing a lab report, just as in writing an essay, there is need for an exchange of ideas with teachers followed by revision. This analysis of evidence constitutes what we call "diagnostic teaching," teaching that responds to the individual degrees of understanding that each student necessarily presents each day rather than following a pre-packed lesson plan. Thus, the search for evidence drives each teacher's work each day.

Evidence may sometimes lead us to false conclusions, of course. The stripes in a rock that remind a student of sedimentary strata may actually be the banding of metamorphic rock. Likewise, we may misinterpret a child's understanding or intentions and correct our construal only by delving more deeply. At Arbor we find that the science of teaching requires just what we ask of our students: close observation, testing of hypotheses, data collection, discussion, and reexamination of evidence to begin the cycle anew.

– *Annmarie Chesebro, ACT Director*

PLAYFUL PHYSICS

PRIMARY ENGINEERS IN THE BLOCK AREA

by Felicity Nunley, grade K-1

"Play is the beginning of knowledge."

Sometimes the real work in school starts before class begins. In the Primary classroom, we start each day with a Choice period. After they arrive in the classroom, hang their coats on their hooks, and sign themselves in, our students get to "make a choice." For some students, that means continuing work on a book they started writing yesterday, for some it means a chess game with a friend, and for some it means being a waitress in the dress-up area.

We have also found that this informal, playful time provides a wonderful opportunity to dabble in the principles of physics. Whether they are color mixing, messing about with magnets, connecting batteries and bulbs, peering through prisms, taking apart small broken appliances, or constructing in the Junk Box, the work that the children do at Choice Time is purposeful, fueled by the enthusiasm of avid hobbyists who are driven by genuine interest to try the next experiment and to make the next discovery. Given the time to play with diverse objects and materials, children naturally work scientifically — they build, test, adjust, and re-try. Together with their classmates, they practice working in collaboration. As they work they debate design ideas, promoting the merits of a particular design while being open to the possibilities in others' ideas, and together they celebrate successes. In the end, this devoted, playful experimentation yields results that we, the teachers, would never have imagined.

Take what has been happening lately in the block area, for instance. Our block area is stocked with what you would expect: a set of large wooden blocks, a set of smaller wooden blocks, and a set of even tinier blocks with ramps and tunnels that are intended to be used to make marble chutes. At the beginning of the year, the marble-chute set was used at a table top, with children working to build a chute that would guide a marble to ring a bell. At some point, the marbles found their way over to the block area and the endlessly inspiring task of building marble chutes with the big blocks was born.

Another Choice Time favorite is Junk Box. In the back room there is a collection of "junk" sorted into "plastics," "cardboard," "metal," and "wood" and an array of tools from hammers to hot glue guns. There the children make all kinds of things: shoebox apartments for toy critters, trains with an oatmeal box as a boiler, ships with chopstick masts. They practice flexible thinking as they convert a pen cap into a bowsprit and a plastic net bag that once held potatoes into a cargo net. They get to struggle with

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We teachers quickly learned that we had to put a couple of constraints on our budding designers: 1) a marble catcher was required by code; 2) despite the undeniable thrill inherent in releasing a can full of marbles at once from the top of the chute, we had to limit the release, for our sanity's sake, to one marble at a time.

Within a few days, the builders had mastered the physics of marble chutes enough to construct chutes that changed direction several times within one run. The children designed chutes with multiple tracks, keeping a record of the marbles' paths with tallies. That quickly led to the construction of "secret compartments," little niches where marbles were likely to land according to the obstacles they encountered. The children exulted as each marble ricocheted pinball-style down the course. Naturally that led to the next innovation: the "log jam," a feature that traps a mass of marbles (a nifty way, incidentally, to circumvent the aforementioned One Marble rule.)

Most recently there has been another happy marriage of Choice Time enthusiasms — the engineers have developed a version of the card game War that is played in a marble chute. They set up cards at the end of the chute; the card that the marble knocks over is the card that is played.

As this game was invented, the block area rang out with the "how 'bouts" of possibility: "How 'bout it doesn't count if your card isn't knocked all the way down?" "How 'bout you can have two cards in the middle to guard your really good ace?" "Let's just say it doesn't count if a marble goes down there."

As they continue to play, the children identify problems with their designs. As marbles get stuck or fly off the track, they search for the reasons: "The problem is there's a gap right here," and when something goes really astray, "What the heck happened over here?" They discover that the marble needs to travel at a certain rate to knock a card over. To maximize the momentum of the marble, they remove some of the zigs and zags in their chute design and experiment with the "free fall," sending a marble off a cliff for extra acceleration. They soon realize, though, that a "free fall" is hard to control and that design feature, despite its promise of speed and power, is retired.

Their design gets increasingly sophisticated as they continue to tinker or, as they call it, "redo the obstacle courses." They grow increasingly strategic and start to predict what will happen on the course: "You're probably gonna get my two." "Your precious one should go in the back," and "This ace is very well blocked." They refer to the evidence of previous runs to inform their building choices: "Remember one of my marbles went up to the highest one and came down? So you can put your cards up here."

As well as observing the laws of acceleration and force in the block area, the children are practicing the language of collaboration and clear communication. They fetch marbles for each other, let each other know when the track is ready for the next marble, and

the mechanics of making a hinge and wrestle with designing an axle. We hope that, given a lot of time in the Junk Box, children will become resourceful, well versed in the way things work, capable of manipulating a variety of materials with their hands, and practiced in the habit of discovering possibility in a pile of recycling.

Henry's Junk Box sailboat

Quincy shows off his chute design. The photo at right shows the view from the top of the track with target cards arrayed for a game of Marble War.

congratulate each other with words like “good idea,” and “thanks.” Together they celebrate their successes, squealing in delight when a marble successfully reaches its target: “Whoa, that was a super good one!”

There are days when it is hard to ring the bell to start school, to interrupt the hypothesizing, the testing, the modifying, the re-testing, the celebrating that these kids are doing in the block area. Of course all this experimentation paves the way for the formal labs they will undertake in years to come, when they will learn to describe the physics of the marble chute in the language of science. But the play has its own merits, too. We are reminded of the playful, informal “Friday evening experiments” practiced by Nobel Prize-winners Andre Geim and Konstantin Novoselov. Their groundbreaking experiments with graphene were the results of “off the clock” curiosity. Finding and preserving time to “muck about” during the course of a busy school day can be tricky, but when children are provided with rich materials and the luxury of time for real experimentation, we find the results rewarding and exciting.

LAVA HOLES AND CRYSTAL CLUSTERS

JUNIORS BECOME ROCK DETECTIVES

by Peter ffitch and Janet Reynoldson, grade 2-3

If you have questions or comments about this article, please feel free to contact Peter directly at peter@arborschool.org.

During our ten-week study of geology in the Junior class at Arbor School we consider the relationship between energy and matter via an investigation of the rock cycle and the effects of heat, pressure, and time on the raw material of the earth. As we do so, we pick up a thread that runs through much of our thematic work: the search for evidence to support our understanding. We ask children at each step of their educational journey to be able to explain *how* they know what they know.

Our geological journey begins on the first day of school in the fall, when children bring in rocks, sand, and soil that they have collected on their summer adventures. Though we know that at this point in the year they lack the knowledge to read the story of the rocks they are holding in their hands, we take the time for a first look at what has become an interesting classroom collection. Together we sort their specimens in terms of geographical origin and then refine our sort to consider proximity to water, elevation, and any other classification that emerges from the collection or from the students’ interest. In the process we look for similarities and differences and try to draw connections between the characteristics of the specimens and the environment in which they were found. We wonder about the smooth, round shapes of the river rocks and the rough edges of those found high on the mountainside. We note that some of the rocks from faraway places look new to us and that those from our own backyard seem common. In this way we take our first step to becoming rock detectives, to finding the clues that will help us tell the story of each rock we hold.

To help our students develop an understanding of the rock cycle, we spend a week or so investigating each stage.

It is a common misconception that rocks are permanent, that they are fixed forever in the state that we find them. As we move from the first exploration of our classroom rock collection to our work in the science lab and out on our campus, it is our primary goal that students begin to see that each rock is actually always in transition: that what is igneous now will become sedimentary in time, and then morph yet again into a new form deep beneath the crust of the Earth, only to find its way to the surface once again. The centerpiece of each week is our time in the science lab, where we are introduced to the concepts and facts that inform our investigations in the classroom and beyond.

To introduce the idea of looking for evidence and to lay the groundwork for understanding sedimentation, we begin by collecting soil samples from three different locations to build familiarity with the particles and sediments that make up soil. (These samples will be made into soil sample cards: see Cambium Vol. 1, Number 2.) Here we begin to build our detective skills. Jane Lindquist, our Science teacher, sets up two different stations to help us understand both sediments and compaction. At one we examine several different sedimentary rocks to look for clues to their formation. First we look for actual sediments, large or small. Students describe them as chunks, as in conglomerate rocks, or small like grains of sugar or salt, as in sandstone. We also look for the layers that form as one layer of sediment compacts another. Through looking, touching, and questioning, we are training our eyes to seek evidence of sedimentation. At the second station we use our hands to replicate the process of compaction, the gluing of sediments together with minerals, making a solid out of tiny pieces. Sand and glue are our ingredients; we press and press until we have formed a solid mass.

Download instructions for the compaction lab and others described here at: http://www.arborschool.org/pdfs/RockLabs.pdf

Beyond the Science Barn we see our students begin to apply what they have learned. They notice layers as they dig holes on campus; they experiment with layers of soil, sand, and gravel in jars, watching water percolate through; and they examine every rock they pick up for layers or the varied larger particles of conglomerate.

Many of the rocks children bring from trips to the beaches and mountains of Oregon display neither layers nor embedded large particles but are intriguingly riddled with holes. These are igneous lava rocks. *Ignos* is the Latin word for fire, and that fire is the molten magma that cools either slowly or quickly to form igneous rocks. We take a very close look at many different igneous rocks, distinguishing between those that cool quickly from lava (extrusive) and those that cool slowly from magma (intrusive). The clues we use to decipher how the igneous rocks cool lie in the texture of the minerals present in the rocks. Imagination is needed as we explain how a slower cooling process underground would allow like minerals time to find one another, accounting for the clumping of crystals, and how quickly cooling rocks don’t allow for these formations. To further our appreciation of bubbling lava, we make “pumice rocks” from bubbling corn syrup and sugar. This shows the process of a warm liquid cooling quickly to become a solid in the manner of extrusive igneous rocks.

Max and Hastin simulate a magma bubble with a balloon in a tray of sand. Below, Stella, Peter, and Sophia investigate sedimentary and metamorphic rocks that line a man-made pond on the Arbor campus.

Children love to build volcanoes. We help them remember the three main types of volcanic mountains by having them build models out of the clay that lies beneath the topsoil all over our campus. Children designate their volcanoes as cone, shield, or strato-volcano and then enjoy creating a baking soda/vinegar eruption.

Igneous rocks are common finds in volcano-rich Oregon, and once they know what to look for, students find them at school, in their neighborhoods, and on trips to the coast. We see them applying their newfound knowledge as they explain how a hole-filled rock might have ended up on the beach where they discovered it.

Heat plus pressure plus time changes existing rocks into metamorphic rocks. We are fortunate enough to have a good collection of these on hand to examine for the telltale signs of folding or banding of minerals. There is something about touching and holding actual metamorphic rocks that gives children a sense of the change these rocks have gone through. Students express that the metamorphic samples feel denser and heavier than the two other types of rocks. After examining actual rocks, we make our own heat and pressure to transform several candy Dots into a metamorphic Dot "rock." This exercise helps our students see the ways rocks can move and melt and transform in color, texture, and shape.

One of the pleasures of working with second- and third-grade children is that they do not confine their learning to the classroom or to formal lessons. As we begin this thematic unit we tell the children that they will become geologists, and they take us at our word. During our study of geology students seem to spot interesting rocks wherever they go. Many become collectors and return to school after weekends to share finds made during family outings. Our recess area includes a wooded ravine, and our students have used their free time to dig in a stream bank where they imagine that there might be fossils. And a walk across the gravel parking lot is seen as a chance to find interesting specimens among the rough pebbles of basalt. Their discoveries spark questions and inspire trips to the library to find answers. Those of our faculty with an interest in rocks are often sought out by children anxious to share new treasures. So when we begin to explore the rocks on our campus in a more formal way, the students are ready and willing.

Armed with content knowledge gained from our weeks of study and skills sharpened by being rock detectives in the controlled environment of the classroom, we set out together to try our skills in the field. Working in groups of four or five, students search for rocks on our campus and look for clues as to their type and their place of origin. During this activity we are not expecting that children will be able to name the rocks they find. Instead, we are hoping that they will look for evidence that will help them categorize the rocks as igneous, sedimentary or metamorphic. When we hear, "Look how big the crystals are on this one, it must have cooled slowly," "I'm pretty sure this is banding right here," and "This rubs off in my hand like sand, I think it is sedimentary!" we know that children have learned to look for the clues that will tell them the story of the rock in front of them. They are giving voice to the evidence that supports their understanding.

Larger rocks have been imported as structural elements in Arbor's landscaping, as in the case of the Rill, the sculptural fountain our detectives are examining in the photo below. We make the foreign origins of these rocks clear to the children to avoid having them form misconceptions. Even so, there is value in "reading" these rocks and imagining the kind of environment they might have been imported from.

REFUTING ARISTOTLE
HOW INTERMEDIATES KNOW WHAT THEY KNOW

by Charles Brod, grade 4-5

As a teacher I find considerable tension exists between the requirement to impart a body of knowledge to students and a deeper obligation to the development of habits and attitudes that will carry them forward through years of schooling and life. It is often too easy to fall back to a stance of merely imparting content knowledge and basic skills for a discipline such as science. For elementary-aged children there is much to be explored in the world through the lens of science. However, developing the habits and attitudes of a good scientist, of a thinking individual, lie at a stratum well beneath the recitation of knowledge within biology, physics, chemistry, or other fields. A good thinker gathers evidence to support his ideas and reexamines beliefs in the light of new evidence. How do we know what we know? And how did those who came before us know what they knew?

This year at Arbor, Intermediate students (grade 4 and 5) are undertaking thematic studies of Inventions and Discoveries, an investigation of humankind's cultural and historical development. Setting the bar high, we ask them to grapple, as some of the greatest minds from previous millennia have grappled, with nothing less than humanity's place in the universe. Through construction of a timeline of the universe that stretches the 14 billion years from the Big Bang to the present day and other astronomy-based projects, students develop a sense of the immensity of time and space and humankind's minute presence on such a stage.

In biweekly meetings in the Science Barn this fall, our focus was closer — relatively speaking — to home. Students were charged with comprehending the heavenly motions of earth, sun, moon, planets, and stars. These studies provided rich opportunity for encouraging them to think afresh about the complex motions of heavenly bodies by gathering evidence through observation and modeling. Students worked collectively, in pairs, and individually to untangle ideas and uncover common misconceptions.

Mystery boxes

To highlight the ideas of investigating and observing, the first class was taken up with table groups each receiving a "Mystery of the Universe" box: a sealed cardboard container enclosing a collection of like objects. The box had several small holes through which students could poke a "probe" (a bamboo skewer). Groups were given time with the box and asked to record on large paper their observations and surmises based on the evidence their senses provided and then to report to the rest of the class. Considerable excitement surrounded the solution of each "mystery" as wooden blocks, small stuffed animals, marbles, and a variety of other objects were revealed. Through follow-up discussion this exercise served as a useful metaphor for human beings' long struggle to understand our place in the universe. It also primed them for what was to follow.

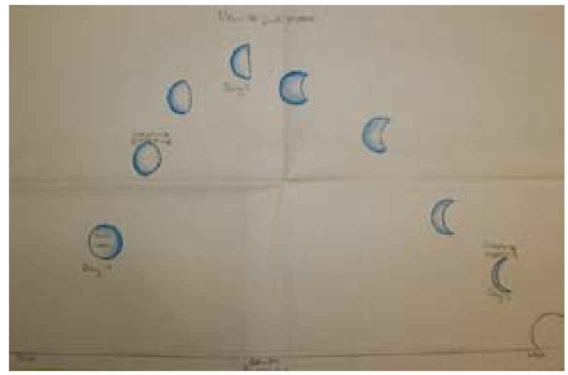
The earth and the sun

In a subsequent session the personage of Aristotle appeared before the class (yours truly in wig and costume) and presented them with the wisdom of the ancients: that the earth was the center of the universe around which all other heavenly bodies rotated. As evidence Aristotle presented the wheeling sun rising in the East and setting in the West, along with the motions of the moon and stars.

It was at this point that students truly began to invest themselves in correctly understanding and articulating their understanding of heavenly motions. They were asked to refute Aristotle and to explain the occurrence of night and day. The openness of this assignment fostered considerable discussion amongst students. Globes were sought and diagrams made. At one point we all stopped, paired up, and imagined one partner as the sun and the other as the earth. Spinning in place, the 'Earth' student had to make the sun rise in the east and set in the west, or cross from the left to right side of her face. Ultimately students expressed their understandings in words and drawings in their science journals. An important component of this work was the process of student drafting, teacher commenting, revision, and a final copy.

… and the moon

Next we worked to further refine student thinking about the motions of the moon. Students had observed the moon as homework over the summer during daylight hours in the morning. They then observed the moon moving from new to full over the course of two weeks in the evening. In class moon phases were modeled with a styrofoam ball on the end of a pencil in front of a light bulb (see Cambium Vol. 1, Number 2). Students drew on their observations and experiences to construct two drawings, the first teacher-led and showing the progression of the moon from new to full, and the second independently executed, showing the second half of the cycle from full to new.



Lily's illustration of the phases of the moon

Throughout this work and beyond, an emphasis was placed on students' expressing what they understood *at that moment* and refining it further in detail and depth. It wasn't uncommon for students to reveal misconceptions: the moon is always "behind" Earth and the sun; the earth revolves around the sun to create a day; seasons are caused by the proximity of the earth to the sun. By design science sessions became an iterative process of introducing ideas, exploring them, making initial attempts at explanation, receiving feedback, and finally creating a more sophisticated explanation:

We feel it is critical to establish a classroom culture in which it's perfectly acceptable for initial ideas to be wrong. Scientists and other good thinkers need freedom to make many wrong guesses in pursuit of new knowledge.

"Dear Aristotle, my understandings of the earth and moon are much different than yours. After much studying I believe that the earth revolves around the sun, instead of everything revolving around the earth. The earth also spins in its own axis, this makes night and day. Night and day happen when the earth is spun so half of it is facing the sun. It's day. But the part facing the sun slowly spins until it's not facing the sun. When it's not facing the sun, it's night." – *Maxwell*

"Dear Aristotle, here is what I know about night and day: The earth spins to the east on its axis. The earth's axis runs from the North Pole to the South Pole and is tilted at about 23 degrees. As the earth spins it shows different hemispheres to the sun. The hemisphere that is illuminated by the sun is in daylight. The hemisphere facing away from the sun is in night. I know this because every day I see the sun rise in the east and set in the west." – *Olivia*

The seasons

This process work had its fullest expression as the Intermediates tackled the complicated reasons for the seasons. Aristotle made another appearance to read the story of Persephone, the Greek myth of how the seasons came to be. Once again challenged to reveal their own thinking, students wrote an initial statement about their understanding of the seasons. Leila wrote a poem: "Fall: The wind blows / it is cold / the leaves flow and look like gold." Lily wrote, "There are four seasons, summer, spring, winter, and fall. Each season lasts about a quarter of the year." Miah explained, "When our country is facing the sun, it is summer, since the sun's heat is facing us. When our country is not facing the sun, however, it is winter. This is the reason for the seasons in all countries, states, and continents."

From this launching point, we spent several classes wrestling a series of questions:

- *What evidence do you have from the environment that the earth is tilted on its axis?*
- *What evidence do you have from the environment that the earth orbits the sun?*
- *Describe the climate of the tropics. Describe the climate of the polar regions. How do you explain the differences between these regions of the globe?*
- *'The seasons are caused by the distance of the earth from the sun.' Give evidence to support or deny this claim.*
- *Sun dials show the daily passing of time. What might you use to record the passing of the year?*
- *The sun's path across the sky differs throughout the year. How does it differ from season to season?*

Students presented their answers to the rest of the group, often in the form of skits and demonstrations.

Physical modeling also helped support student thinking. After we shone a flashlight beam against a large sheet of graph paper to calculate the area over which the beam's energy was spread when the light source was directly overhead (as in the tropics) versus at a lower zenith (as in the higher latitudes), Miles was able to write, "When the sun is high in the sky its rays hit a concentrated spot, so it's hotter. When the sun is low in the sky a little, the rays are at an angle, so it diffuses (spreads out) and it's cooler."

Intermediates were also able to think about the earth's tilt by making use of the curved space of our Amphitheater: by standing along different lines of "latitude" in this half-circle, they could observe the relative height of "the sun" (a ball passed overhead by the teacher) in the sky.

Physical modeling by Leila, Louise, Solomon, Seth, Peach, and Nolan

All this work had a final culmination in a written piece that encapsulated each student's newly refined understanding about the seasons:

"The earth revolves around the sun, but if it didn't, we would be stuck in a single season. If it didn't take a year to go all the way around, the seasons would be longer." – *Lily*

"The main reason for the seasons is because of Earth's tilt, and the axis of rotation around the sun. The rotation of the earth around the sun causes the seasons while the tilt causes how many hours there may be of daylight, from season to season. For example, the autumnal equinox has equal amounts of day and night, and so does the spring equinox, all because of the tilt. Also because of the tilt, winter has fewer hours of daylight, while summer has more." – *Miah*

Some useful books:

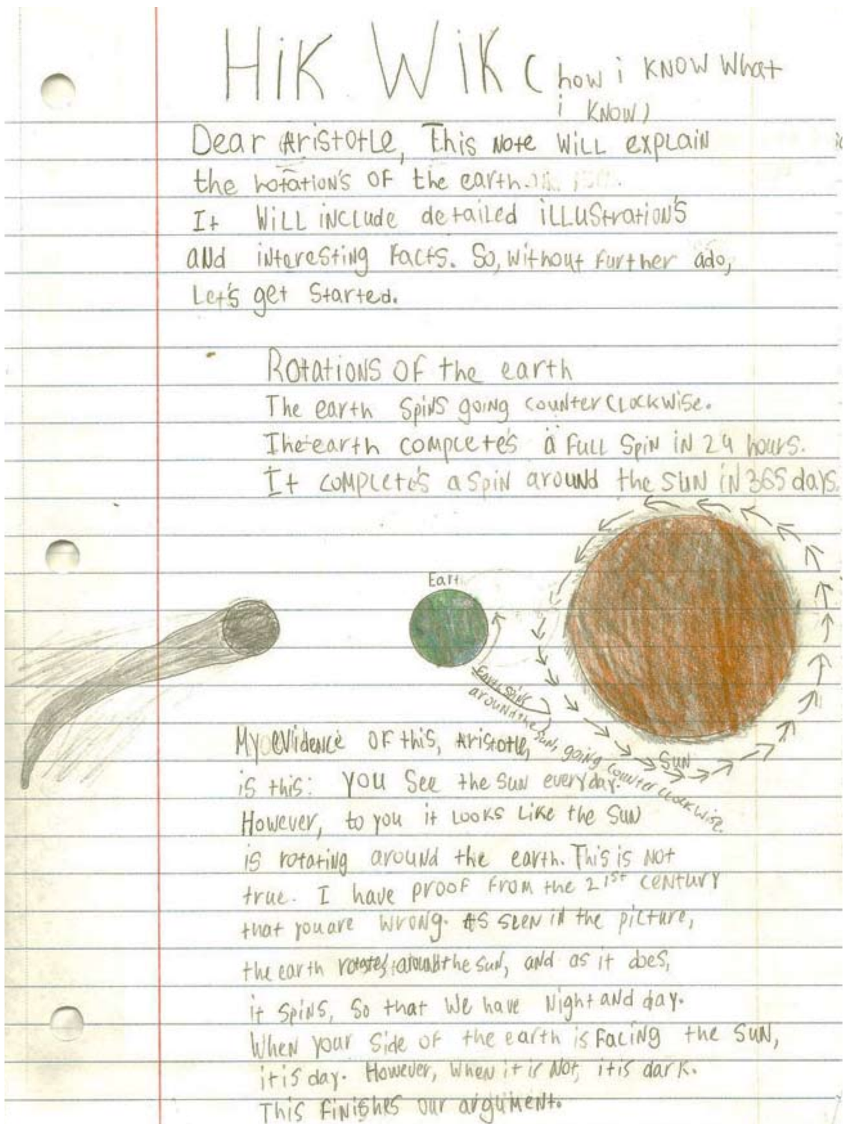
– *Heath, Robin.*
Sun, Moon, & Earth
A little book packed with mathematical information about the motions of these bodies, beautifully illustrated by the author. Best for students who are advanced readers and thinkers.

– *Long, Kim.*
The Moon Book
Clearly written and illustrated with effective diagrams and maps; covers all things to do with the moon. Accessible to good readers, but probably most useful for lesson prep.

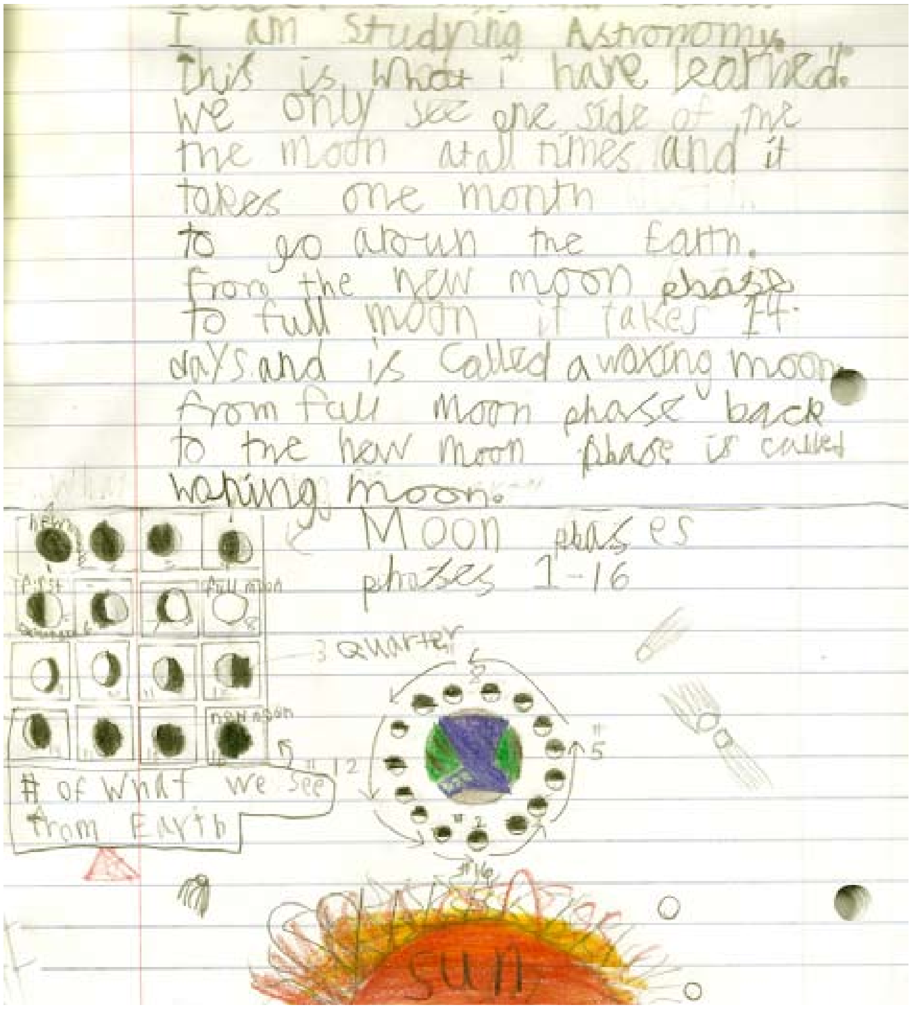
– *Stepans, Joseph.*
Targeting Students' Science Misconceptions: Physical Science Concepts Using the Conceptual Change Model
A book designed to help teachers guide students through meaningful modeling exercises. It doesn't really address the science content behind the exercises, but it helped me think through what I wanted children to express in their Hik Wiks.

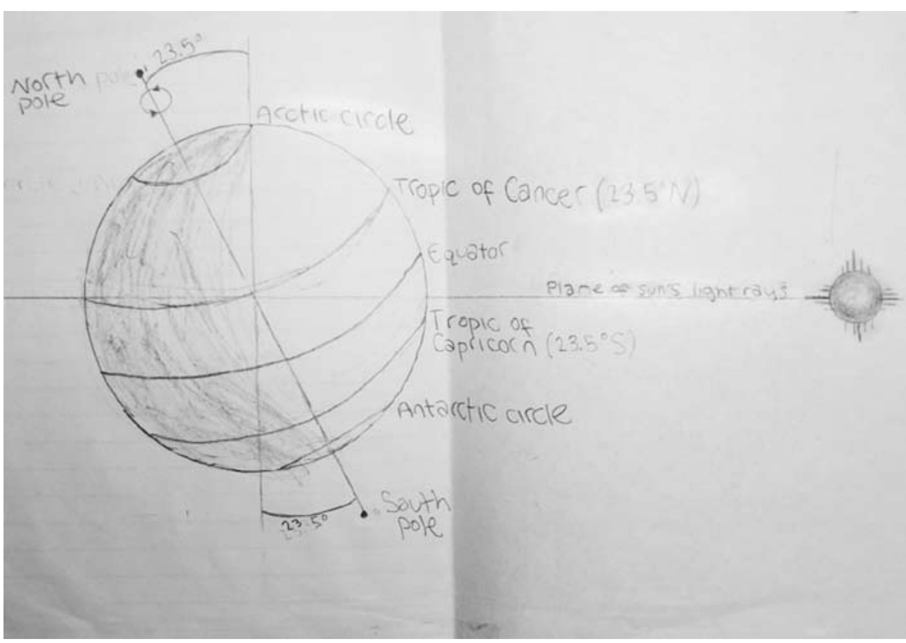
Hik Wiks

These final explanations have come to be known as Hik Wiks — How I Know What I Know — in Science and serve as capstones to units of study. Students write and diagram their understandings about the creation of night and day, the phases of the moon, and the reasons for the seasons. As individual expressions of understanding, the Hik Wiks demonstrate each student's ability to synthesize information from various activities and experiences. I know that I am reaching those underlying goals of creating solid habits and attitudes when these pieces are unique and individual expressions of understanding and read as such. These final pieces allow students to rehearse and cement their understandings on the subject while practicing a range of writing and illustration skills. As a means of assessment, they allow me to gauge not only content knowledge but also each child's process of formative thinking and drawing on evidence. These are ideas that students have struggled to understand on their own terms and the sweat of that grand struggle often shows in the work on the page.



Miah's final Hik Wik about the motions of the earth





Hik Wik excerpts: Miles's understanding of the phases of the moon (above) and Lily's diagram of the earth's tilt (below)

ACCORDING TO NEWTON

SENIORS DESIGN (AND REDESIGN) BALLOON CARS

by Jane Lindquist and Johannah Withrow-Robinson, grade 6-8 Science

Our Sixes needed practice constructing graphs, particularly in choosing the proper scale for the x- and y-variables. Most Arbor Seniors do not encounter two-variable graphing in the math curriculum until the seventh grade. We worked to help all our students understand that the graph paper squares do not need to represent the same value for the x- and y-axes.

Most students worked in pairs during this lab.

Arbor students engage in a three-year curriculum cycle in Science during their sixth- through eighth-grade years. This year they are absorbed in studies of Energy and Motion, undertaking a series of experiments that sound Newton's Laws. Our philosophy that abstract principles are best first understood through thoughtful observation and well-designed, first-hand experience has led the Seniors through a set of labs on friction, inertia, speed, velocity, acceleration, and force. As an example, in order to gain familiarity with friction and inertia, students measured the force in Newtons required to move a stack of two textbooks 1.5 meters across a table by wedging a rubber band between the books and pulling the rubber band with a spring scale. They then tried to decrease the friction acting on the books by placing different objects beneath the books. One team decreased the force from 8 N to 0.5 N by letting the books roll on top of pens. Throughout their lab experiences, the Seniors have practiced accuracy in data collection and graphing.

Mastering graphing skills has been a priority because data from physical science are commonly expressed in graph form; the ability to construct and draw conclusions from graphs is essential. Graphs that Seniors have completed this fall document their investigations of the average speed of a marble roll, their walking speed, the acceleration of Hot Wheels cars released from varying ramp heights, and the distance an object rebounds after crashing into a barrier at varying speeds.

Our most recent work has been the popular Balloon Car challenge used by many schools as a summative experience in studies of the Laws of Motion. We have chosen to reinterpret this experiment as a formative experience, however, in which the children's understanding of the Laws of Motion becomes transparent and then informs the true summative assessment: a group evaluation of results and mistakes that separates technical issues from those arising from the Laws and culminates in a new design for a supercar. A successful outcome for this activity is for each student to be able to critically evaluate his design and to articulate ideas for improving it based on his understanding of the Laws of Motion and the evidence of the car's performance.

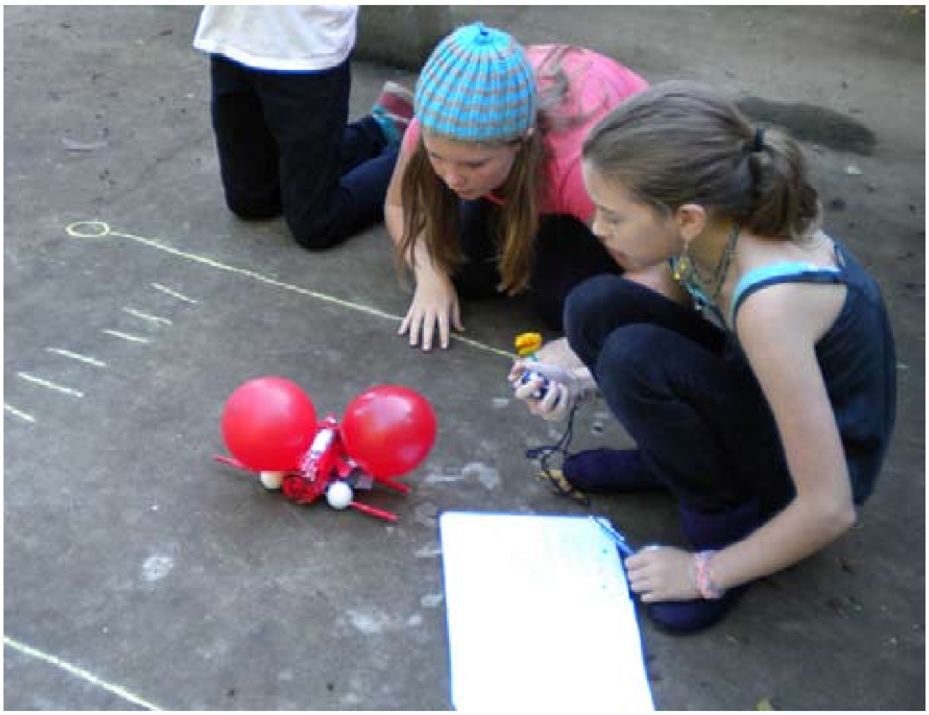
The challenge

Outside forces tend to interfere with Newton's Laws of Motion. Using the force from one or two balloons to power your car, you will discover how tricky it can be to account for the effects of inertia, friction, and other factors you have studied.

- *The car must be powered by balloons.*
- *You can build the car out of anything.*
- *It must have at least three wheels. Wheels are defined as anything that is round and goes around.*
- *The wheels may not be wheels from a toy car, etc. They must be made out of something that was not originally meant to be used as wheels.*
- *The car may not leave the ground.*
- *The car should travel at least 5 meters.*
- *Balloons and straws will be provided.*

The creative possibilities in developing a car design intrigued everyone. Which wheels would roll the best? Which type of axle would spin the best? Which design would generate the greatest momentum? How do you make an aerodynamic car? How much friction do the wheels need to have? Students knew that the only force helping their car accelerate would be from the air escaping the balloons. Most were able to apply Newton's Second Law, which shows that acceleration equals force (air from the balloon) divided by mass (of the car), to understand that mass would be a key variable.

At home, students gathered materials: ping-pong balls, juice caps, jar lids, plastic balls, candles, CD's, bobbins, and thread spools became wheels. Some students placed thick rubber bands or tape around their wheels to increase friction while others applied Vaseline to decrease friction. Many thought that using two large balloons would create the greatest force and thus push their car the farthest; their knowledge of the Third Law (for every action there is an equal and opposite reaction) led them to identify the escaping air as the force and the balloon/car unit as the object being acted upon. Axle materials included straws, toothpicks, dowels, nails, and screws. Car frames were built from styrofoam, cardboard, balsa wood, aluminum cans, and plastic bottles. No two cars were alike and students created unique designs while giving thought to force and motion.



Helen and Alice time their balloon car on the trial course and graph the results

Revision

Many of the Seniors discovered flaws, major or minor, in the designs of their cars once they actually assembled them. Some groups had enough time to re-build or modify their cars after initial test trials. A few groups tested their cars on different surfaces to see how varying friction affected speed. They traded votive candle wheels for bottle caps, wire axles for wood dowels, and replaced plywood bases with balsawood. Whether or not the students had time to tinker with their designs, all of the groups had ideas for modifications to their theoretical next racecars based on the evidence of Newton's Laws and other physics concepts in action.

Students knew that the First Law of Motion states that an object at rest will remain at rest unless an outside force acts on it. A number of groups reduced the mass of their car by "using a lighter base for the body, such as styrofoam," as they had discovered through both the formula $F = ma$ and from experience that mass is integral to how fast the car will be able to accelerate. Cars with greater mass experienced greater inertia; designs with a greater surface area also met with greater air resistance. But some groups also calculated that a heavier car would have greater momentum to continue rolling forward if the inertia could be overcome. One group did choose to increase the mass of their 9-gram car after the initial trials.

Other student groups aimed to change the direction of the air escaping from the balloons, reasoning that if it hit the ground at a 45-degree angle, the force would push back off the ground to power their car forward. As one student wrote, "I observed that when I had the straw pointed all the way down my car hardly moved. After that I had the straws pointed all the way horizontal and that didn't make the car go any farther or faster so I tilted the straws halfway in between and the car worked out well." Others decided they would change the balloon type they used. One young engineer designed a car with one long, skinny balloon for initial speed and a larger, standard balloon for sustained force: the air would escape more quickly from the long, thin balloon to provide a quick burst of force to overcome the car's initial inertia. Another student stated, "With the balloon car, we can actually see that little things that we change can make enormous differences in the functioning of our car." The challenge was for students to integrate all they knew about the concept of motion with the evidence from their previous labs.

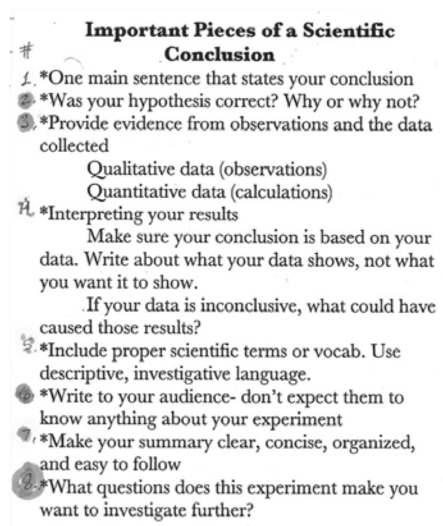
Technical issues plagued many of the cars; the wheels were often a main source of friction and frustration. "We should have focused on ways to stick the wheels on but still have them move," lamented one designer. In their future plans, many students mentioned that they would alter the attachment of their wheels so they could roll more smoothly. Friction occurred from the power source itself in some cases. On many cars, the balloons dragged on the ground when they were fully inflated. One student said that next time she would "build a taller structure to hold up the straw and balloon so that I could blow the balloon up bigger and it wouldn't drag on the ground."

Lab reports

A solid lab report required the students to make accurate observations, record data, come up with sound explanations as to why their car was or was not able to travel 5 meters, and finally to suggest modifications to their car to increase the distance it traveled. To help them succeed in meeting these criteria, teaching apprentice Johannah Withrow-Robinson led a mini-lesson to guide students through a self-assessment of their first drafts. Johannah writes:

Johannah's list of essential components and an exemplar are available for download here: http://www.arborschool.org/pdfs/ScientificConclusions.pdf

Because reflection on the lab is so important, we have been focusing on writing scientific conclusions. We wanted our expectations to be explicit and accessible and packaged in a way that students could refer back to for future assignments. After they had written summaries for a few lab activities, we spent about 15 minutes as a whole group brainstorming the components essential to a conclusion that is well written and that clearly presents the data from the experiment.


Important Pieces of a Scientific Conclusion

*One main sentence that states your conclusion
*Was your hypothesis correct? Why or why not?
*Provide evidence from observations and the data collected
Qualitative data (observations)
Quantitative data (calculations)
*Interpreting your results
Make sure your conclusion is based on your data. Write about what your data shows, not what you want it to show.
If your data is inconclusive, what could have caused those results?
*Include proper scientific terms or vocab. Use descriptive, investigative language.
*Write to your audience- don't expect them to know anything about your experiment
*Make your summary clear, concise, organized, and easy to follow
*What questions does this experiment make you want to investigate further?

At a later time, we also brainstormed and recorded a list of important "thinking words," such as "I observed," "As a result of," and "Although," that students should use in their conclusions.

To practice recognizing these components, we created a brief lab summary that included each of the elements on their list. We then asked students to identify and label each element where they found it in the sample summary. Both the list and the summary were pasted into their Science journals as an exemplar against which students can check future work.

Students were then asked to apply what they had practiced to their own writing. Before they handed in the first draft of their balloon car lab reports, we asked them to check their own conclusions for these essential concepts and then to trade with a partner and check their peers' writing as well.

Students' first drafts of their lab reports tended to focus on technical challenges their cars had faced, such as wheels that didn't roll smoothly enough or weren't connected securely to their axles. For their final drafts, they were required to articulate how the Laws of Motion had affected the results. Each student explained in writing how she would make changes to their car to increase the distance it could travel in a straight line:

"My car went farther on concrete than it did on the flat surface of the classroom and I think this is because my car had wheels that were smooth so it was hard for them to grip a smooth surface. For another race on a smooth surface I could add traction to the wheels with rubber bands."

"I would build a better structure to hold up my straws and I would make sure it is strong. I wonder if a car made with more than two balloons would work? I wonder this because when I tried just two balloons it didn't work because the car would stop when the balloons touched the ground or each other. I might test this by making a wide and long car that is close to the ground and spacing the balloons far apart so they wouldn't cause friction and slow the car down."

Summative design

Next each class was divided into two groups to share their information and brainstorm ways to build the most efficient balloon car. Each group had to write a new hypothesis based on its members' previous results and then build a new car to compete in one final test, presenting their revised design to the other group and explaining how they had taken the Laws of Motion into account. In the seventh-grade presentations, one group explained:

"We decided to wrap long balloons around our axles [and stretch them] to create force when you let our car go [in addition to] the original idea of balloons pushing air out of straws to propel the car forward. We used Newton's First and Third Laws of Motion: the First Law in that once air is done escaping our balloon and our long balloons are done unraveling, the car still keeps moving, due to inertia. We used the Third Law in that we had actions and reactions: the actions of the air coming out of the balloon and of the long balloon unwrapping from the dowel both caused the reaction of our car moving forward."

The other group focused on reducing mass:

"We decided to make our car very light so the acceleration will be greater. This uses the Second Law of Motion: acceleration equals force divided by mass. Take a real-world example: sports cars go at a very high speed, and you don't see sports cars the size of buses. This is because, for a greater acceleration, you need a smaller mass."

Every group was gratified to see its improved design travel farther than any of the original cars. We teachers measured their success by their ability to demonstrate how the Laws of Motion affected the cars' performance and to manipulate their designs accordingly.

ARBOR SCHOOL
OF ARTS & SCIENCES

4201 SW Borland Road
Tualatin, OR 97062

Cambium

INNOVATIVE K-8 CURRICULUM FROM THE ARBOR SCHOOL OF ARTS & SCIENCES

THE ARBOR CENTER FOR TEACHING AT
ARBOR SCHOOL OF ARTS & SCIENCES

Arbor Director: Kit Abel Hawkins
ACT Director: Annmarie Chesebro
Editor: Sarah Pope
Design: Mary Elliott
Photos: Sarah Pope, Jane Lindquist, Felicity Nunley

4201 SW Borland Rd.
Tualatin, OR 97062
503.638.6399
cambium@arborschool.org

Cambium: (n) the cellular growth tissue of trees and other woody plants, from medieval Latin "change; exchange."

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Masthead by Jake Grant, after an 1890 botanical illustration.

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Grace readies her balloon car for trial

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ASSESSMENT

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