NOTES from the FIELD

Teaching for

Conceptual Change:

Uncovering

Student Thinking

in Science

Through

Action Research

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NOTES from the FIELD

Teaching for Conceptual Change

Edited by Joyce Tugel with an Introduction by Page Keeley

Maine MATHEMATICS and SCIENCE Alliance

Maine MATHEMATICS and SCIENCE Alliance

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Introduction

The practice of teaching, even for teachers who do not think of themselves as researchers, is one in which the elements of research are present. Asking questions about practice, collecting evidence, making sense of the evidence, and sharing conclusions with others: These activities are happening all over schools during every school day, and they are elements of research. (Roberts, Bove, and van Zee, 2007).

The monographs you are about to read are the capstone professional development experience of teachers involved in a grades K-8 science professional development partnership grant awarded to the Maine Mathematics and Science Alliance (MMSA) by the Maine Department of Education with funding from the U.S. Department of Education's Math-Science Partnership Program. Four school districts, including Maine SAD 35, Maine SAD 60, Maine School Union 29, and the Auburn School Department, with faculty and professional development partners from the University of New England (UNE) and the Maine Mathematics and Science Alliance (MMSA) participated in this three-year professional development program called the Science Content, Collaboration, and Conceptual Change (SC4) Project.

The elementary and middle school teacher researchers who contributed the monographs in this publication participated in a rigorous three-year continuum of professional learning by building, applying, and producing knowledge about teaching and learning in the physical sciences. Their professional journey began by *building* new knowledge of conceptual change teaching in the first year; transitioned to *applying* their knowledge using strategies such as formative assessment to elicit their students' ideas, and culminated in *producing* new knowledge through teacher action research using the CTS Action Research Model (Mundry, Keeley, and Landel, 2009). The SC4 focus on teacher action research is in direct keeping with the National Research Council's recommendations that professional development create teachers who are *producers of knowledge about teaching* (NRC 1996). For most of these teachers, this was their first experience with teacher action research; and the results are quite impressive!

Action research is a professional development strategy that has had a long and varied history. First introduced in the 1940's, action research has evolved into a variety of different forms in the education community. All of these forms involve some type of ongoing process of systematic study in which teachers examine their own teaching and students' learning by posing questions, collecting and analyzing data, drawing conclusions from the evidence gathered and analyzed, and reflecting on what was learned through the action research process. One of the benefits of teacher action research as a teacher learning strategy is that teachers have ownership over the professional development process and are committed to promoting changes in practice indicated by their findings (Loucks-Horsley, et al, 2003).

The action research model used in the SC4 project is a specific type of inquiry that combines curriculum topic study (Keeley, 2005) with an examination of teachers' own students' thinking using formative assessment probes (Keeley et al., 2005, 2007) and a variety of data collection techniques designed to reveal alternative students have about science concepts. Furthermore, the process provides teachers with new insights into how they can build a bridge from where their students currently are in their understanding to where they need to be as science learners. This CTS Action Research model was developed for the NSF-funded Curriculum Topic Study (CTS) Project and piloted with the SC4 teachers in the context of physical science and conceptual change teaching.

CTS Action Research differs from other types of action research because it focuses specifically on understanding student thinking related to important concepts or skills in the standards. It is an informal type of teacher research that relies less on rigid data collection protocols and quasi-experimental design and more on methods that involve exploration and reflection on teaching and learning in an individual's own classroom. The CTS Action Research can be conducted by an individual teacher in his or her own classroom or as a collaborative action research project conducted by two or three teachers. It can be embedded within a variety of professional development structures, such as the Math-Science Partnership programs, professional learning communities, reflective practice groups, etc. and embodies the characteristics of transformative learning that are reflected in high quality professional development.

The goals of CTS Action Research are to:

— Investigate questions of direct and immediate interest to a teacher.

— Deepen teachers' understanding of commonly held student ideas and implications for curriculum and instruction.

— Generate and share CTS and new knowledge with colleagues.

The literature search that preceded the teachers' action research that is described at the beginning of each monograph came from doing a curriculum topic study (CTS). CTS was an integral component of the SC4 professional development. The teachers learned how to use and apply the tools and resources of CTS throughout the different stages of the SC4 professional development. CTS provided a lens through which teachers could focus on the key ideas in the standards and how those ideas are made accessible to students through effective instruction and a coherent curriculum. It also engaged the teachers in using the research on students' commonly held ideas in science to uncover their own students' preconceptions and learning difficulties.

Using a variety of formative assessment techniques and tools, teachers collected information on their own students' thinking related to key ideas in standards-based science. The data collected and analyzed from their own students and school context was looped back to the CTS findings in order to inform action steps to be taken as a result of the study.

Before conducting their research the teachers met with their colleagues from the SC4 partner schools and MMSA professional development specialist, Joyce Tugel, to learn about action research and how to conduct the CTS Action Research model. This professional development support was essential in preparing the teachers to conduct their research as well as build a collaborative community of teacher researchers who supported each other throughout the process. The teachers commented that it was one of the best professional development experiences they ever had. A culminating event for the teacher researchers was the opportunity to display their posters and share their research projects at the Teacher Research Day during the 2008 NSTA National Conference in Boston.

For teacher leaders and staff developers who are interested in replicating the CTS Action Research model in their setting, a full description of the CTS Action Research Process along with the tools to facilitate the professional development is available in *A Leader's Guide to Curriculum Topic Study- Designs, Tools, and Resources for Supporting Professional Learning* (Mundry, Keeley, and Landel, 2009). The following summarizes the steps the SC4 teachers went through during the action research process. As you read the monographs, you will see each of these sections reflected in their writing:

Step 1

Defining the Purpose of the Study

In this step, the teachers were asked to think about what they wanted to learn from their classroom research and how it could help them as a teacher. Questions asked during this step included:

- What student learning problem related to a specific concept or skill in the curriculum would you like to learn more about?
- Why is it important for you to learn more about this problem?
- What do you hope to learn about your students?
- What do you hope to learn about your teaching?

Step 2

Formulating Three Specific Questions to Guide the Research and Future Actions

Three specific questions guide the research. These questions ground the teacher researcher in the standards and research on learning, focus the research on ideas teachers' own students have, and help identify factors that may have contributed to students' ideas that can be used to inform instruction. The three questions include:

- One question focused on finding out what the specific ideas are in the standards and what research says about student learning related to the concept or skill selected.
- A second question focused on the ideas the students may have about the concept or skill. These ideas may be commonly held ideas similar to the research findings, commonly held ideas that are not noted in the research, or idiosyncratic ideas that some students have that are worth noting.
- A third question focused on what may have impacted or contributed to the students' ideas that could inform future actions the teacher might take. These may come from life experiences, activities encountered in school, curricular gaps, etc.

Step 3

Formulating an Overarching Question and Title

In addition to the 3 specific questions that will guide the research, the teacher researcher develops one overarching question that frames the study.

- Consider the purpose of the research and the three specific questions to formulate one overarching research question.
- Use or adapt the overarching question to be the research project title.

Step 4

Conduct CTS Background Research

Teachers first conduct a CTS to ground their study in standards and research before examining their students' ideas. This is similar to conducting a literature review. The CTS background research provides information about the content, specific ideas in the standards, curricular and instructional considerations, and research on student learning. The information is used to clarify teachers' own (or the reader of the monograph) understanding of the content as well as examine the specific content and skills the students at the grade level are expected to know and do. The suggestions from the national standards and findings from the research provide the teacher researcher with a lens through which to critically analyze the students' thinking, difficulties they have, or prior experiences that may have impacted their learning and inform actions the teacher might take as a result. The following describes the CTS background research steps conducted prior to starting the research study with the students:

- Choose the CTS guide that matches the concept or skill that is the subject of the research.
- Clarify what all science literate adults should know about the concept or skill (CTS Section I).
- Identify specific ideas related to the concept or skill at the targeted grade level that are described in the national standards (CTS Section III and V). Note the terminology and sophistication of the ideas.
- Identify specific ideas related to the related concepts described in your state standards, district frameworks, or curriculum materials (CTS Section VI).
- Identify teaching considerations to be aware of, such as appropriate contexts for instruction, relevant phenomena, common difficulties, developmental issues, and instructional approaches (CTS Section II).
- Identify related findings from cognitive research such as commonly held ideas, types of reasoning used, and age-related differences in student thinking (CTS Section IV and notes from V).
- Examine a strand map for coherency and connections, making note of important prerequisites that contribute to understanding the concept or skill (CTS Section V).

- Identify any supplementary resources from the CTS web site at *www.curriculumtopicstudy.org* that contribute to the above and add to the background research.

Step 5

Identifying and Collecting Classroom Data – Triangulate!

Choose at least 3 types of data to collect that provide information about the students' thinking and provide valid and reliable data for the research questions. Data can be quantitative and/or qualitative. Examples can include but are not limited to:

- Assessment probes (published or teacher-designed)
- Specific tasks students are asked to complete
- Informal student interviews
- Formal, structured student interviews
- Observations during activities
- Notes recorded from class discussions
- Surveys, Questionnaires, Likert Scales
- Concept Maps
- Labeled or Annotated Drawings
- Card Sorts
- Transcripts of students' discussions

Step 6

Organizing and Displaying the Data

Think about different ways to organize and display the data. Suggestions include but are not limited to:

- Probe tier 1 response graphs
- Categories of reasoning
- Transcripts
- Class profiles
- Annotated examples of student work
- Charts and tables

Step 7

Analyzing the Data

An analysis of the data will drive interpretations that lead to supportable and logical conclusions and action steps. Questions to guide the analysis include:

- What patterns, trends, or similarities do the data show?
- Is there a relationship between the CTS findings and the student data?
- Is there a need to disaggregate data or collect further data?
- What might be some limitations of the study?
- What inferences can be drawn from the data that might require further investigation?
- What conclusions can be drawn from the data?

Step 8

Connecting Findings to Teachers' Work

This is the stage where teacher researchers make sense of both the CTS and student evidence in light of their own work and decide on actions to take. It is also the time to think about the significance of the findings for others.

- What significance do these findings and conclusions have for the classroom?
- What actions will be taken as a result (e.g. how might teachers improve upon instructional materials, change teaching approaches, etc.)?
- How could other teachers benefit from the research study?
- How will the research be shared with others- faculty meeting? Informal or formal published paper? Poster session? Professional learning community forum?

Step 9

Reflection

It is important for teachers to take the time to reflect on the impact of the CTS action research they conducted. Teachers reflect on how they now think about their students and their learning as well as their teaching practice. Another critical part of the reflection includes sharing how the action research process impacted teachers' professional learning and beliefs about professional development. Teachers are encouraged to use a reflective journal throughout the process and share excerpts from it in their monographs.

- What significance did the action research project have in helping understand students and their learning?

- What impact did the action research project have on teaching?
- What is the value of CTS action research as a form of professional development?

Step 10

References and Artifacts

Materials used to carry out the research should be cited and artifacts shared where appropriate.

- Include a bibliography of all references cited.
- Include samples of forms and instruments used if not included in the body of the research.
- Include student artifacts where appropriate following district guidelines for using student work or images.

As you read these monographs, you will see the knowledge-building, action research process come to life through these teachers' eyes. The same process of inquiry that engages elementary and middle school students in an inquiry-based science classroom has invigorated these teachers and deepened their understanding of student learning. The process of asking questions about learning and collecting data in a quest to find answers to these questions has transformed these classrooms into the types of learner-centered environments described in *How People Learn* (Bransford et al., 1999). By sharing their lessons learned through this publication, these teachers contribute to the learning of all educators the SC4 community as well as outside of it.

And finally, on behalf of the Maine Mathematics and Science Alliance, I want to acknowledge the pioneer work of these teachers who diligently piloted this new model of CTS Action Research while being receptive to new ways of learning; and in so doing, aptly demonstrated a tremendous degree of professionalism. The intellectual work of these teachers, guided by the outstanding leadership and professional development support provided by their SC4 facilitator, Joyce Tugel with the help of her MMSA colleagues Nancy Chesley and Mary Dunn, has generated knowledge we can all benefit from as we work collaboratively to narrow the gap between research and practice.

Page Keeley,
Senior Science Program Director and
SC4 Co-Principal Investigator

Maine Mathematics and Science Alliance

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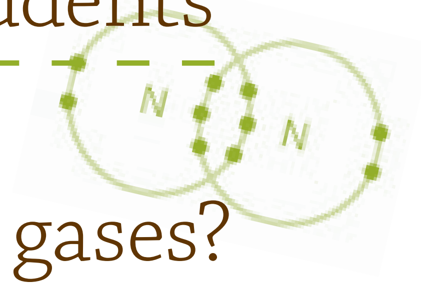
How do my Eighth-Grade students perceive the behavior and characteristics of gases? Exposing students' ideas on the particulate nature of gases



Steve Barteaux

Noble Middle School

Berwick, ME

Steve Barteaux is an eighth-grade teacher in Berwick, Maine. He has been teaching Chemical Interactions, Planetary Science, and Populations and Ecosystems for the past three years. A Maine native originally from Norridgewock, Steve currently resides in South Berwick. He is a member of his school district's curriculum development team.

Purpose of the Study

I chose to explore student thinking within the area of the particulate nature of matter because I will teach a chemical interactions unit for the first time during this action research investigation. Past teaching experiences also have shown me that my students seem to lack both the exposure to and understanding of the particulate nature of gases. The data and experience gained in this process will help me more accurately identify areas of misunderstanding as well as aid future instruction.

Research Questions

1. What does the research say about middle school students' understanding of the particulate nature of gases?
2. Which ideas do my students have to explain the concept of the particulate nature of gases?
3. Which areas within this concept should I spend more time developing when I teach this unit?

Curriculum Topic Study (CTS)

Background Research, "Particulate Nature of Matter (Atoms and Molecules)" (p.169) (Keeley, 2005)

Clarification of the content from *Science for All Americans* (SFAA) and *Science Matters* (SM)

- At high temperatures, the agitation of the atoms and molecules overcomes the attractions between them and they can move around freely, interacting only when they happen to come very close—usually bouncing off one another, as in a gas. (*SFAA*)
- Many gases, like the air you breathe, are invisible, but you know something's there when the wind blows. (*SM*)
- The distinctive feature of all gases is their ability to expand, filling whatever volume is available. This behavior reflects the atomic structure of gas. (*SM*)
- If we could magnify gas atoms and molecules a hundred million times they would look like the wildly flying Ping-Pong balls of lottery games. Gas particles do not stick to one another, but rather careen off walls and collide with other particles. (*SM*)

Student learning goals *Benchmarks for Science Literacy (BSL)*

Grades 6-8

- All matter is made up of atoms, which are far too small to see directly through a microscope.
- Different arrangements of atoms into groups compose all substances.
- Atoms and molecules are perpetually in motion. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions.

Student learning goals from *Maine Learning Results*, 2007

Grades 6-8

- Describe that all matter is made up of atoms and distinguish between/among elements, atoms, and molecules.
- Explain the relationship of the motion of atoms and molecules to the states of matter for gases, liquids, and solids.
- Explain how atoms are packed together in arrangements that compose all substances including elements, compounds, mixtures, and solutions.

Student learning goal from *Full Option Science System (FOSS)®: Chemical Interactions*

- Students investigate the macroscopic properties of gas and develop a particulate model to describe the invisible composition and interactions that account for the observable behaviors of gas.

Teaching considerations from *Benchmarks for Science Literacy (BSL), National Science Education Standards* (NSES), and *Making Sense of Secondary Science* (MSSS)

- Middle-school students have trouble with the ideas that all substances are composed of invisible particles and atoms are in continual motion. Coming to terms with these concepts is necessary for students to make sense of atomic theory and its explanatory power. (*BSL*)
- There is a need for effective teaching strategies to lead students from a macroscopic to microscopic understanding of matter. (*BSL*)
- At this grade level (middle school), elements and compounds can be defined operationally from their chemical characteristics, but few students can comprehend the idea of atomic and molecular particles. (*NSES*)
- A study of high-school students proposes the use of a conceptual-conflict-based teaching strategy for particle theory. (*MSSS*)

Cognitive research from *Benchmarks for Science Literacy* (BSL) and *Making Sense of Secondary Science* (MSSS)

- By the end of eighth grade, students should have a sufficient grasp of the general idea that a wide variety of phenomena can be explained by alternative arrangements of vast numbers of invisibly tiny, moving parts. (*BSL*)
- Students often get the idea that atoms somehow just fill matter up rather than the correct idea that the atoms *are* matter. (*BSL*)
- Elementary- and middle-school students may believe that matter does not include liquids or gases or they are weightless materials. (*BSL*)
- Middle-level students are deeply committed to a theory of continuous matter. (*BSL*)
- Students of all ages have difficulty appreciating the intrinsic motion of particles in solids, liquids, and gases as well as conceptualizing the forces between them. (*BSL*)
- Many students explain matter as something that takes up space. (*MSSS*)
- Students are often not aware that air and other gases have material character. (*MSSS*)
- Pupils may not regard "gas" as having weight or mass. (*MSSS*)
- Children tend to predict that gases have the property of negative weight and that the more gas is added to a container, the lighter the container becomes. (*MSSS*)
- Students who had already been instructed in the particulate theory of matter may indicate that gas is composed of particles; that there is empty space between particles; and that intrinsic motion accounts for the distribution of particles in space. Pupils who have developed an awareness of the material character of gases may not regard gas as having weight or mass. (*MSSS*)
- Although many middle-school students think air has negative mass or no weight, the concept of air having mass can be acquired when taught at the age of 13. (*MSSS*)

Classroom Research

Classroom Context

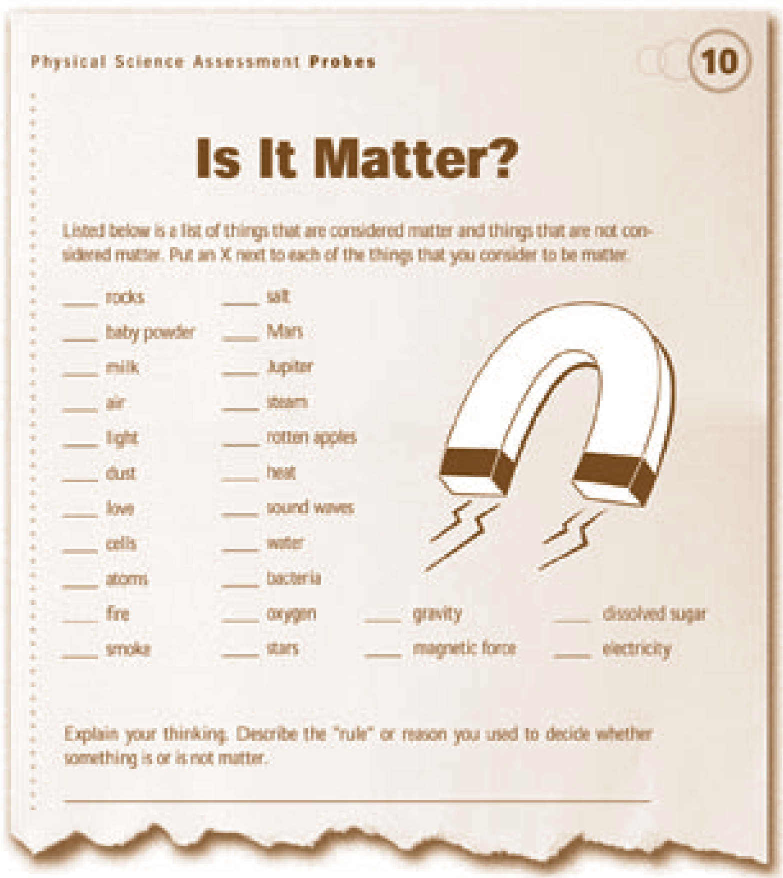
I collected data from a rural, seventh- and eighth-grade middle school located in York County, Maine. The student population is 247 boys and 266 girls. There is one ESL student and 150 students who receive free or reduced lunch. My sample population consisted of 35 boys and 43 girls.

Methodology and Data Collection

Three aspects of the nature of matter guided my inquiry:

1. Air as matter
2. The particulate nature of gases
3. The intrinsic motion of gases

I used the "Is It Matter?" probe (Keeley, 2005) as my first mode of data collection. The probe was given at the beginning of our *Full Option Science System* (*FOSS*)® *Chemical Interactions* unit and 68 students completed it.


Physical Science Assessment Probes 10

Is It Matter?

Listed below is a list of things that are considered matter and things that are not considered matter. Put an X next to each of the things that you consider to be matter.

___ rocks ___ salt
___ baby powder ___ Mars
___ milk ___ Jupiter
___ air ___ steam
___ light ___ rotten apples
___ dust ___ heat
___ love ___ sound waves
___ cells ___ water
___ atoms ___ bacteria
___ fire ___ oxygen ___ gravity ___ dissolved sugar
___ smoke ___ stars ___ magnetic force ___ electricity

Explain your thinking. Describe the "rule" or reason you used to decide whether something is or is not matter.

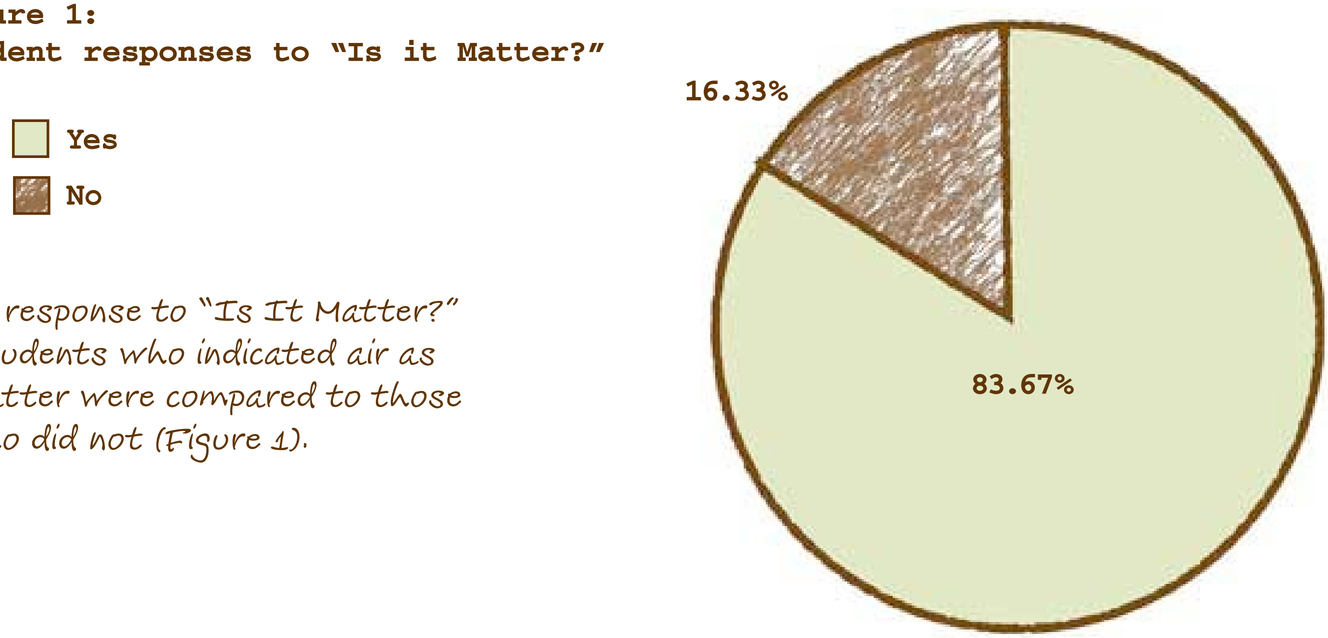
Used with author's permission (Keeley, Eberle, and Farrin, 2005)

I created a "What Are You Thinking?" questionnaire (Appendix A) that was completed by 72 students at the midpoint of our unit. I focused on questions four through seven for data collection and analysis. Question 4 "Does air have mass?" data were separated by response; all Yes respondents were asked to describe three prior experiences that convinced them that air has mass. In response to Question 6, students were asked to draw what they believe the air looks like within two basketballs having different amounts of air inside them.

Students were chosen randomly and then, according to availability and willingness, asked to take part in an interview. I used an interview adapted from Novick and Nussbaum (Novick, 1978). Two weeks after our chemical interactions unit exam, ten students (six boys and four girls) were interviewed. An additional task (1b) was added; I asked students to "Imagine that we weighed the flask before I removed some of the air and then weighed it after I removed some air. What would we find?" Students were shown a flask containing air. A hand pump was attached and then operated to resemble the Novick and Nussbaum apparatus. (See Appendix B.) I then asked students to depict what the imagined air would look like in the flask before and after operating the pump. Task 1b followed the drawing task. Finally, students were shown several examples of drawings and asked: "Which drawing do you think is the best 'picture' of the air in the flask? Explain what there is between the dots in the drawing. Explain why all these particles don't fall to the bottom of the flask."

Organization of Data and Findings

Figure 1:
Student responses to "Is it Matter?"



In response to "Is It Matter?" students who indicated air as matter were compared to those who did not (Figure 1).

Table 1:
The "rule" or reasons students used to decide whether something is or is not matter

Rule or Reason Response Category	Number of Respondents
Has mass and takes up space.	16
You can see, touch or hold it.	17
If it is a solid, liquid, or gas.	8
If it has elements in it.	19
Not sure why.	5
"Real or not real." "Made of more than one thing." "Never goes away."	One each

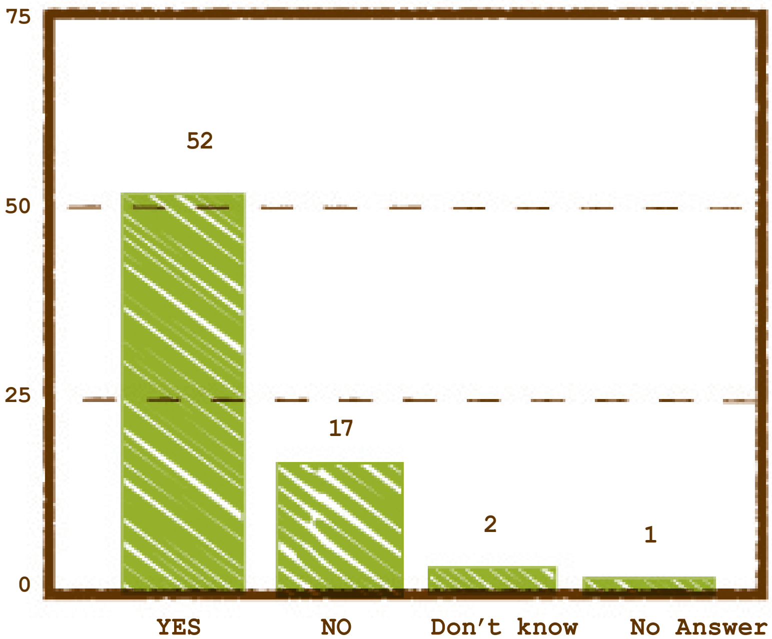


Figure 2:
Student responses to "Does air have mass?"

Responses to the question "Does air have mass?" from the questionnaire I created are shown in Figure 2. The three prior experiences that convinced them that air has mass are shown in Table 2. Not all students provided three examples.

Response Category	Number of Respondents
Everyday events:	
Observed a balloon inflate or pop	11
Observed a bag move	3
Used a CO2 powered gun	3
Have seen it (breath, exhaust, fog)	5
From watching television	3
Other people told them (not teachers)	2
Felt it when wind blows	12
Air compressor/vacuum	2
Puff up cheeks/fill lungs	4
Ears popped	3
Humidity	4
Bubbles in liquid	2
Science class:	
Experiments	5
My teacher(s) told me	16
Has elements in it	3
Interesting previously held ideas:	
"When air carries a baseball."	1
"Gravity" and "Keeps things from floating."	2

Table 2:
Categories of types of experiences that convinced students that air has mass. Responses are from students who answered 'Yes' to Question 4

The "rule"' students used to explain their choices are categorized and displayed in Table 1.
Students gave descriptions in response to the request (in "What Are You Thinking?") to draw what they believe the air looked like within two basketballs having different amounts of air inside them. In Table 3, I categorized the descriptions by the response types (Appendix D).

Table 3:
Categorized responses to the drawing prompt in question 6 from the student questionnaire: "Please fill in the basketballs below using dots to represent the air."

Response Category	Number of Respondents
Particulate:	
Evenly scattered, fills space	34
Concentrated in some part of confined space	16
Concentrated in some part of confined space with "Big" and "Little" air molecules	3
Particulate and drew unidentified "air" molecules	1
Continuous:	
Evenly scattered, fills space	4
Concentrated, in some part of confined space	11
Other:	
Particulate but confused air with water molecules-drew water molecules	2
Zigzag	1

All student responses to the interviews were audio recorded, transcribed (Appendix D), and then grouped by response type (Tables 4-7).

Table 4:
Responses of students when asked to compare the weight of the "before" and "after" flasks (Task 1b from Student Interview Appendix D)

Response Category	Number of Respondents
Correct with correct explanation: Air has mass	6
Correct with incorrect explanation: Increased room for particles to move results in increased mass	1
Correct with no explanation	1
Incorrect: They weigh the same	2

Table 5:
Categories of drawings created by students who were asked to draw how the air in the flasks would look before and after a vacuum pump was used to remove some of the air
(Task 1) and diagram types chosen by the same students when asked to identify the "best" picture of the "before" and "after" flasks (Task 2).

Response Category	Task 1 Number of Respondents	Task 2 Number of Respondents
Particulate:		
Evenly scattered - More room between particles	9	9
Concentrated - In some part of a confined space		1
Continuous:		
Evenly scattered - Fills space, air becomes thinner		
Concentrated - In some part of confined space		1

Table 6:
Responses from students who were asked to explain what is between the dots in the drawings (Task 3 from Student Interview Transcripts Appendix D).

Response Category	Number of Respondents
Empty Space - Confident	7
Empty Space - Doubtful	1
Other Particles, Dust, etc.	2

Table 7:
Responses from students who were asked to observe a diagram and explain why the particles don't fall to the bottom of the flask (Task 4 from Student Interview Transcripts Appendix D).

Response Category	Number Responded
Internal Motion - Correct	2
Other Internal Factors - Incorrect	4
External Factors - Incorrect	
Internal Motion - Correct with alternate explanation: Incorrect diagram.	4

Air as Matter

Figure 1 summarizes the percentage of students who were given the probe who believed air is matter. Overall, 86.67 percent believed air had mass while 13.34 percent did not. When asked to explain the rule they used to decide whether something is matter or not, 19 students believed that it would be if it contained elements, 17 said it would be is if they could see, hold, or touch it, and 16 believed that if it had mass or took up space it was matter (Table 1).

Interestingly, one student replied "If it never goes away" as the rule to explain if something is matter or not.

Seventy-two percent of the students who took the questionnaire believed that air has mass. Two students said they did not know and a single student did not answer the question. When asked to describe experiences in their lives that convinced them that air has mass, the majority drew from "out of class" experiences. Of those experiences mentioned, feeling the wind blow, observing a balloon inflate or pop, and when they can see it (their breath in the cold, exhaust from a combustion engine, fog) were the most common. Twenty-seven students relied on class experiences. The more common responses were "My teacher told me" and experiences from science experiments. Three students relied on unique previously held ideas to explain why air has mass. One student believed air has mass because of how it "carries a baseball" while another explained that air "keeps things from floating." The word "gravity" was used by one student to support a yes answer.

Table 4 shows responses from students asked to compare the mass of flasks containing different amounts of air. Six of the ten students interviewed correctly explained that the "after" flask would weigh less. One student chose the correct answer but failed to explain it correctly. Two students answered incorrectly, and one student answered correctly without an explanation.

The Intrinsic motion and particulate nature of gases

Interview tasks 1, 2, and 3 are summarized in Tables 5, 6, and 7 respectively. Data collected from Task 1 shows that all but one student interviewed drew, and then chose, the correct particulate model to represent air in the flasks. The single student who incorrectly drew the continuous model diagram then correctly identified "the best" particulate model when provided with the opportunity. Seven of the ten students completing Task 2 in the interview correctly and confidently explained that empty space is the only thing that exists between the dots. One student answered correctly, but with doubt. Two of my students still believed something other than space existed between air particles. Table 7 shows that six of the ten students interviewed correctly referred to the intrinsic motion of gas particles to explain the diagram. Four of the six students who were correct also identified the diagram as incorrect in their explanation. It is for this reason that I added the incorrect diagram response category not found in Novick and Nussbaum. A few students uniquely interpreted the diagram as being inaccurate:

"It's kind of like an inaccurate drawing."

"Nothing would be holding them up. It would be moving around because it's empty space. They should be moving around."

"I would think that they wouldn't stay up. Particles are always moving wherever they want to go so I don't think that the drawing is accurate."

"Ummmmm, I don't know. I thought they'd all just . . . I think . . . that's not right though. It's supposed to be all spread out. It's not supposed to just stay in one spot."

"There's really nothing holding them up. It's, there's nothing in there. Those are the air particles."

I categorized the results from question 6 from the questionnaire (Table 3). Thirty-four of the seventy-two students correctly drew an evenly scattered particulate model of what the inside of basketballs with different amounts of air would look like. Nineteen drew concentrated particulate diagrams and fifteen believed a continuous model best fit the scenario. Appendix C shows student examples of the four major category types: particulate evenly spaced, particulate concentrated, continuous evenly spaced, and continuous concentrated.

Data Analysis

Air as Matter

The literature cited in the cognitive research suggests that the majority of students at this grade level don't consider air as something that has mass. I was quite happy to see that almost all of the students completing the probe, questionnaire, and interview did not fit into this category. Most of them seemed to solidly grasp the concept that air is matter and has mass. It is also interesting to mention how my students compared to the literature in terms of the rules they used to determine what matter is. Twenty-four percent of my students explained matter as something that has mass and takes up space, whereas 20 percent mentioned the same rule found in the literature. I expected my students to use that rule more frequently than they did as I am certain they were exposed to that rule in previous years. I was not surprised to see that many also explained matter as something they can see, hold, or touch. It is such a prevalent idea in many adults' minds, not to mention middle-school students. It does worry me that at the end of our unit only six of the ten students interviewed could correctly explain why a flask with less air weighs less than a flask with more air. This is an area that I will spend more time developing next year. The rules students used to support air being mass were equally interesting.

The intrinsic motion and particulate nature of gases

According to the literature, students in middle school have trouble understanding the intrinsic motion of gases as well as their particulate nature. Research shows that many are "deeply committed to the theory of continuous matter" and struggle with the notion that "atoms are in constant motion." I was pleasantly surprised to find that only one of my interviewed students followed the continuous matter trend. However, I was unpleasantly surprised to see that 30 students who completed the questionnaire incorrectly drew particulate concentrated or continuous concentrated diagrams. I would like to believe that many more students would be able to correctly complete the diagrams if the questionnaire was given at the end of the unit. I was very excited to discover the majority of the interviewed students, 60 percent, also correctly explained the prompt in Task 4. Although Novick and Nussbaum did not discuss the significance of the diagram and how accurate it truly was, I thought the student responses were absolutely noteworthy. The diagram showed a flask with all the particles in the upper portion and nothing underneath them. Four of the six students who answered correctly clearly understood the intrinsic motion of gases based on their responses. Each of them deemed the diagram incorrect because it did not depict the gases evenly spread throughout the flask. It was an amazing experience for me to watch as they rationalized what they were looking at. My favorite expressions were proclamations, such as "They should be moving around," "That's not right though," and "It's kind of like an inaccurate drawing." I loved it! Four students did answer incorrectly, however. In retrospect, I would have used a different diagram to elicit these ideas related to intrinsic motion. It would be interesting to see what their ideas are one year later, not just two weeks after experiencing the unit. Similarly, the majority of the students also correctly drew the before and 'after' flasks in Task 1 and chose the diagram that best represents the particulate nature of gas. This indicates to me that my students are not as deeply committed to the continuous theory as they may have been at the beginning of the year. Success? It was not pleasing to see that three of the ten students interviewed still were not convinced that there is simply empty space between air particles. I will spend more time developing this idea the next time I teach this unit.

Significance

The results of this process truly helped to focus my energies as a teacher. It was extremely helpful to see how much information the probe and questionnaire produced and how each facilitated the implementation of the conceptual change model.

Attacking student thinking in a variety of ways provided me with a significant amount of insight into what the students believe to be true! Simply asking a student to draw what they believe to be air is one thing. Asking them to explain *why* they drew what they did extends the piece much further and provided me with a much finer gauge for appropriate instruction. Using strategies like the probe and questionnaire in my teaching will increase my ability to successfully initiate the first two stages of the CCM. This experience demonstrated the power of probe-type exercises.

I will certainly use some form of probe or questionnaire to elicit student ideas before I teach this unit again. The data effectively delineated my students' understandings and beliefs before and after I taught the unit. As much as it stung to see what ideas my kids still clung to, the chance to experience their thoughts in a format other than a unit exam was extremely beneficial. I will spend much more time developing the ideas that seemed difficult for some students to comprehend.

I am also very excited about the potential use of interviews in my classroom! When time allows, it seems to have the potential to be an excellent supplement to a written test or quiz, especially for those who have reading/writing challenges. Removing the static of the classroom environment and allowing myself to completely focus on the students' responses was an amazing experience. I picked up on nuances of explanations and styles of rationalization that might have been overlooked or simply drowned out in the "normal" classroom environment. It seemed to benefit the students' thought process as well. They were more focused on the task at hand, not limited by the number of environmental distracters, and given as much wait time as necessary. I feel the data and information I gained during this experience is worth sharing with the other teachers in my school.

Reflection

I was very eager to take part in this project. I believed that regardless of what I was going to find, the resulting data could only improve my teaching. And I was right. I was apprehensive as a first-time data collector and wondered if I was focusing on the strongest data set possible to avoid wasting time or energy. As it turns out, all the data I collected was extremely helpful and allowed for intense reflection on my teaching process. It also helped to restructure my expectations of the students. If I don't clearly understand my students' thoughts and beliefs, how can I expect them, or my teaching for that matter, to change their minds? I was also able to momentarily slow the pace of communication that normally takes place in the classroom and hear what my students were trying to say, not just what they were saying. I have become more aware of what I need to do as a teacher to effectively reach my students. Just because I taught the material, discussed the material, and then tested the students on the material, does not mean they walked away from the classroom with their minds changed. I have improved as a teacher!

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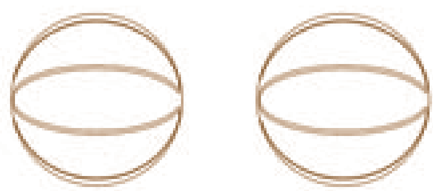
Appendix A *Student questionnaire*

WHAT ARE YOU THINKING?

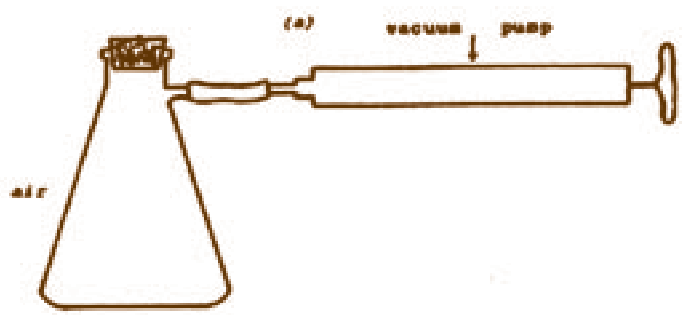
Please answer the following questions to the best of your ability. Take your time and remember to THINK! As always with these types of questionnaires, I am very much interested in your thoughts and not necessarily whether you are right or wrong. Take your time.

1) What is matter?
2) What is mass?
3) What is air?
4) Does air have mass?
5) If you answered "Yes" to the last question, describe three or more times in your life when you were convinced that air had mass.

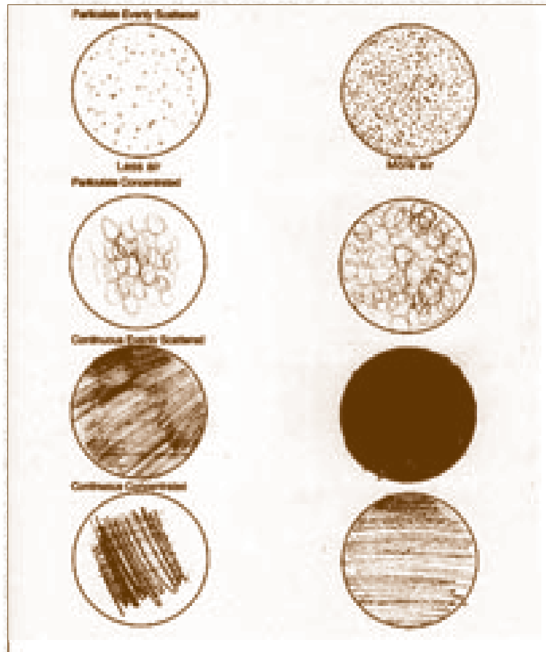


6) The two basketballs above are the same sizes but have different amounts of air inside them. The one on the left has less air and would be difficult to bounce. The one on the right has quite a bit more air and would easily bounce. Imagine now that you could see air. What would the inside of the basketballs look like? Please fill in the basketballs below using dots to represent the air.

Appendix B *Diagram of apparatus used in Novick and Nussbaum*



Appendix C *Examples of categorized student drawings from question 6 in the questionnaire*



Appendix D *Interview transcripts*

TASK 1B: "Imagine that we weighed the 'before' flask and then weighed the 'after' flask. What would we find?"

S1: "The 'after' container would weigh less because there are less air particles inside."

S2: "What we would find is that the 'after' flask would weigh less because you are taking away some air. Everything that has particles has mass. Everything that has weight is a substance. So before we had oxygen in the flask and we take some of that out it loses some of its mass because it's not all in there anymore."

S3: "Well, basically they are the same mass and weight and when you take some out it really doesn't change weight much it just like separates more and there is still empty space."

S4: "You'd find that this one [the 'before'] would probably be heavier because there is more particles in it and from you taking the air out that's putting less particles into the 'after'."

S5: "I think they would maybe be the same weight."

S6: "There would be a very, very, very tiny difference. Like almost not noticeable but something. You would see less in the 'after' one."

S7: "There would be more room for the particles to move around and they wouldn't be bumping into each other as often. The 'before' one would be a little heavier and the 'after' one would be a lot less because the particles would be moving around more so it would be making it heavier and the other would be a lot less because the particles aren't bumping into each other as much and it would make it light."

S8: "This one ['before' flask] would weigh a little more because of the air particles and it's more dense and it has more pressure and this one [after flask] would weigh a little less because there is less air in there and there's not as much pressure and the air particles have more room to move around."

S9: "That the 'before' flask is hardly heavier than the 'after' diagram."

S10: "That the 'after' flask would weigh less."

TASK 3: "Explain what is in between the dots in the drawings."

S1:"Between the dots there's empty space where the air particles move around."

S2: "In between air particles there's nothing. There is nothing between particles because particles are the smallest type of thing you can go. Basically if there is no air particles there is nothing there because it's as small as you can go. There could be millions and millions and millions in there but you can't get any smaller than that and there is nothing in between them.

S3: "I think there is just empty space because there is stuff between particles but it's not like anything it's just empty space."

S4: "Between the dots there is nothing it's all empty it's just nothing there is no space between particles."

S5: "I think there are spaces between the air particles."

S6: "Nothing."

S7: "Well, in between the dots there is more room so the particles will be moving around more easily. There's air too."

S8: "It's nothing, the dots are the air particles and in between there are just little spaces so there's nothing so there's no matter no particles, no nothing."

S9: "Well, because the dots are air particles, there is nothing between the air particles but there could be different kind of things, elements, or atoms."

S10: "Nothing is in between."

TASK 4: "Look at the 'after' diagram in drawing b. Explain why these particles don't fall to the bottom of the flask. What holds them up?"

S1: "I would think that they wouldn't stay up. Particles are always moving wherever they want to go so I don't think that drawing is accurate."

S2: "Well, basically when you suck all the air out of it the particles will come because they are trying to get out and trying to push out of it. Basically, it's kind of of like if you are pushing air into it they try to compress and burst out the sides. Where if you were compressing it and trying to pull it out they will try to come out from the point where they will escape from. Nothing is really holding them there, they are just trying to burst out."

S3: "I was thinking that they are being compressed or the heat is at the top so they are all up there bumping around each other."

S4: "It's probably the uhhhh, mmmm, it depends if these are like, these aren't air particles because they are all hovered around so they are probably solid particles. Probably the air is holding them up."

S5: "Well I think since you pumped this up that maybe that it lost some air and the air went up.

S6: "Ummmmm, I don't know. I thought they'd all just..I think..that's not right though. It's supposed to be all spread out it's not supposed to just stay in one spot.

S7: "The oxygen is holding them up.

S8: "There's really nothing holding them up it's there's nothing in there those are the air particles it's kind of like and inaccurate drawing.

S9: "Could be pressure from the bottom but I wouldn't see why that would happen. As you suction the air out it could be just staying there.

S10: "Nothing would be holding them up it would be moving around because it's empty space. They should be moving around."

Scientific Inquiry: How do eight year olds wrap their heads around science?

Melanie Dodge

Eliot Elementary School

Eliot, ME

Melanie Dodge teaches third grade at Eliot Elementary in Eliot, Maine. She received her master's degree in Elementary Education from the University of New Hampshire and has taught in Maine, New Hampshire, and Washington. She has taught general education, special education, and English-language learners at all levels, from kindergarten through college. According to Melanie, teaching is the most important job in the world, the ultimate community service, and her opportunity to positively affect other lives on the planet.

Purpose of the Study

How can I, as an early elementary teacher, provide the right kind of learning experiences that will help my students to develop a deep understanding of science? How do I scaffold and organize inquiry in my classroom? These questions, in addition to the ones listed below, come out of a flurry of distinct experiences in my science education. Beginning with my science methods course during graduate school, I have been trained in the constructivist model of teaching and learning. This training has continued from more than 50 hours of professional development in inquiry-based science with the Seattle School District to working with the University of Washington's Everyday Science and Technology Group (creating classroom interventions that study how children come to understand the nature and purposes of scientific inquiry and knowledge) to rich professional development experiences with MMSA.

My current work in this project spun out of a challenged posed by different groups of students living on opposite coasts, at different grade levels, during different technological design science units over the last three years. Both groups of students had trouble seeing the importance of the testing, redesigning, and retesting phases; they saw it as a task to be completed in order to move on to the next task. How was I to guide their inquiry throughout the entire design process? As I began to focus my research, I realized I did not have a conception of my students' understanding of technological design, inquiry, or even science. It became apparent that before students can understand technological design, they need groundwork in understanding science and inquiry.

First, I had to define what science is. It is inquiry: a never-ending curiosity about, questioning of, and quest for understanding of the natural and technological world around us. Inquiry is the search for information, which is something that humans do naturally without even thinking about it. Therein was the challenge. How do you explicitly teach something we do as intuitively as breathing? How do you focus that into the realm of science? What kinds of experiences have my students had that have shaped their conceptions of scientific inquiry, and how stubborn are their misconceptions? What kinds of experiences must I orchestrate in order to guide their science education?

Before embarking on any science teaching, it was important that I read the current cognitive research, instructional considerations, and national, state, and district standards and learning goals related to student understanding of scientific inquiry. I also needed to have a clear picture of my students' understandings of scientific inquiry. In order to gather this evidence, I used the "Doing Science" probe from *Uncovering Student Ideas in Science: Another 25 Formative Assessment Probes, Volume 3* (Keeley, et.al., 2008). The probe was designed to find out if students recognize that scientists investigate the natural world in a variety of ways. I also conducted and transcribed both formal and informal student interviews, in addition to collecting student artifacts and writing down my observations during learning experiences. I also designed three online probes. The first one asks students to watch videos of people describing and demonstrating what they do. Students then decide if the people they viewed are scientists. The second probe allowed me to gather more data about my students' thinking by asking them to state whether scientists always, sometimes, or never do the things discussed the previous probe. The last probe inquired about where the students' views of science and scientists come from.

Research Questions

Through my research, I hope to answer the following questions:

1. What do science standards and current research say about scientific inquiry and what third graders should know and understand about it?
2. What previously conceived notions do my third graders have about scientific inquiry?
3. What experiences and notions may have contributed to their ideas about scientific inquiry?

Curriculum Topic Study (CTS)

Background Research, "Inquiry Skills and Dispositions" (p.238) (Keeley, 2005)

Clarification of content from *Science for All Americans* (*SFAA*)

Although there is no fixed set of steps that scientists always follow, there are certain features of science that give it a distinctive character as a mode of inquiry.

- Science demands evidence.
- Science is a blend of logic and imagination.
- Science explains and predicts.
- Scientists try to identify and avoid bias.
- Science is not authoritarian.
- Science is a complex social activity.

Student learning goals from *Benchmarks for Science Literacy* (*BSL*) and *National Science Education Standards* (*NSES*)

- Develop student abilities necessary to do scientific inquiry and to enrich student understanding of science. (*NSES* Grades K-4)
- Scientific investigations involve asking and answering a question (explanations based on observations [using senses and tools] and evidence) and comparing the answer with what scientists already know (scientific knowledge). (*NSES* Grades K-4)
- Scientific investigations may take many different forms, including observing what things are like or what is happening somewhere, collecting specimens for analysis, and doing experiments. Investigations can focus on physical, biological, and social questions. (*BSL* Grades 3-5)
- Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence. (*BSL* Grades 6-8)

Student learning goals from Maine Learning Results, 2007

Grades Pre-K-2

Students describe the use of questions and accurate communication in scientists' work.

- Describe how scientific investigations involve asking and answering a question.

Students recognize that people have always engaged in science and technology and that there is a difference between the natural and designed worlds.

- Recognize that people have always had problems and invented tools and ways of doing things to solve problems.

Grades 3-5

Students describe how scientific investigations result in explanations that are communicated to other scientists.

- Describe how scientists answer questions by developing explanations based on observations, evidence, and knowledge of the natural world.
- Describe how scientists make their explanations public.

Students describe why people use science and technology and how scientists and engineers work.

- Describe how scientists seek to answer questions and explain the natural world.

Teaching Considerations from *Benchmarks for Science Literacy (BSL), National Science Education Standards (NNES)*, and *Uncovering Student Ideas in Science (USIS)*

- Students should experience science in a form that engages them in the active construction of ideas and explanations and enhances their opportunities to develop the abilities of doing science. (*NSES*)
- Full inquiry involves asking a simple question, completing an investigation, answering the question, and presenting the results to others. (*NSES*)
- Students should be actively involved in exploring phenomenon that interest them . . . should have lots of time to talk about what they observe and compare . . . to others . . . [with] a premium . . . placed on careful expression. (*BSL* Grades K-2)
- Embedding explicit instruction of the various ways to do science in the actual investigations done by scientists is a better approach to understanding how science is done. (*USIS*)
- Help students maintain a consistent image of science as inquiry throughout the year by paying more attention to the words they use. (*USIS*)
- Opportunities to experience a variety of ways that science is conducted are not enough for students to develop deep understandings about inquiry. Students need to be given time to reflect on what they have done. Like the nature of science, these understandings need to be explicitly addressed. (*USIS*)
- Provide students with a variety of ways to investigate scientific questions . . . point out the . . . different ways to do science. (*USIS*)
- Use historical accounts and nonfiction readings . . . about scientists doing their work. (*USIS*)
- Ensuring that students develop the abilities to carry out scientific inquires is an important part of the standards. However, it is just as important for students to develop understandings of inquiry. Students can perform investigations yet not understand why they are done in a particular way. (*USIS*)

Cognitive research from *Benchmarks for Science Literacy* (*BSL*), *Making Sense of Secondary Science* (*MSSS*), and *Uncovering Student Ideas in Science* (*USIS*)

- Students generally have difficulty with explaining how science is conducted because they have had little contact with real science. Their familiarity with doing science . . . is "school science," which is often not how science is generally conducted in the scientific community. (*USIS*)
- Research still shows that students typically have inadequate conceptions of what science is and what scientists do. (*USIS*)
- By directly experiencing a variety of ways that questions can be answered in science through simple investigations, students will begin to develop the idea that there is no one fixed way to go about answering scientific questions . . . if students are asked to reflect on what they have done and instruction explicitly addresses the understandings of inquiry. (*USIS*)
- There are few studies that investigate which elementary-school learning experiences are effective for developing an understanding of the nature of science. (*BSL*)
- Some students of all ages believe science mainly invents things or solves practical problems rather than exploring and understanding the world. (*BSL*)

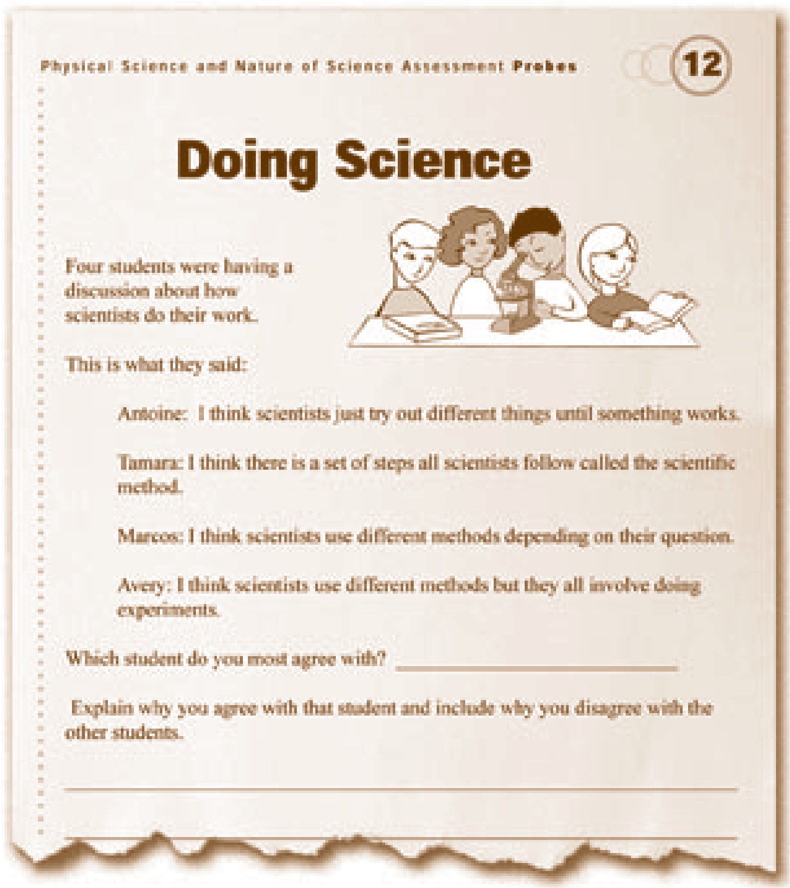
Classroom Research

Classroom Context

My third-grade classroom of 19 students is self-contained and one of four third-grade classrooms in a building that spans Grades pre-K-3. My school is in a rural southern Maine town of about 6,000 people.

Methodology and Data Collection

I began my research by reading everything I could find about students' understanding of scientific inquiry and science, not only at the elementary level but at all levels and on a national scope. While reading, I began firming my definition and conceptualization of science. In addition, I started reflecting on my own experiences with learning and teaching inquiry and science. Next, I began collecting data about my students' understandings by administering the "Doing Science" probe as well as three probes—"What Is a Scientist?" "Scientists," and "My Science Story"—that I created using the customizable forms option on my class Web site through MyTeacherPages.com (School World). I also began conducting formal and informal interviews.



Physical Science and Nature of Science Assessment **Probes** 12

Doing Science

Four students were having a discussion about how scientists do their work.

This is what they said:

Antoine: I think scientists just try out different things until something works.

Tamara: I think there is a set of steps all scientists follow called the scientific method.

Marcos: I think scientists use different methods depending on their question.

Avery: I think scientists use different methods but they all involve doing experiments.

Which student do you most agree with? ______

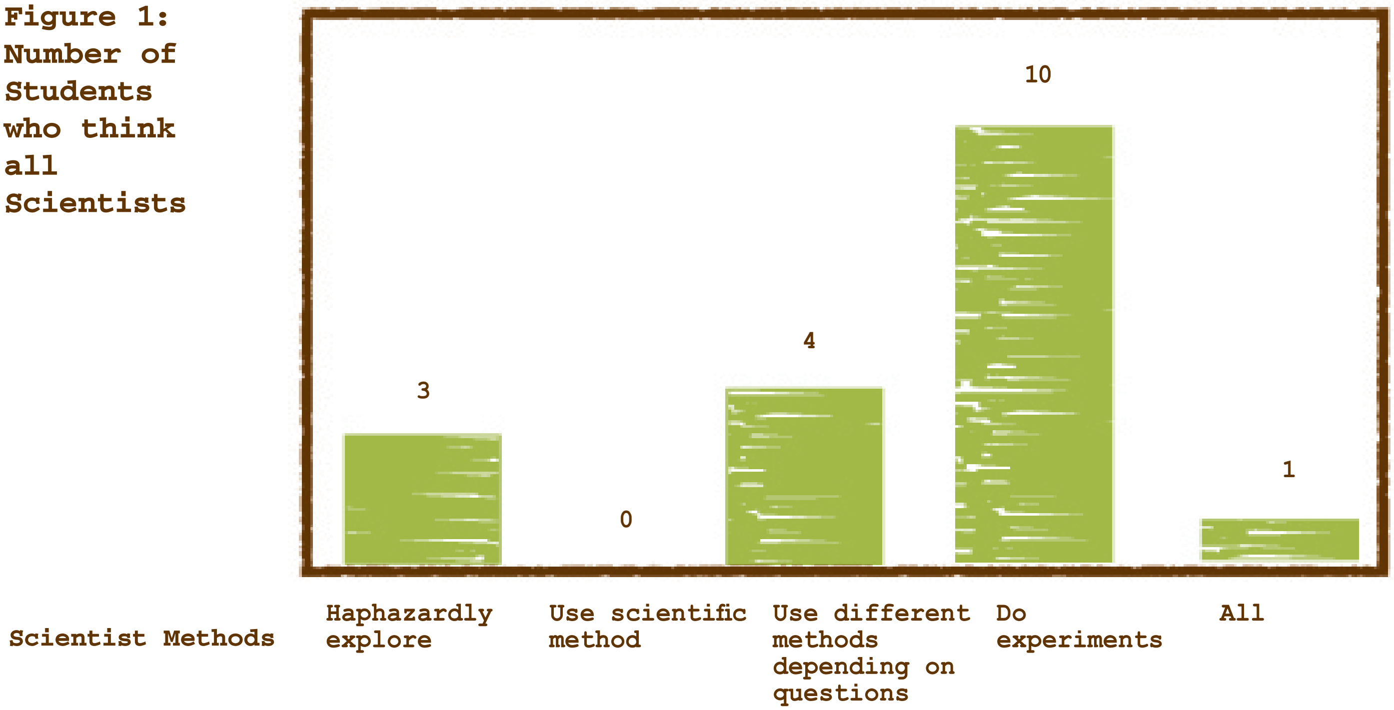
Explain why you agree with that student and include why you disagree with the other students.

Used with author's permission (Keeley, Eberle, and Dorsey 2008)

Organization of Data

I created graphs of the data from each probe. I also transcribed our classroom discussions and interviews.

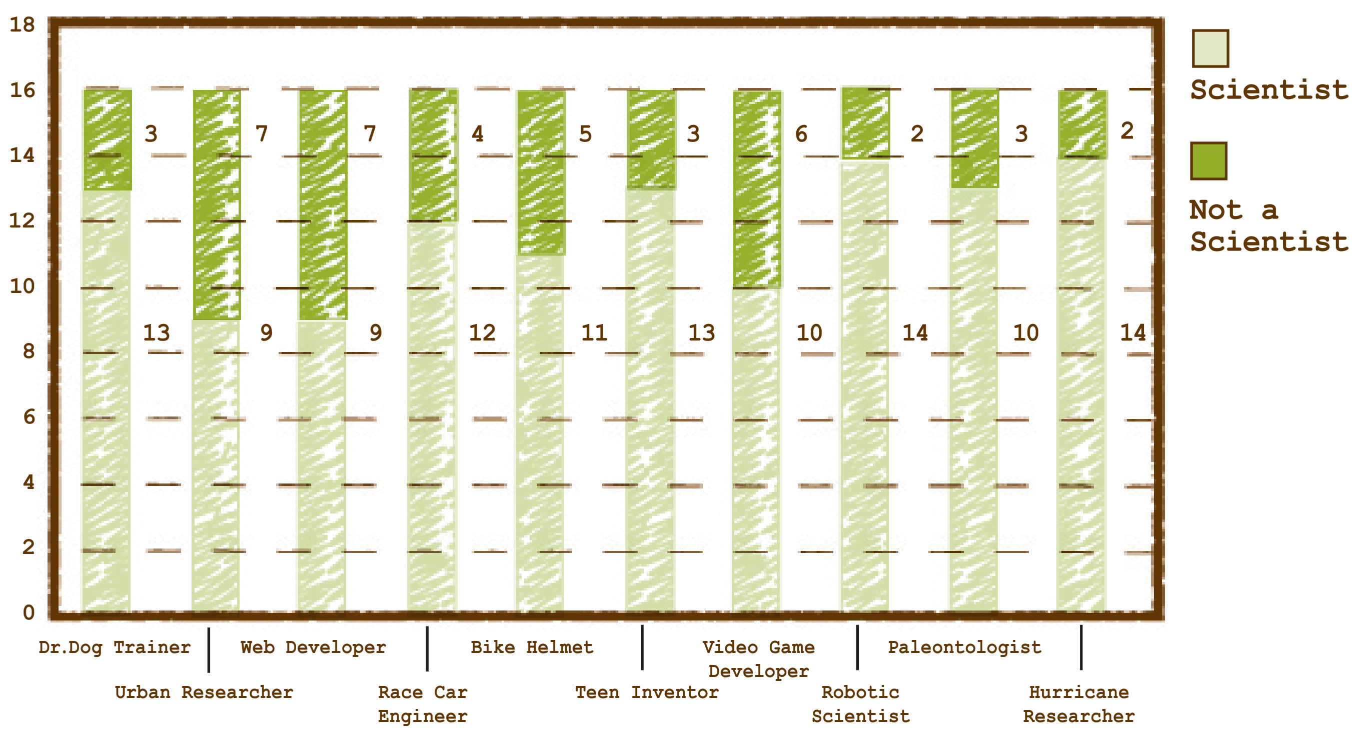
Figure 1: Number of Students who think all Scientists



Data Analysis

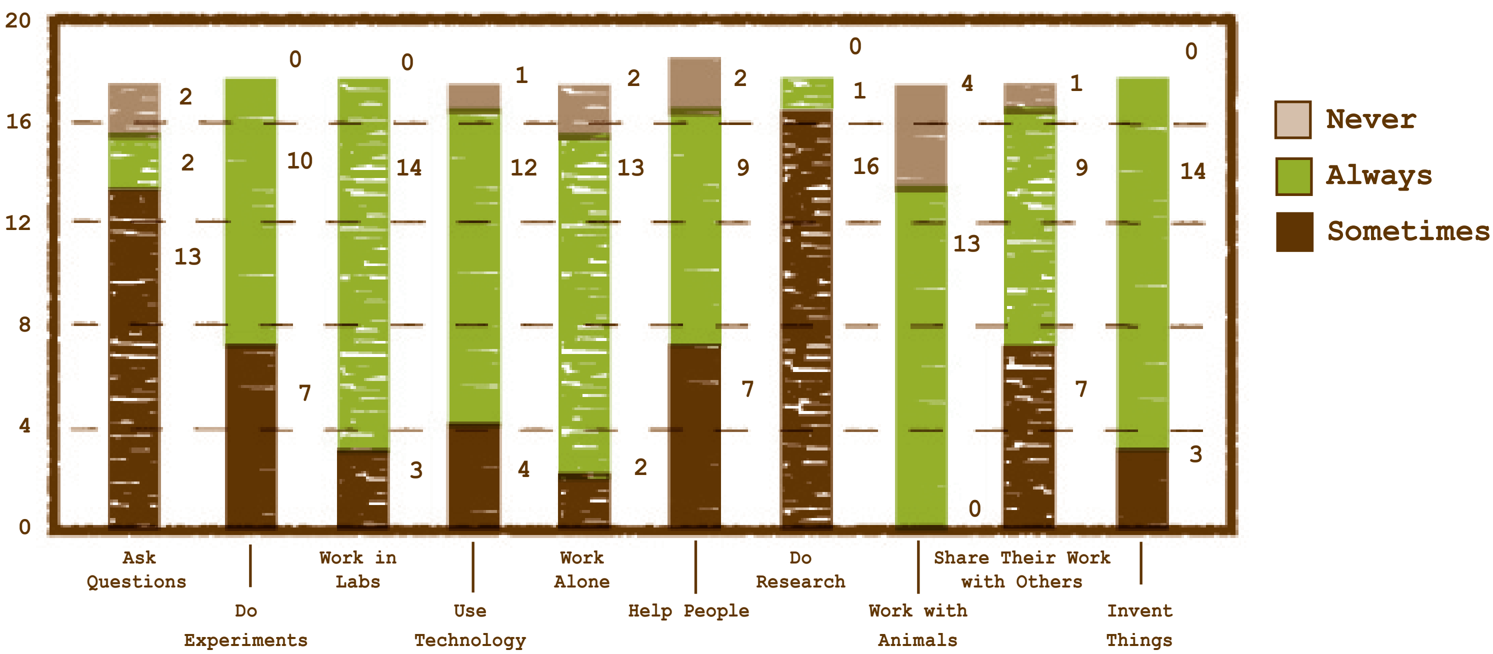
Given the data gathered from the "Doing Science" probe, it is easy to see that most of the kids in my classroom equate science with doing experiments. A total of five students thought that scientists all do different things depending on what they are studying or researching. According to the research, we want students' thinking to move in this direction. In our discussions, students stated that their belief that all scientists do experiments came mostly from mass media and their experiences outside of school.

Figure 2: Who's a scientist?



During the “Who Is a Scientist?” probe, students watched videos of people describing and modeling their jobs. The students then had to decide if they believed (based on their own conceptions of science and scientists) the person was a scientist or was “doing science.” All of the people were scientists because they ask questions, seek answers to those questions, and then do something with that new information. The jobs the students had the hardest time believing were science-related were an urban researcher (who researches children’s play to understand their choices and organize activities and recreation areas in cities), a website developer (who creates online learning environments), and a video game designer (who used technology to study NFL stars and create virtual, interactive counterparts).

Figure 3: Scientists...

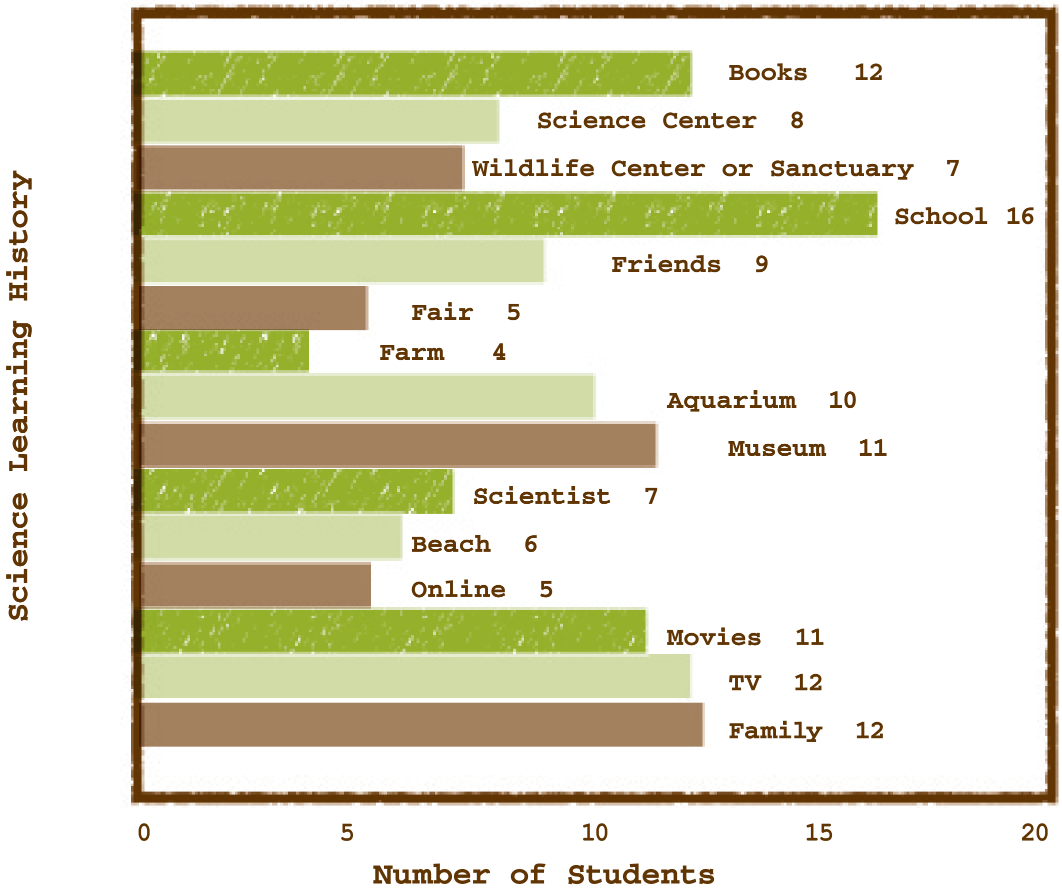


For the “Scientists” probe, I wanted to understand what my students believe that scientists do and science is all about. Their generalizations about scientists are that scientists ask questions, work in labs, invent things, and do research. Because this probe came after some of our discussions about what science is, the students’ conceptions were beginning to change and they started conceptualizing science as inquiry, though they never would use those words. What was interesting to me was trying to find out where these ideas came from.

Like many other elementary schools throughout the country, we do not spend a lot of time teaching science at our school. This is because more time is devoted to other subjects such as reading and math. There is not a lot of instructional time devoted to science at the early grades. The ideas that my students have are coming from outside of school (see Figure 4 next page).

Students agreed that school was the number one place they learn about science. Again this information highlights the fact that to them science is still a very narrowly defined enterprise. From my experience working with the University of Washington’s ethnographic research into the science experiences of elementary students, I learned that although students often are engaged in science activities outside of school, they are not aware that what they are doing constitutes science. Outside of school, students said they learned about science at aquariums and museums, in books, in movies and on TV, and through discussions and experiences with their families. An interesting thing that came up during our discussion was that a few students did not see going to an aquarium or museum as a science activity.

Figure 4: My science story



Findings and Conclusions

The data I collected confirmed what I had read during my research. Students see science as a narrow band of activities done by a certain type of person in an even narrower setting. From my interviews, students frequently used phrases, such as the following: "Scientists only," "I've only seen scientists who . . ." "Work in labs," "Are not teachers," "They do not save peoples' lives," "He did not invent anything," and "Most scientists . . ." The use of these phrases told me that they are trying to conceptualize science and scientists but their conceptions are very narrowly defined and not inclusive.

Also interesting was the idea that the two people least likely to be scientists in the minds of my students were women. Of the ten scientists featured, three were women and six were non-white males. I tried to show a variety of possible scientists but, according to the National Science Foundation, the reality in America is that male outnumber female scientists by more than 20 percent and white scientists outnumber non-whites by more than 300 percent.

One of my students noticed that we watched an episode of PBS Kids' "Dragonfly TV" entitled, *Real Scientists*. In my interview, this particular student realized that the people portrayed were indeed all scientists. Yet a few of the people did not meet his narrow definition and, therefore, were in his view "definitely not scientists." This interesting confrontation of ideas and conceptions tells me that there need to be many experiences contrary to students' conceptions to force them to really confront and change their thinking.

Significance

Importance of findings and conclusions

The underlying challenge I see with my third graders is that students do not necessarily see that there is connection between all of the forms of science and that science is really natural curiosity about the world around us. They define science as the study or creation of a very narrow set of realms. They form this definition from mass media: the Internet, movies, TV, and video games. My own research corroborates the fact that students do not understand what science is. Because of this, they do not see themselves as scientists or choose science as a career. What is exciting is that, although there is little research investigating student's understanding of the nature of science, there is a project at the University of Washington that is investigating students' understanding of science by using ethnographic research and interventions across all settings (in school as well as inside and outside of the home experiences, Everyday Science and Technology Group, University of Washington, Seattle.).

Impact on teaching

According to widely published research, few families are discussing science at home. In addition, science in schools has taken a backseat for decades. Fewer and fewer Americans are going into the sciences and either science jobs are being exported or science employees are being imported. For the sake of the future of our country, students need to see themselves as scientists and we elementary teachers need to foster and guide their natural curiosity. We need to make science real by engaging them in authentic scientific experiences and helping them see the science that takes place in their daily lives. We need to introduce them to scientists of all disciplines, ethnicities, genders, and localities. Science must be taught on a daily basis if we really want to help students with their conceptualizations because they are so stubborn. Students need time to reflect on their learning (before, during, and after learning), which will help their continuous re-conceptualizations. Almost more important, we want scientifically literate students, future citizens in our democracy who understand that their role in the world is to make responsible decisions for our communities and country.

Plans for taking action

I plan on directly teaching science as a form of inquiry and embed it into each science unit. I will introduce them (physically and virtually) to current and historic scientists work in diverse fields all over the world. In addition, because of how deeply rooted their misconceptions are, science will be discussed continually throughout the year with lots of opportunities for reflection. I also hope to help them see the science in their daily lives (curiosity, energy, health and nutrition, recycling, weather, etc.) in addition to the explorations taking place in our science units.

Plans for sharing research with others

As the de facto science person at my school, I have shared this research with my third-grade teammates and will be presenting my project to teachers in my school—who I hope will then share their learning with their students. I also plan on asking the assistant superintendent if she would like me to share this with the district. While working on this project I thought about the work I did in Washington. I hope to get back in touch and share what I have done with the university and find out what their data is showing now that they are entering the sixth year of their project.

Reflection

How has the action research process impacted me personally?

Throughout the research process, I have grown more and more curious about my own definition of science as inquiry. As I described the focus of this project to others, I was always asked "Well, what is science?" So, I had to continually simplify my definition of science to answer the question, especially when asked by those who are not educators and are not especially scientifically literate. I had to keep exploring and redefining until I came to my own simplest conception of science as inquiry, a never-ending curiosity for, questioning of, and quest for understanding the natural and technological world around us. This is something that my students and I can begin to wrap our heads around so that we can increase our own scientific literacy and also that of all citizens. It was interesting to find that as I created a probe to gather the data, the data and subsequent discussions brought up more questions. These questions then guided the creation of other probes designed to gather more refined information about my students.

I have a renewed interest, focus, and passion for science education that includes a need to share it with everyone I can. It will indeed take a village (actually a country) to raise the next generation of scientists and scientifically literate citizens. I am ready to embark on that journey. The questions that are now brought up for me are how can I best help my "village" and more important, what constitutes my village? Is it my classroom, school, district, state, or country? What village will I choose to work with next? Do I continue my work in my classroom, school, and district or do I take my passion to the next level by pursuing my doctorate?

How has action research contributed to professional growth?

In addition to having a much deeper grasp of my students' experiences and understanding and of science and scientists, I have created learning experiences that have allowed them to confront their own definitions and misconceptions. Together, we have begun to discuss, explore, construct, and deconstruct what science means to us and how that affects the world in which we live. I have a renewed focus on my science teaching and future professional development. This project has opened doors both inside my own mind and professionally that would have remained closed for who knows how long. I highly recommend this process to all teachers for both the process and results have been astounding and life changing. Action research is one of the best professional development experiences I have had because of the student understanding and instruction implication centered model.

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Sweet Lemonade: finding student preconceptions about the conservation of matter

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Sandra Ferland is a middle-school science teacher in Minot, Maine. She has a BA in Medical Technology and an MS in Education from the University of Maine. She previously has taught first and fifth grades. Teaching science has always been important to her; she works hard to excite her students about learning science. She consistently has had a role in science education reform at her school and in her school district and has played an integral part in writing the district K-12 science curriculum.

Purpose of the Study

Conservation of matter is difficult for middle-school students to understand. It is an abstract concept. Students often think that when a substance dissolves, it "disappears." Even with knowledge of particulate matter, they consider small particles to be weightless. Some students think that the more volume there is, the more matter there is. My purpose is to find out what students' preconceptions are about conservation of matter so that I can formulate experiences that will help them to understand this concept.

Research Questions

1. What preconceptions do my students have about what happens to matter during a physical change that interfere with their understanding of the Law of Conservation of Matter? What are their ideas about the following aspects of the conservation of matter:
   - The amount of "stuff" involved in a physical change is the same before and after the change takes place.
   - Substances do not disappear when dissolved in a solute.
   - All matter has mass and weight even though the particles are very small.
   - Mass and volume are different measurements.
2. What experiences do students need to have to address misconceptions and gain an understanding of the conservation of matter?

Curriculum Topic Study (CTS)

Background Research, "Conservation of Matter" (p.163) (Keeley, 2005)

Clarification of the content from *Science for All Americans (SFAA)*

- The total amount of matter and energy remains constant, even though its form and content undergo continual change.
- Over long spans of time, matter and energy remain constant, even though their form and location undergo continual change.

Student learning goals from *Benchmarks for Science Literacy* (BSL) and *National Science Education Standards* (NSES)

Grades 6-8

- No matter how substances within a closed system interact with one another, or how they may combine or break apart, the total weight of the system remains the same.
- The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are arranged, then their total mass stays the same.

Student learning goals from *Maine Learning Results, 2007* (MLR) and *School Union #29 Science Curriculum* (SC)

Grades 3-5

- Explain that the properties of a material may change but the total amount of the material remains the same. (*MLR*)

Grades 6-8

- Use the idea of atoms to explain the conservation of matter. (*SC*)

Grade 8

- Demonstrate the conservation of matter. (*SC*)

Teaching considerations from *Benchmarks for Science Literacy* (BSL) and *National Science Education Standards (NSES)*

- Students must know about the properties of materials and their combinations, changes of state, effects of temperature, behavior of large collections of pieces, the construction of items from parts, and even about the desirability of nice, simple explanations. All these elements should be introduced in middle school so the unifying idea of atoms can begin by the end of eighth grade. *(BSL)*
- By the end of the eighth grade, students should have sufficient grasp of the general idea that a wide variety of phenomena can be explained by alternative arrangements of vast numbers of invisibly tiny, moving parts. *(BSL)*
- It can be tempting to introduce atoms and molecules or improve students' understanding of them so that particles can be used as an explanation for the properties of elements and compounds. However, use of such terminology is premature for these students and can distract from the understanding that can be gained from focusing on the observation and description of macroscopic features of substances and of physical and chemical reactions. *(NSES)*
- At the Grades 5-8 level, elements and compounds can be defined operationally from their chemical characteristics, but few students can comprehend the idea of atomic and molecular particles. *(NSES)*

Cognitive research from *Benchmarks for Science Literacy* (BSL), *Atlas of Science Literacy, Volume 1* (ASL, 1), and *Making Sense of Secondary Science* (MSSS)

- Students cannot understand conservation of matter and weight if they do not understand what matter is, or accept weight as an intrinsic property of matter, or distinguish between weight and density. (*BSL*)
- By fifth grade, many students can understand qualitatively that matter is conserved in transforming from solid to liquid. They also start to understand that matter is quantitatively conserved in transforming from solid to liquid to gas—if the gas is visible. (*BSL*)
- If students perceive that a particular change is dominated by the apparent disappearance of some materials, then students are not likely to believe that the mass or matter is conserved. (*MSSS*)
- When students are unable to see continuously the particles of a substance during a change, they are unlikely to see conservation of mass during a change. (*MSSS*)
- When students observe a solid changing to a liquid, they may think that it loses weight or mass. (*MSSS*)
- Students may perceive that sugar added to water disappears, melts away, dissolves away, or just turns into water. (*MSSS*)
- Students in middle school may conserve the substance but not the weight of the substance added in a solution. They may believe the substance is suspended in the solvent, but no longer having a gravitational force on it. (*MSSS*)
- Eventually, many students in middle school will conserve both weight and mass of a solute. (*MSSS*)
- Many students cannot discern weight conservation in some tasks until they are 15 years old. The ability to conserve weight in a task involving transformation from liquid to gas may rise from 5 % in nine year olds to about 70 % in 14 to 15 year olds. (*ASL*, *1*)

Classroom Research

Classroom Context

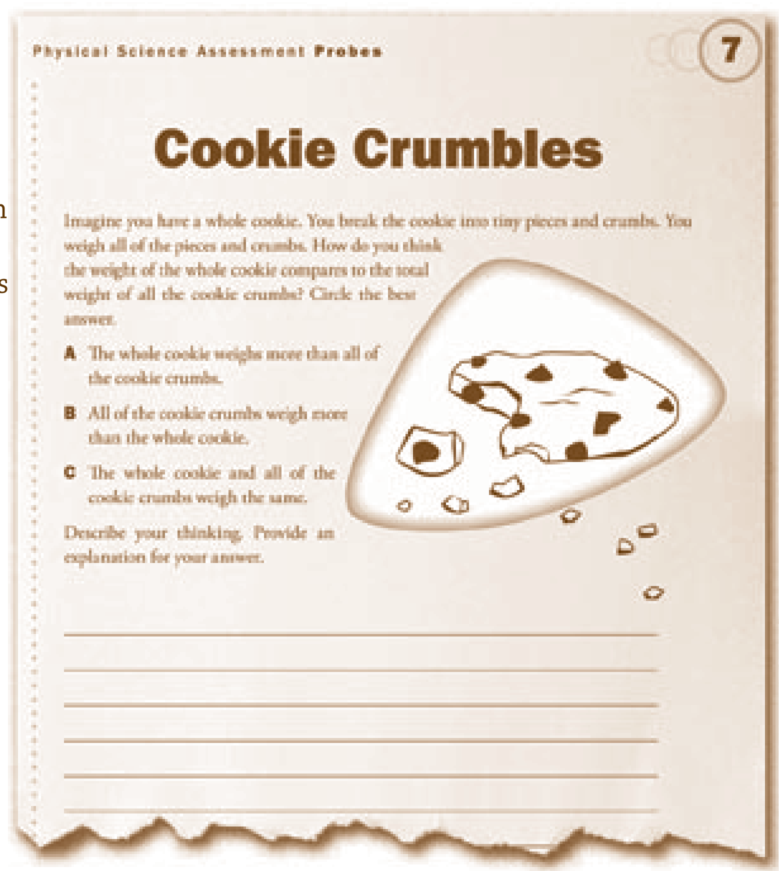
The research was conducted with seventh- and eighth-grade students in a rural central Maine K-8 school with approximately 300 students. My research is specific to two eighth-grade classes with 29 students (18 boys and 11 girls). Five of these students have special needs.

Methodology and Data Collection

I began my research by administering three formative assessment probes found in *Uncovering Student Ideas in Science: 25 Formative Assessment Probes, Volume 1* (Keeley et. al., 2005).

The first probe, "Cookie Crumbles," asks the students to imagine that they have a whole cookie that they break into small pieces and crumbs. They are asked how the weight of the small pieces and crumbs compares to the weight of the whole cookie. Twenty-eight students were given this probe.

The second probe, "Ice Cubes in a Bag," deals with a phase change from a solid to a liquid using ice cubes enclosed in a ziplock bag. Twenty-three students responded to this probe.



Physical Science Assessment Probes 7

Cookie Crumbles

Imagine you have a whole cookie. You break the cookie into tiny pieces and crumbs. You weigh all of the pieces and crumbs. How do you think the weight of the whole cookie compares to the total weight of all the cookie crumbs? Circle the best answer.

A The whole cookie weighs more than all of the cookie crumbs.

B All of the cookie crumbs weigh more than the whole cookie.

C The whole cookie and all of the cookie crumbs weigh the same.

Describe your thinking. Provide an explanation for your answer.

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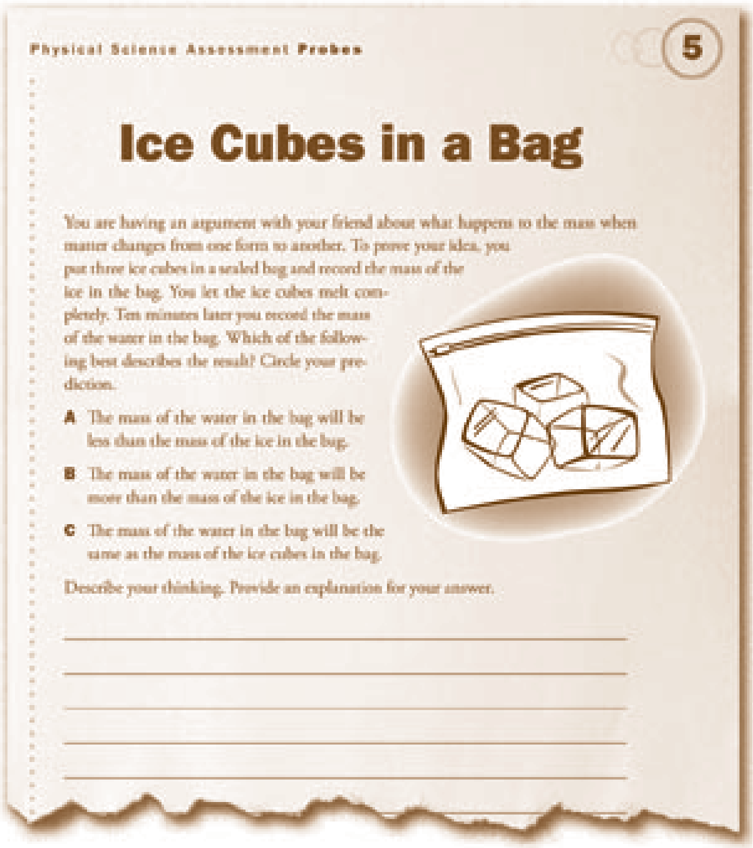
The third and final probe that I gave to the students was "Lemonade." This probe is different from the other two,


Physical Science Assessment Probes 5

Ice Cubes in a Bag

You are having an argument with your friend about what happens to the mass when matter changes from one form to another. To prove your idea, you put three ice cubes in a sealed bag and record the mass of the ice in the bag. You let the ice cubes melt completely. Ten minutes later you record the mass of the water in the bag. Which of the following best describes the result? Circle your prediction.

A The mass of the water in the bag will be less than the mass of the ice in the bag.

B The mass of the water in the bag will be more than the mass of the ice in the bag.

C The mass of the water in the bag will be the same as the mass of the ice cubes in the bag.

Describe your thinking. Provide an explanation for your answer.

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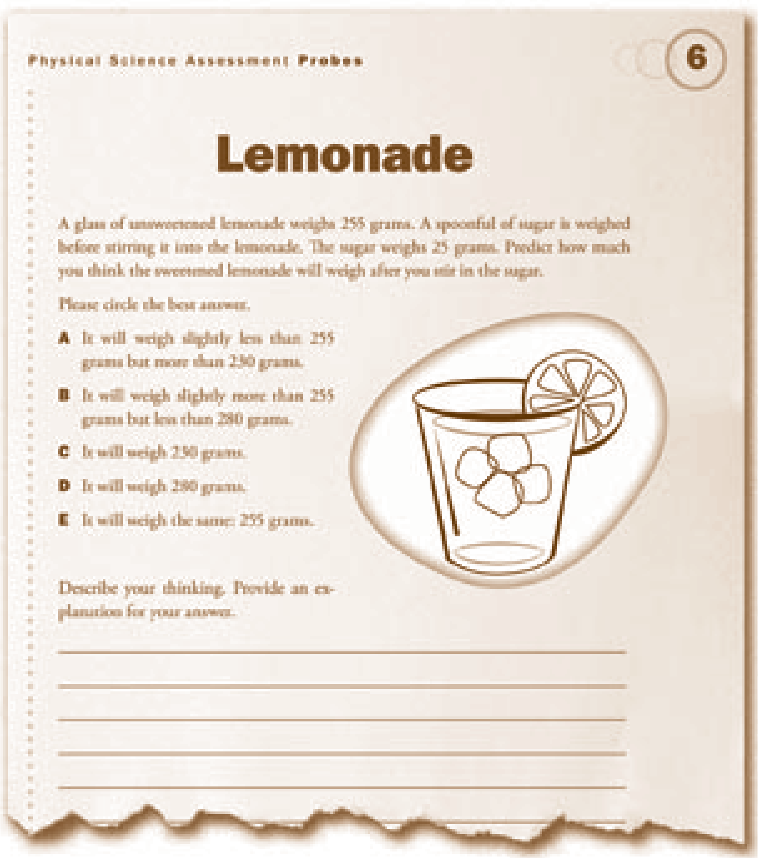

Physical Science Assessment Probes 6

Lemonade

A glass of unsweetened lemonade weighs 255 grams. A spoonful of sugar is weighed before stirring it into the lemonade. The sugar weighs 25 grams. Predict how much you think the sweetened lemonade will weigh after you stir in the sugar.

Please circle the best answer.

A It will weigh slightly less than 255 grams but more than 230 grams.

B It will weigh slightly more than 255 grams but less than 280 grams.

C It will weigh 230 grams.

D It will weigh 280 grams.

E It will weigh the same: 255 grams.

Describe your thinking. Provide an explanation for your answer.

Used with author's permission (Keeley, Eberle, and Farrin, 2005)

because it deals with the solubility of sugar in a liquid. The sugar is not visible after it is stirred into the lemonade. Therefore, students can no longer see the matter involved in the physical change. They dealt with a closed system concept and solubility. When the sugar dissolved, it seemed to disappear. Twenty-five students were given this probe.

The next part of my data collection involved interviews with students about their responses to the three probes. For "Ice Cubes in a Bag," I explained the situation to each student and asked them to predict how the mass of the ice would compare to the mass of water after the ice melted. Each student made a prediction and then recorded the mass of the ice and bag. After the ice melted, the students returned to test their predictions.

The interviews for the "Lemonade" probe began with the same question for all students. I asked them to predict what the mass of the glass of lemonade would be after we added the sugar and stirred it up.

Organization of Data and Findings

I recorded and analyzed the data that I received from each probe by sorting it according to the answers the students gave to the choices provided in the probes.

Seven of the 28 students completing "Cookie Crumbles" answered A: "The whole cookie weighs more than all of the cookie crumbs." (See Figure 1.) The most common reason they gave was that the cookie crumbs have less mass and matter than the whole cookie. Another reason considered the spaces inside the cookie as reducing the mass of the cookie. One student stated that, because the "whole cookie had chocolate chips, it would weigh more that the crumbs."

Fourteen of the twenty-three students who completed "Ice Cubes in a Bag" answered that the mass of the water and the mass of the ice would be the same, noting that it was the same matter, i.e., nothing was taken out, and merely a phase change. (See Figure 2.)

Five students said that the mass of the water would be more than the mass of the ice. The

Figure 1: Cookie Crumbles

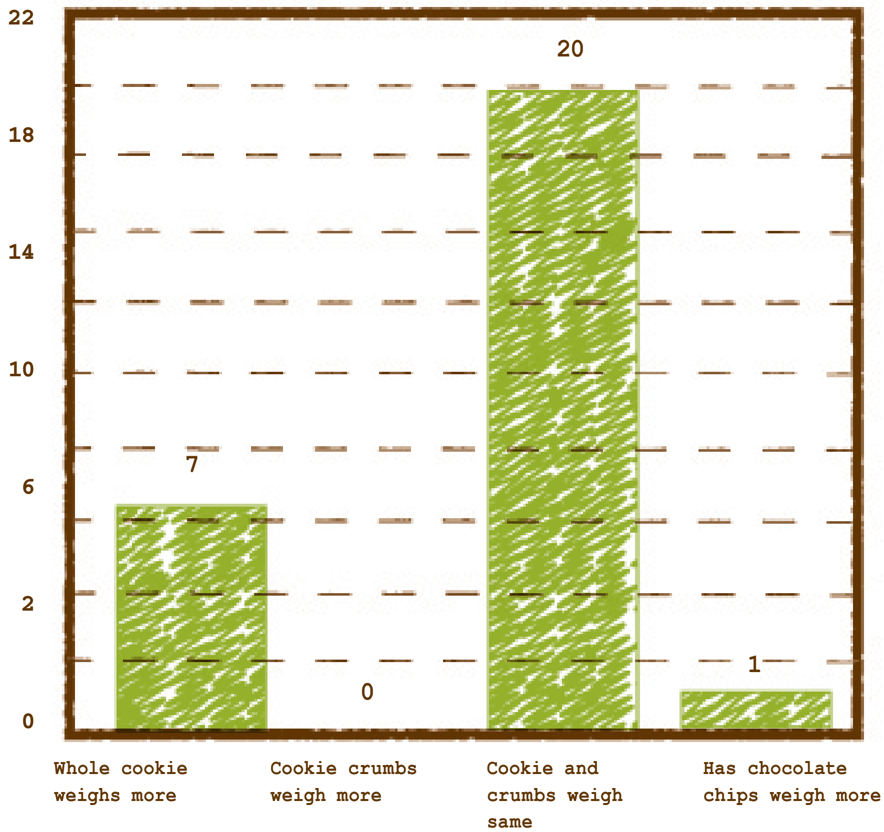


Figure 2: Ice Cubes in a Bag

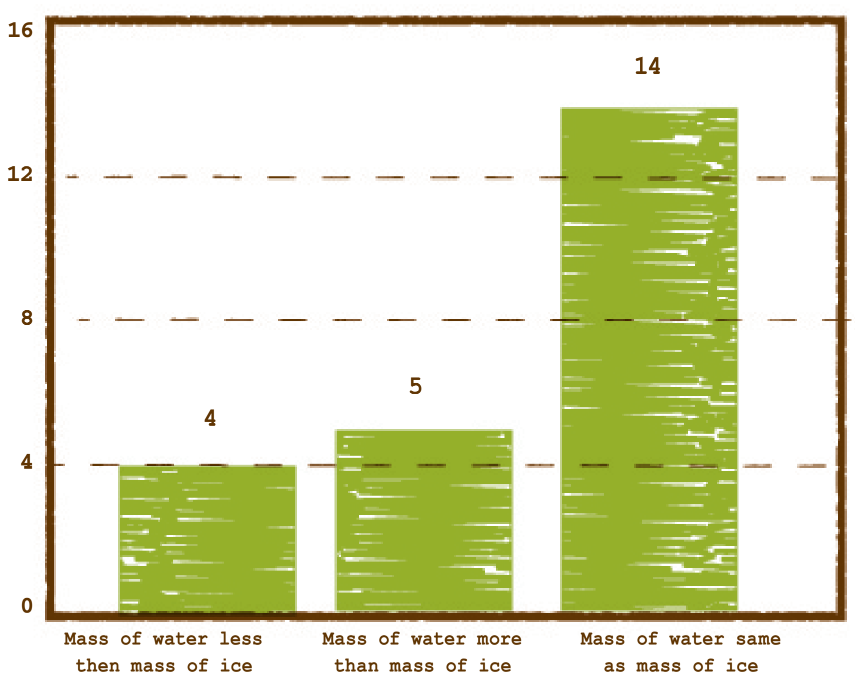
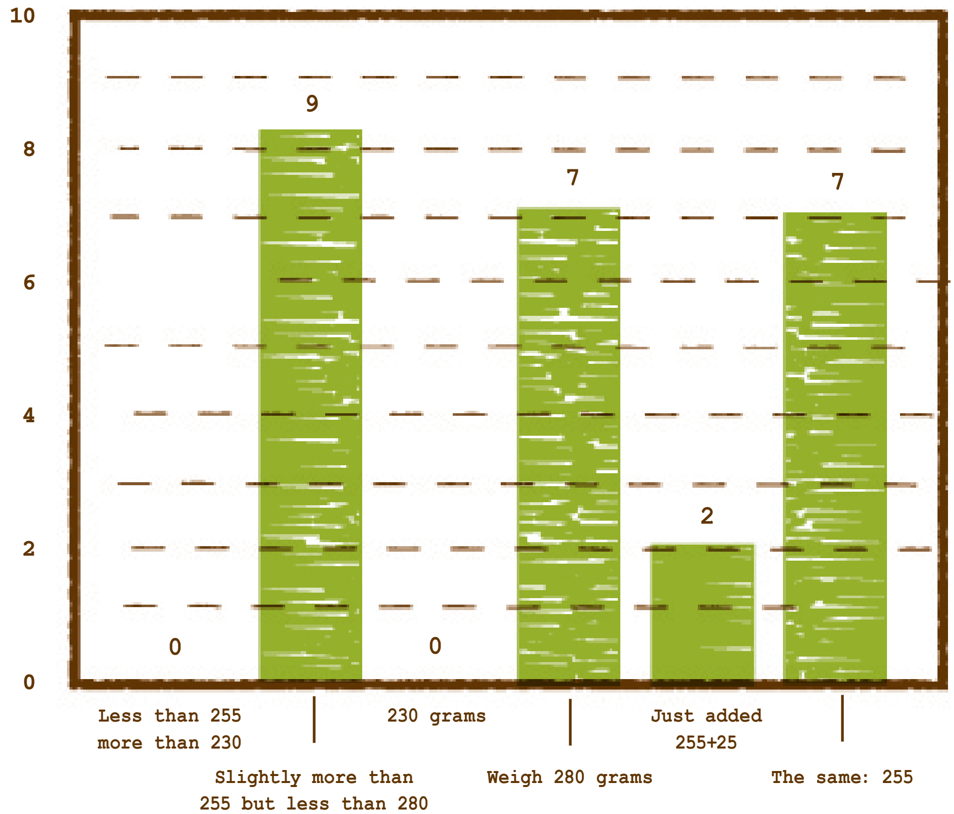


Figure 3: Lemonade



reasons given were that the water takes up more space, the water has a greater volume, and the matter is different. Four students said that the mass of the water would be less than that of the ice. The reasons given were that the ice is a solid and takes up more space, more matter equals "bigger mass," and water expands when frozen making more mass.

None of the students said that the sweetened lemonade would have less mass than the unsweetened lemonade. (See Figure 3.) Nine students said that the solution would have more mass, but not the same as the mass of the sugar added. Their reasoning was that since the sugar dissolved, it would weigh less. The students did not say that the sugar was still there, but that the sugar "melts" away. The students' comments included the following:

"The sugar is going to dissolve, but, at the same time, it is going to add slightly more mass, because it is going to take up more space in the glass."

"Whatever sugar doesn't dissolve will add more mass."

"But, the sugar is still there."

"If all of the sugar dissolved, you wouldn't taste the sugar in the lemonade."

Seven students said that the mass would remain the same. The reasons they gave included the following:

"The sugar will dissolve, so the mass won't change."

"If it is dissolved, it (the sugar) won't have any mass."

"Because it is soluble, the mass won't change."

"The sugar is going to dissolve only leaving a sweeter glass of lemonade."

Gary: I think the mass is going to stay the same, because it's just going to dissolve in it.

Teacher: Do you know what dissolve means?

Gary: Disappear.

Teacher: You predicted that the mass would stay the same. Is that right?

Gary: Yes.

Teacher: Test your prediction by stirring the sugar into the lemonade and then finding the mass.

Gary: It went up more.

Teacher: Can you tell me how much it went up?

Gary: Five grams.

Teacher: Why do you think it went up five grams?

Gary: Because that's how much sugar I put in.

Teacher: What do you think about your prediction now?

Gary: That it stays the same.

Teacher: What do you mean by it stays the same?

Gary: I mean that it goes up by five more 'because you're actually putting more mass into the lemonade.

Teacher: OK, what is making it have more mass?

Gary: The sugar we put into it.

Teacher: At first, you said that it disappeared. What do you think now?

Gary: That it didn't. (Laughs)

Teacher: Where is the sugar now?

Gary: It just stays there. It just gets tinier so you can't see it.

Nine students said the mass would be the mass of the lemonade plus the mass of the sugar. These students stated that if you had a glass of unsweetened lemonade and you added 25 grams of sugar, you would have a total mass of 280 grams. Two of these students said they just added 255 and 25 together.

Each of the interviews that I conducted for the mass of a whole cookie and the mass of the crumbs and part of a cookie resulted in the students seeing and grasping quickly that the mass of the cookie would remain the same. They each stated that all of the parts of the cookie were still there and the mass would be the same.

For "Ice Cubes in a Bag," 'Tommy' predicted the same mass, and his test showed that his prediction was accurate. 'Mark' predicted that the mass would be the same, "because the water expanded when it became ice, and it is the same water that made the ice." 'Kaye' predicted that the mass would be the same when the ice melted, because "the ice is just in a different form." 'Ann' predicted that the mass of the water in the bag would be more, because the water will take up more space than the ice. When 'Ann' returned, she tested to find the mass of the water in the bag. I asked 'Ann' why she thought that she got this result. (The mass was the same.) 'Ann' immediately stated, "It made sense, because the ice and the water were both in a closed bag and nothing came out of the bag so all the same stuff was there. Nothing changed."

'Dan' predicted that the mass would not change and explained, "Ice is just frozen water. They are the same material. I'm sure they will never change as long as you don't add more ice cubes or water." 'Dan' came back after his ice had melted, and I asked him to test his prediction by finding the mass of the melted ice. He was pleased with his result in finding that his prediction was correct. Before he left he said, "Do you see how this tissue only has a mass of 1.2 grams when unfolded. When crumpled up it has the same mass."

Responses to the "Lemonade" interview prompt to predict what the mass of the glass of lemonade would be after we added the sugar and stirred it up came from the group that thought that when sugar dissolved, it disappeared. An abbreviated interview with 'Gary' is as follows:

'Gary' tasted the lemonade to make sure before he left.

Other students made these comments about their predictions and tests:

'Karen' said "I was right! Groovy! It's dissolved, but it's still there." In answer to the question, "Do you think that would happen in every situation when you add two substances together?" 'Larry' answered, "Probably yes." He told me he needed more tests to be definitely sure. 'Ken' had to try the test twice before he was convinced that the sugar was still in the lemonade. It just spreads out. 'CJ' needed to taste the lemonade to be totally convinced. 'Dillon' knew that the two masses had to be added together, because it just made perfect sense to him.

Data Analysis

"Cookie Crumbles" is aimed at elementary-level students, but it's a good probe to use to get an idea of what my eighth graders are thinking. These students have worked with mass and volume, states of matter, phase changes, and particulate matter, but they have not yet worked with solubility and the concept of a closed system. I thought that most of the students would understand that, even though the cookie was broken, the pieces of the cookie would have the same mass as the whole cookie. Using probes is a great way to see how and what students think!

My students readily understood that matter is conserved in phase changes from a solid to a liquid; however, some perceived that when the ice cubes melted, the volume appeared to increase or decrease, and they thought that was the reason for a change of mass. *Benchmarks for Science Literacy* points out that many students cannot understand conservation of weight until they are fifteen years old. Students cannot understand conservation of matter and weight if they do not understand what matter is. Sixty percent of the students mentioned matter as a reason for the mass not changing in "Ice Cubes in a Bag."

When the sugar dissolved in the lemonade, less than one fourth of the students understood that dissolving meant that the sugar was still in the lemonade and the mass of the two substances would be the total of the masses of the sugar and the lemonade. *Making Sense of Secondary Science* states, "If students perceive that a particular change is dominated by the apparent disappearance of some materials, then students are not likely to believe that the mass or matter is conserved." My students said that the sugar had disappeared, because they could no longer see the particles. In "Cookie Crumbles," however, the students understood that the mass was conserved, because they could still see the particles. The students who responded to "Lemonade" knew that there should be more mass because they added something, but they could not see the sugar, so they were not totally convinced.

Benchmarks for Science Literacy notes that middle-school students begin to use particle ideas and closed systems to support their explanations about conservation of matter. Several students used the concept of matter, stuff, particles, and atoms. Students are expected to understand conservation of matter by the end of their eighth-grade year according to our district curriculum.

Significance

My students are close to understanding conservation of matter. They note that matter is the "stuff" that everything is made of and that mass is the amount of "stuff" in matter. Kids understand "stuff!" I learned that using the term "stuff" to explain matter and mass makes these concepts easier for students.

I will continue to offer experiences that show the conservation of matter during physical changes to help my students understand the concept through observation and testing. 'Larry' put it very well when I asked him what would make him definitely sure that the sugar did not disappear in the lemonade. He said that he probably would be definitely sure "if he did a couple more experiments." Students need exposure to repeated experiences with an idea to internalize the concept.

I found that using a protocol (that includes identifying patterns of reasoning, comparing them to the cognitive research, and making instructional decisions that are compatible with the Conceptual Change Model (CCM) (Stepans, 1999) to examine student thinking about a specific learning goal is a great method for teaching science concepts. The CCM calls for students to commit to an outcome and helps them to work through experiences in order to accept and understand the concept. The CCM also supports students in applying their knowledge to new situations.

Each interview began with asking the student to commit to an outcome. The student made a prediction based on their current thinking about the concept. Using a series of questions, I led each student through a discussion of their beliefs about whether a cookie, ice cubes, and lemonade would have the same mass after a physical change had taken place. The students were then asked to test their predictions. Some of their tests did not come out as they expected, so the students had to come up with explanations for why their predictions and the results of the test were not the same. Even though these students agreed that the mass in these tests would stay the same, when asked if they thought that this would be true for any two substances that were added together, they still needed more proof. In conceptual change, doing more testing is a good idea. In fact, it is important to test enough substances to convince each student that mass is conserved during a physical change even though it's no longer obvious that the substance is still there.

The next step that I will take in my eighth-grade classroom is to teach the concept of conservation of matter through investigation and inquiry. I know that my students will come to understand that mass and matter are not created or lost during a physical change. Then we can go on to look at conservation of matter during a chemical change.

I am very excited about this research with a focus on conceptual understanding for students. I know that this is how I want to continue to teach science to my students. I have received a lot of satisfaction in knowing that this is a plan for effective teaching and learning.

Reflection

The interviews were fascinating! I was able to watch as the students changed their ideas about conservation of matter. This process was so much more effective than reading through the research even though I understood the preconceptions that were written there. I read the literature but did not always internalize its importance. I saw my students with the same preconceptions that the literature addressed, and I saw how my students reacted to the Conceptual Change Model (CCM). This process is hands-on learning for teachers! I know that I will continue to do action research in my classroom, because I know that it benefits my students and makes me a more effective teacher.

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Do the parts weigh the same as the whole? Third graders' ideas concerning the conservation of matter

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Purpose of the Study

The purpose of my study is to find out why third graders have a hard time understanding conservation of matter. As part of our science committee work, third-grade teachers analyzed how our students were learning the content within our unit, "What Is Matter?" Looking over the final assessment, we found that many of the students were missing the test questions concerning conservation of matter. I want to learn what common ideas and misconceptions they have about conservation of matter. I am wondering if I do too much talking about ideas instead of questioning and guiding students through experimentation and discussion to analyze their own thinking.

Research Questions

1. What do the standards and research say about conservation of matter?
2. What preconceptions do students have about conservation of matter?
3. What prior knowledge do students have that contribute to their thinking about conservation of matter?

Curriculum Topic Study (CTS)

Background Research, "Conservation of Matter" (p.163) (Keeley, 2005)

Clarification of the content summarized from *Science for All Americans (SFAA)*

- Over long spans of time, matter and energy are transformed among living things, as well as between them and the physical environment.
- In these grand-scale cycles, the total amount of matter and energy remains constant, even though the form and location undergo continual change.
- Antoine Lavoisier, a French scientist, experimented with fire and found that the total weight of materials produced by burning (gases and ash) is the same as the total weight of the reacting materials (wood and oxygen).

Student learning goals from *Benchmarks for Science Literacy* (BSL) and *National Science Education Standards* (NSES)

- No matter how parts of an object are assembled, the weight of the whole object made is always the same as the sum of the parts. When a thing is broken into parts, the parts have the same total weight as the original thing. (*BSL* Grades 3-5)
- Objects have many observable properties, including size, weight, shape, color, temperature, and the ability to react with other substances. Those properties can be measured using tools, such as rulers, balances, and thermometers. (*NSES* Grades K-4)

Student learning goals from *Maine Learning Results, 2007*

Grades 3-5

- Describe how the weight of an object compares to the sum of the weight of its parts.
- Explain that the properties of a material may change but the total amount of material remains the same.

Student learning goals from *Auburn's Third Grade Science Curriculum*

- What happens to the weight of an object when you take it apart?

1. The weight of the object decreases overall, but the total weight of all the parts will equal the weight of the whole.
2. No matter how the physical properties of an object change, the total amount of matter stays the same.

Teaching considerations summarized from *Benchmarks for Science Literacy (BSL)* and *National Science Education Standards (NSES)*

- Concrete perceptions must come before abstract explanations. (*BSL*)
- Students need to become familiar with the physical and chemical properties of many different kinds of materials through firsthand experience before they can be expected to consider theories that explain them. (*BSL*)
- Students should design and build objects that require different properties of materials. (*BSL*)
- Students should write clear descriptions of their designs and experiments. (*BSL*)
- Students should present their findings whenever possible in tables and graphs and enter their data and results in a computer base. (*BSL*)
- Students need many experiences with weighing and, if possible, with sensitive balances. This should also include weighing piles of small things and dividing to find the weight of each. (*BSL*)
- Students need to carefully observe and keep track of how the world works. (*NSES*)
- Students need opportunities to observe, describe, and measure the properties of objects, changes in properties over time, and changes that occur when materials interact. (*NSES*)

Cognitive research from *Benchmarks for Science Literacy* (*BSL*), National Science Education Standards (*NSES*), and *Making Sense of Secondary Science* (*MSSS*)

- It is not clear to elementary students that wholes weigh the same as the sum of their parts. (*BSL*)
- Students cannot understand conservation of matter and weight if they do not understand what matter is. (*BSL*)
- Students need to accept weight as an intrinsic property of matter and distinguish between weight and density. (*BSL*)
- By fifth grade, many students can understand qualitatively that matter is conserved in transforming from a solid to a liquid. They also start to understand that matter is quantitatively conserved in transforming from solid to liquid and qualitatively in transforming from solid or liquid to gas—if the gas is visible. (*BSL*)
- The idea of liquids is more nebulous and requires more instructional effort than working with solids. (*NSES*)
- Students are often unable to conserve mass when the size of the particles changes. (*MSSS*)

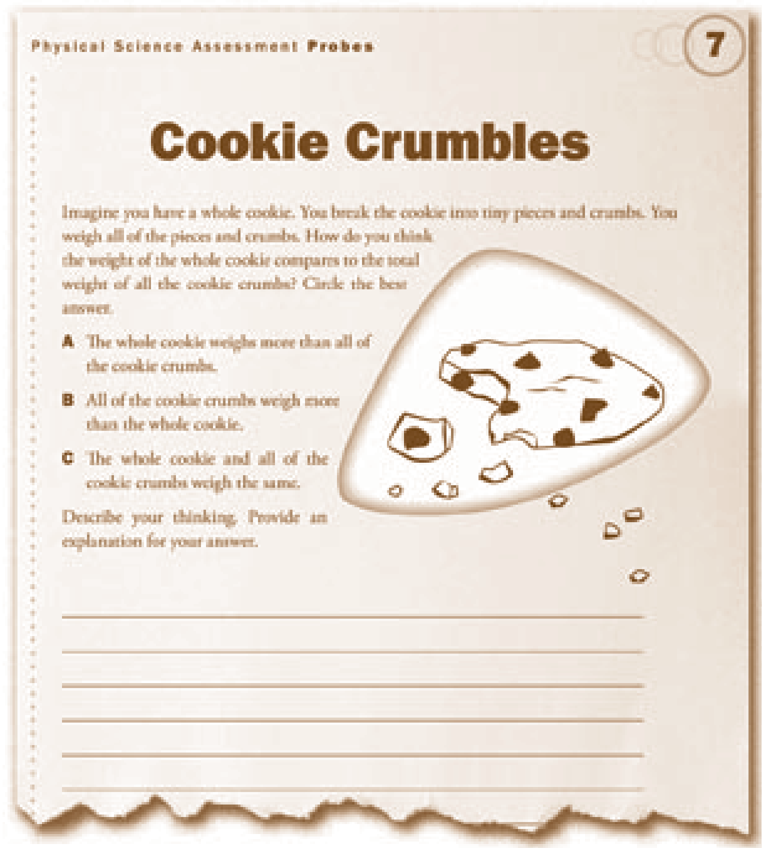
Classroom Research

Classroom Context

This research was conducted with a third-grade class in an urban school in central Maine. The school has approximately 450 K-6 students. Within this third-grade class, there are ten boys and 12 girls.

Methodology and Data Collection

I began my research a week before my class began working on the science unit, "What Is Matter?" Knowing that I was going to be focusing my research on students' ideas about the conservation of matter, I decided to give them the "Cookie Crumbles" probe (Keeley et.al., 2005). I gave each student a cookie in a plastic bag, asked each of them to keep the bag closed throughout our exploration and explanation time, and told them that later they would be allowed to open the bag and eat the cookie. After the students had completed the questions on the probe, I placed them in small groups to discuss their thinking. Forty-one students took the "Cookie Crumbles" probe.


Physical Science Assessment Probes 7

Cookie Crumbles

Imagine you have a whole cookie. You break the cookie into tiny pieces and crumbs. You weigh all of the pieces and crumbs. How do you think the weight of the whole cookie compares to the total weight of all the cookie crumbs? Circle the best answer.

A The whole cookie weighs more than all of the cookie crumbs.

B All of the cookie crumbs weigh more than the whole cookie.

C The whole cookie and all of the cookie crumbs weigh the same.

Describe your thinking. Provide an explanation for your answer.

Used with author's permission (Keeley, Eberle, and Farrin, 2005)

During the next two weeks, we worked through seven hands-on lessons exploring what matter is, how matter is described, what the different states of matter are, and what the properties of matter are. Then, we were ready to look at what happens when matter changes form. (See Appendix A.) The students completed a number of activities involving physical changes and recorded their results in their scientists' notebooks. The last activity involved weighing a Popsicle stick, breaking it up, and predicting whether the pieces would weigh more, less, or the same. Then, they weighed the pieces and recorded their results.

At the end of the unit, the students took the summative assessment. One of the multiple choice questions was as follows: "A block of wood weighs one pound. You cut the wood into four pieces. The four pieces weigh: A) nothing; B) more than the block; C) less than the block; and D) the same as the block." Below the question the students were asked to explain their answer.

After looking at the data collected from these three sources, I interviewed and recorded five students to look more closely at their ideas and thinking. (See Appendix B.)

Organization of Data and Findings

Figure 1: Conservation of Matter

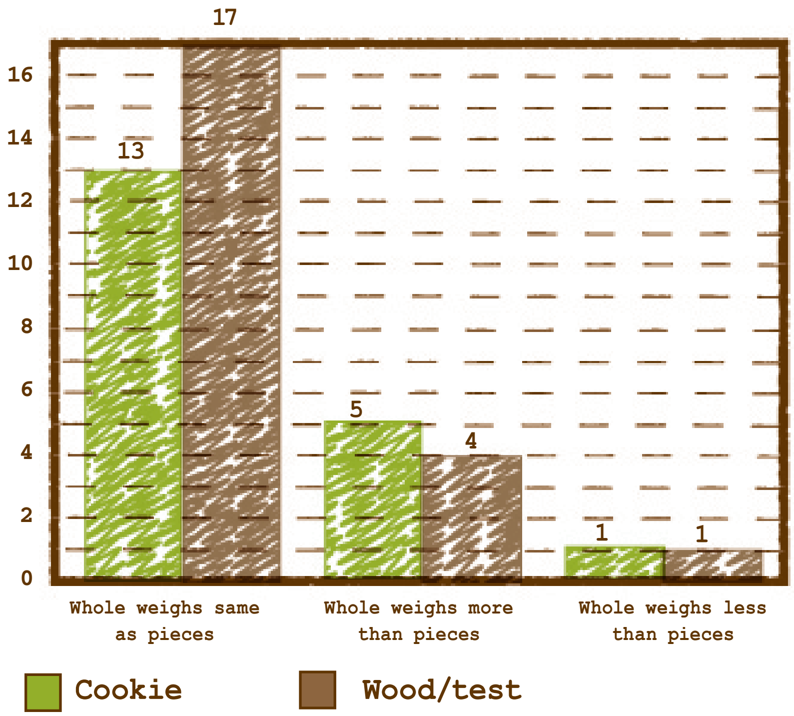


Figure 1 summarizes the results of the students' answers to the "Cookie Crumbles" probe and the summative assessment test question. In the summative assessment, two of the students had the correct answer on each task. Two students had the correct answer when given a concrete object to work with but missed the test question, which was more abstract. One student said that the whole weighed more on the probe, but had the correct responses on the other two tasks. Table 1 summarizes the data from all four sources.

Data Analysis

When students were given actual materials to work with, many were able to correctly predict the whole object (cookie or wood) weighs the same as the pieces. The percentage of students who correctly predicted they would weigh the same increased from the first to the second task. (See Figure 1). But some of these same students were not able to correctly predict when it was conveyed in an abstract manner on a test (Table 1, students 2, 9, 15). According to the research, concrete perceptions must come before abstract explanations.

Many of the students described the size of the cookie compared to the crumbs as having a direct relationship to the weight. ("The whole cookie is bigger than the crumbs, it must weigh more," or "Because the whole cookie is bigger than a crumb, the whole cookie is heavier than the crumb.") According to the research, students are often unable to conserve mass when the sizes of the pieces change.

Another observation I see when looking at the data is that when the object was placed in an enclosed container (plastic bag), many of the students were more likely to say that the whole weighed the same as the pieces. Students' predictions as to whether the objects would weigh the same did increase with each task – from 68 percent with the probe to 71 percent with the science notebook to 77 percent with the test question. This shows the importance of providing students with a variety of opportunities to observe, describe, and measure properties of matter.

Significance

The findings and conclusions I have drawn from my work have given me a better understanding of the importance of inquiry and teaching for conceptual change. Students need to be allowed to discover their own ideas concerning science concepts. They need the opportunity to use hands-on materials to confront their own misconceptions and

Table 1:
Summary of Student Data

Students	Probe #	Sci. NB*	Test	Interview#	% correct response
1	More	Same	Same	Same	75%
2	Same	Same	More		66%
3	Same	More	Same		66%
4	Less	More	Same		33%
5	Same	Same	Same	Same	100%
6	Same	Less	Less		33%
7		Same	Same		100%
8	Same	Same	Same		100%
9	Same	Same	More		66%
10	Same	Same	Same	Same	100%
11	Same		Same		100%
12	Same	More	More		33%
13	More	Same	Same	Same	75%
14	More	More	Same		33%
15	Same	Same	More	Same	75%
16		Same	Same		100%
17	Same	Same	Same		100%
18	More	More	Same		33%
19	More	Same	Same		66%
20	Same	Same	Same		100%
21	Same	Same	Same		100%
22		Same	Same		100%
Results	**13/19**	**15/21**	**17/22**	**5/5**	
	68%	**71%**	**77%**	**100%**	

* Sci. NB = Scientist's Notebook

When an object is broken into smaller pieces, does the whole weigh more than the pieces, less than the pieces, or the same as the pieces?

deepen their thinking. As students become aware of their initial ideas, I need to provide them with opportunities to observe, measure, and describe objects and changes that occur. As their understanding deepens, they need to be able to apply what they have learned to new situations.

I have already begun to use what I learned in my research within my school and third-grade team. I teach all three third-grade classes our science curriculum. My research was conducted through my first rotation of the "What is Matter?" unit. Due to this research project, I have added the "Cookie Crumbles" probe as the first lesson and given students more opportunities to explore properties of matter. I have added more chances to weigh items as a whole and later broken into pieces. As an active member of our school system's science committee, I am already sharing my work at our monthly committee meetings and as part of the small group making revisions to the third-grade kit. Due to our partnership with the University of Southern Maine, I continue to mentor and share the work I am doing with future teachers.

Reflection

Conducting research while teaching full time was challenging, though I feel the benefits far outweigh the challenge. First, this project pushed me to look at the research and to deepen my understanding of students' thinking. It gave me a deeper understanding of the standards I teach. Next, gathering the evidence pushed me to truly listen to what my students were saying and to come up with ways to gather and store the data for later analysis. Later, looking at my findings and conclusions deepened my teaching practice and helped me to make changes in the lessons I teach.

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Appendix A

Lesson 8 "What happens when matter changes form?" Full Option Science System (FOSS)® Time: 1 class

Unit Questions	Key Concepts
What happens when matter changes form? **What happens to the weight of an object when you take it apart?**	• When matter changes physically no new substances are formed. The substance is the same. Examples: bending, cutting, and folding. This is physical change. • Some properties of an object may stay the same even when other properties change. • No matter how the physical properties of an object change, the total amount of matter stays the same. • Substances may move from place to place, but they never appear out of nowhere and never just disappear. • The weight of an object decreases overall, but the total weight of all the parts will equal the weight of the whole.

Objectives: Students should be able to:

1. Explain that matter changes form and this is called physical change;
2. Explain that some properties change while others stay the same;
3. Demonstrate that an object when broken apart will equal the weight of the whole object; and
4. Explain that matter may change form, but the total *amount* stays the same.

Materials: For each student/group:

1. "Physical Change" pages in Scientists' Notebooks
2. Popsicle stick, pipe cleaner, paper cup, piece of paper, cup with ¼ cup warm water, mints (three per group), ice cube in a cup, and scale

Lesson Sequence:

1. Begin the lesson by reminding students about the properties of solids, liquids, and gasses that they have learned about over the last few lessons.
2. Ask them to turn and talk with a neighbor about the properties of materials. They should review their Scientists' Notebooks.
3. Now that they have remembered some of the property words they used in the beginning of the unit, tell students that in today's lesson they will be changing objects. When you change some properties, but the substance or item stays the same, it is called PHYSICAL CHANGE. Physical change is a change in form, state, or appearance, but the substance stays the same. Changing state of matter also is a physical change.
4. The class should be broken up into groups of three to five students. Have each group get materials for the upcoming experiments.
5. Tell students to find the page about Physical Change in their Scientists' Notebooks.
6. Point out the directions on the page and make sure that students are aware that they must observe the item before the change and write or draw the properties they see. THEN, they make the change and write or draw the properties in the third column.
7. Direct students to complete each activity, giving each student the opportunity to perform one change. Remind students to keep the Core Values in mind as they work with their group.
8. If students have trouble answering the question, "Is the substance (item) still the same?" tell them that substance is a word for what the item is made out of. This is in their glossary.
9. Rotate around the room with the scale to be used for the clay change. Give each group the opportunity to weigh a whole chunk of clay and record the weight in their notebooks. Then, let the students break the clay into pieces. Ask students what they think the weight of the clay will be now. Again, weigh all the parts. Note: They should be the same or VERY close!
10. Get students' attention for the final two experiments. Direct each group to drop their mints into the cup of warm water. Discuss the idea of dissolving versus disappearing as students are recording results on their data sheet. Leave one cup to "dry" out over time so that students see that the sugar was dissolved in the water.
11. Now that the ice has been sitting for a while, ask students to record and discuss what they observe. Walk students through the Physical Change questions in the Scientists' Notebook.

Concluding Discussion: Gather the students' attention and review the results that the groups got as a whole class. Help students to realize the following ideas:

1. After each change, some of the properties change, but some stay the same.
2. Each change should have a "YES" in the last column under the question: "Is the substance (item) still the same?" Remind them that this is Physical Change.
3. Changes in a state of matter, from liquid to solid or back again, also is a physical change. This is most difficult to understand with dissolving.

Optional Extension: • Read the FOSS® book, *Solids & Liquids.* • Scientists' Notebook page

Notes from the Field SC4

What is Physical Change?

Name______________________________

Your group should do each item one by one and record your observations. Give everyone a turn.

These are all examples of ***physical change.*** Work with your group to create a definition of physical change. A physical change is when . . . ____

____

____

Item	Observation before change	What you do	Observation after change	Is the substance (item) still the same?
Paper		Crumple it into a ball		
Pipe Cleaner		Twist it up		
Paper		Tear it up		
Paper Cup		Step on it		
Popsicle Stick	Weight:	Break it up	Predict the weight: More Less Same Weight:	

Summative Assessment Question

Circle the correct answer in the column on the right.

9. A block of wood weighs 1 pound. You cut the block into 4 pieces. The 4 pieces weigh: A. Nothing B. More that the block C. Less than the block D. The same as the block	A B C D

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Appendix B

Interview Transcript Student #1

H is a Title I student who got both the probe and test question correct. Teacher hands the student a small plastic bag with a Popsicle stick inside.

Student 1:

T: "Look at these things. What do I have here?"

H: "A Popsicle stick in a bag."

T: "OK, this is a Popsicle stick in a bag." (Teacher breaks stick into four pieces). "What did I just do and what do I have in the bag now?"

H: "You broke the Popsicle stick and now it is broken up."

T: "Do you think the pieces will weigh more than the whole stick, less than the whole stick, or the same as the whole stick?"

H: "All put together?"

T: "Do you think …"

H: "The same."

T: "Why do you think they weigh the same?"

H: "Because if you break something up and you put it all together again, they pretty much weigh the same."

T: "OK, so if you take something, break it up into smaller pieces, and put it back together again, it will weigh the same. Is that what you are saying?"

H: "Yeah."

T: "Have you ever done like that before?"

H: "Yes."

T: "Any other comments you can make about the weight of an object when it is whole and then when it is broken up?"

H: "No."

Interview Transcript Student #2:

A is an average student who got the "Cookie Crumbles" probe wrong and the test question right. Teacher hands the student a small plastic bag with a Popsicle stick inside.

Student 2:

T: "Look at these things. What do I have here?"

A: "A Popsicle stick."

T: "Is there anything else with it?"

A: "No"

T: "Ok, is it in anything?"

A: "Yes, it's inside a plastic bag."

T: "Yes, it's inside a plastic bag. So we have a Popsicle stick inside a plastic bag. I'm going to do something to this Popsicle stick and then I'm going to ask you some questions, OK?"

transcript continues on next page

(Teacher breaks stick into four pieces).

T: Do you think the pieces will weigh more than the whole stick, less than the whole stick, or the same as the whole stick?"
A: "Same."
T: "Why do you think so?"
A: "It still has the same amount of it."
T: "So it still has the same amount."
A: "… of the stick. You just broke it up… you would have to take something out of the bag for it to be less."
T: "I would have to take something out if it was going to be less. Is that what you are saying?"
A: "A part of the stick. And why are you asking me all of these questions?"
T: "Because that is something I want to make sure you understand, and I think you do."

Interview Transcript Student #3:

J is a male third grader who is exceeding the standards in all subject areas. He is involved in enrichment groups. He got the probe correct yet missed the test question.

Student 3:
T: "OK what do I have in my hand?"
J: "A Popsicle stick."
T: "Ok, is there anything else?"
J: "It's in a plastic bag."
T: "Very good. So I have a Popsicle stick inside a plastic bag. I am going to do something to this Popsicle stick and then I'm going to ask you some questions." (Teacher breaks the stick into three pieces.)
T: "Ok, now look at the bag. What do you see?"
J: "I see three pieces of one Popsicle stick."
S: "Do you think the pieces will weigh more than the whole stick, less than the whole stick, or the same as the whole stick?"
J: "The same."
T: "Why do you think so?"
J: "It's just the Popsicle stick except its in little pieces."
S: "So it's just the Popsicle stick except its in little pieces. And so it weighs the same?"
J: "Yes."
S: "Is there anything else you could say about the weight of the whole stick and the pieces of the stick?"
J: "No."

Interview Transcript Student #4:

M is a female third-grade student who is exceeding the standard in reading and math. She is involved in enrichment groups. M got both the probe and the test question correct.

Teacher hands the student a small plastic bag with a Popsicle stick inside.

Student 4:

T: "Look at these things. What do I have here?"

M: "A Popsicle. A Popsicle stick."

T: "Anything else?"

M: "A bag."

T: "OK, I'm going to do something to the Popsicle stick in the bag and then I'm going to ask you some questions about it. (Teacher breaks stick into four pieces). Do you think the pieces will weigh more than the whole stick, less than the whole stick, or the same as the whole stick?"

M: "The same."

T: "Why do you think they weigh the same?"

M: "Because it is just broken up into small pieces. You didn't take anything away from it."

T: "OK, so it weighs the same because I didn't take anything away. Is there anything else you could tell me?"

M: "Yes. The bag is wrinkled and it was flat before."

Interview Transcript Student #5:

D is a male third grader who is a high-average student who is inquisitive and loves to explore a variety of science topics.
Teacher hands the student a small plastic bag with a Popsicle stick inside.

Student 5:

T: "What do I have in my hand?"

D: "A Popsicle stick."

T: "Is the Popsicle stick in anything?"

D: "A bag."

T: "OK, I'm going to do something to the Popsicle stick in the bag and then I'm going to ask you some questions." (Teacher breaks stick into four pieces).

T: "What did I do with the Popsicle stick?"

D: "You broke it."

T: "How many pieces are there?"

D: "Three."

T: "Do you think the pieces of the Popsicle stick will weigh more than the whole stick, less than the whole stick, or the same as the whole stick?"

D: "The same."

T: "The same is what you say. Why do you think so?"

D: "I don't know."

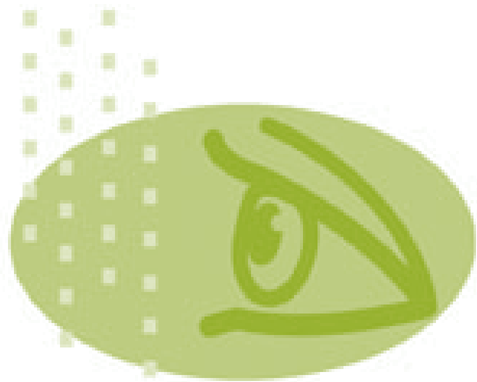
T: "Can you give me some idea?"

D: "Aah…Aah…I don't know."

T: "No idea at all why they are the same weight?"

D: "I'm thinking but it won't come out. It ... It ... Because they are the same."

Making invisible student ideas about evaporation visible



Ingrid Porter

Noble VI School

Berwick, ME

Ingrid Porter's career as a sixth-grade teacher began 17 years ago. Her favorite part of teaching is watching as students discover (or rediscover) the mystery and magic of science. A University of Maine at Farmington graduate, Ingrid currently teaches at the Knowlton School in Berwick, Maine.

Purpose of the Study

One of the Full Option Science System (FOSS)® units that I teach to my sixth grade science classes is Mixtures and Solutions. Evaporation of a solution to separate the solute from the solvent is a major concept of the unit. While teaching the unit during the past seven years, I have noticed that, although students use the term "evaporation" with confidence in their speaking and writing, they consistently confuse evaporation with dissolving and melting. When describing phenomena they see in the lab, they use the three terms—dissolve, evaporate, and melt—interchangeably. This makes me wonder what they believe these processes really involve and why they perceive them as being the same or similar enough to be confused. If students develop an accurate understanding of evaporation, they are less likely to confuse the different processes. A solid understanding of evaporation also allows for comparisons and contrasts with melting and dissolving. In addition, introducing or reinforcing the idea of gases and phase change aids their more sophisticated work with matter in seventh and eighth grades.

I sought to uncover commonly held, if not always correct, ideas that my students have about evaporation and, furthermore, to identify the sources of these beliefs. I also wanted to learn more about the process of evaporation to discover what might cause difficulty for students in thinking about evaporating, dissolving, and melting as three distinct processes. I will use the information I gain about their thinking and combine it with current educational research to design and deliver appropriate, effective learning experiences.

Research Questions

1. What do science standards and current research say about the concept of evaporation and what sixth graders should know and understand about it?
2. What commonly held ideas do my sixth graders have about evaporation?
3. What experiences and notions may have contributed to those ideas about evaporation?

Curriculum Topic Study (CTS)

Background Research, "States of Matter" (p.173) (Keeley, 2005)

Clarification of the content from *Science for All Americans* (*SFAA*)

- Every substance can exist in a variety of different states, depending on temperature and pressure.
- All but a few substances can take solid, liquid, and gaseous form.
- The cycling of water in and out of the atmosphere involves evaporating from the surface, rising and cooling, condensing into clouds and then into snow or rain, and falling again to the surface, where it collects in rivers, lakes, and porous layers of rock.

Student learning goals from *National Science Education Standards* (*NSES*) and *Benchmarks for Science Literacy* (*BSL*)

- Materials can exist in different states—solid, liquid, and gas. Some common materials, such as water, can be changed from one state to another. (*NSES* Grades K-4)
- When liquid water disappears, it turns into a gas (vapor) in the air and can reappear as a liquid when cooled… Clouds and fog are made of tiny droplets of water. (*BSL* Grades 3-5)
- Water evaporates from the Earth's surface, rises and cools…condenses as rain or snow, and falls to the surface where it collects …(*NSES* Grades 5-8)
- Water evaporates from the surface of the Earth, rises and cools, condenses into rain or snow, and falls again to the surface. (*BSL* Grades 6-8)

Student learning goals from *Maine Learning Results, 2007*

Grades Pre-K-2

- Describe what happens to water left in an open container as compared to water left in a closed container.
- Describe changes in properties of materials.

Grades 3-5

- Describe the various forms water takes.
- Describe how the heating and cooling of water and other materials can change the properties of the materials.

Grade 6-8

- Describe Earth systems …cycles and interactions within them (including water moving among and between them).
- Describe how matter… changes from one form to another.

Teaching considerations from *Benchmarks for Science Literacy* and *National Science Education Standards*

- Students must know about the properties of materials and their combinations, changes of state, effects of temperature, behavior of large collections of pieces, the construction of items from parts and even about the desirability of nice, simple explanations. All of these elements should be introduced in middle school so the unifying idea of atoms can begin by the end of eighth grade. (*BSL*)
- Concrete perceptions must come before abstract explanations. (*BSL*)
- Students need to become familiar with the physical and chemical properties of many different kinds of materials through firsthand experience before they can be expected to consider theories that explain them. (*BSL*)
- Students should become familiar with characteristics of different states of matter— including gases—and transitions between them. (*BSL*)
- Students need to study earth processes repeatedly; it takes years to acquire the knowledge they need to complete the full picture. This includes understanding of the concepts of temperature, the water cycle, gravitation, states of matter, chemical concentration, and energy transfer. (*BSL*)
- In grades 5 to 8, students observe and measure characteristic properties, such as boiling and melting points, solubility, and simple chemical changes of pure substances, and use those properties to distinguish and separate one substance from another. (*NSES*)

Cognitive research from *Benchmarks for Science Literacy* (BSL) and *Making Sense of Secondary Science* (MSSS)

- By fifth grade, students start to understand that matter is quantitatively conserved in transforming from solid to liquid and qualitatively in transforming from solid to liquid to gas—if the gas is visible. (*BSL*)
- Students' ideas about conservation of matter, phase changes, clouds, and rain are interrelated and contribute to understanding the water cycle. Students seem to transit a series of stages to understand evaporation. Before they understand that water is converted to an invisible form, they may initially believe that when water evaporates, it ceases to exist, or changes location but remains a liquid, or is transformed into some other perceptible form. (*BSL*)
- Students think that when a solid object, such as a wet saucer dries, the water just disappears or it penetrates the solid object. (*MSSS*)
- With special instruction, some students in fifth grade can identify the air as the final location of evaporating water, but they must first accept air as a permanent substance. (*BSL*)
- The evaporation concept appears to be dependent on the development of notions of conservation, atomism, and (invisible) air, and a conception of evaporation which links these three notions is prevalent by the age of 12 to 14. (*MSSS*)
- When students observe a liquid changing to a gas, they may construct the idea that because the substance seems to disappear, weight or mass is lost. (*MSSS*)
- Few students mention molecules when describing what happens to water evaporating from a plate. (*MSSS*)

Classroom Research

Classroom Context

The sixth-grade class at my school contains 235 students from three towns in rural southern Maine. The number of students receiving free lunch is 57, while the number receiving reduced lunch is 25. Our school is divided into several teams. Four homerooms comprise a team, with about 20 or 21 students per homeroom. Before sixth grade, students attend a self-contained elementary school in the town where they reside. It is important to remember that sixth grade in our district is the first time that all students are guaranteed daily science instruction for an hour.

Methodology and Data Collection

I began my research by administering a probe, “Wet Jeans” (Keeley et.al., 2005), to students in all four science homerooms. This allowed me to determine if any other research about evaporation is even necessary. The “Wet Jeans” probe gives a scenario involving freshly washed jeans that hung outside and, within an hour, are no longer wet. This is a two-tiered probe, where students are first asked to choose the best explanation (among seven) for what happened to cause the change from wet to dry (Tier 1) and then to explain why they chose their response (Tier 2).

Life, Earth, and Space Science Assessment Probes 21

Wet Jeans

Sam washed his favorite pair of jeans. He hung the wet jeans on a clothesline outside. An hour later the jeans were dry.

Circle the answer that best describes what happened to the water that was in the wet jeans an hour later.

A It soaked into the ground.
B It disappeared and no longer exists.
C It is in the air in an invisible form.
D It moved up to the clouds.
E It chemically changed into a new substance.
F It went up to the Sun.
G It broke down into atoms of hydrogen and oxygen.

Describe your thinking. Provide an explanation for your answer.

Used with author’s permission (Keeley, Eberle, and Farrin, 2005)

I let several weeks elapse before beginning the next step in data collection. After that first whole team data sweep with the probe, I wanted to get more detailed ideas from a few students. I interviewed student volunteers about the topic. (Interview questions are found in Appendix B.) I returned the probes and asked all of my students to reread the prompt and their responses. I supplied them with large paper to draw labeled pictures of what they believe happened to the water that was in the wet jeans. I used their pictures in conjunction with a prompt and questions I designed to interview three student volunteers. I also examined the drawings for information about what the whole team of students believes happened to water when it evaporated.

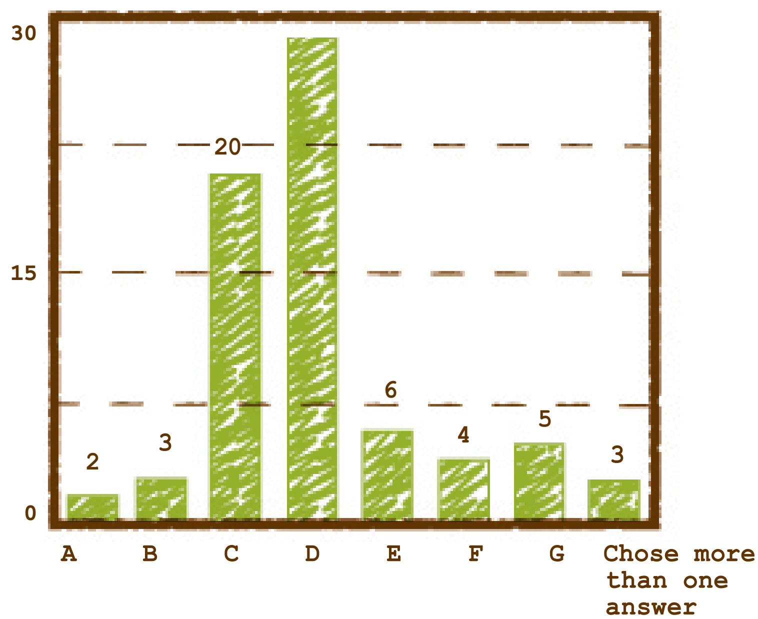
My third data source involved labeled student drawings based on their probe responses.

Organization of Data and Findings

Figure 1:

Wet Jeans Tier 1 Responses

“Wet Jeans” probe: Of the 72 students who responded to the “Wet Jeans” Tier 1, only 20 chose the correct answer. (See Figure 1.) Three students chose more than one answer.



Tier 2 of the probe asks students to explain their reasoning and share the background knowledge they used to make their choice. Although the responses are as individual as the students who gave them, patterns and commonalities emerge. (See Table 1.)

Table 1: Wet Jeans Tier 2 Responses

Reasoning supplied by students	Number of Students Using Reasoning
Think water goes into the clouds	30
Use term "evaporation" with no explanation	8
Use terms "gas" or "water vapor"	11
Think water goes into the air in an invisible form	23
Provide other responses in addition to above	3

Student interviews: Of particular interest to me is whether students use the term *evaporation* in their responses because, although the probe describes the process of evaporation in one of its choices, the term "evaporation" is never used in any part of the probe. Not only did I look for use of the term, but also operating definitions. While responding to the probe, one student complained that she didn't like any of the answers because none of them involved evaporation! Although only 20 students answered correctly, 53 students used the term "evaporation" when sharing their reasoning. It was evident that students had heard the term and used it before, but they didn't have a strong grasp of the concept.

I conducted three interviews, and Alex was my first volunteer. "It moved up to the clouds" was his explanation for what happened to the water in the jeans. He had drawn a mountain, a river, the ocean, and some clouds. When I asked him about the diagram, he stated that in third grade there was a picture of the water cycle in his classroom. He knows that evaporation is connected with the water cycle, but when I asked him what evaporation means, he replied that he had no idea, but knew that heat warms the water and it evaporates into the clouds. I later asked him if there were any probe choices that came in a close second to the one he had chosen. Alex stated that water isn't really like air, that it's a liquid, not a gas, that it's not invisible, but microscopic. So the idea of it being in the air in invisible form didn't seem like a possibility to him.

Margaret, another student interview volunteer, chose "It chemically changed into a new substance." She believes that the water evaporates into the air, but maintains that a cloud is actually water that has changed into a new substance. When I asked Margaret what this new substance looks like, she hesitated, but then said it just "looked fluffy" and you really can't see the water, but it is there because it is bottled up in a cloud and when the cloud gets too big, it starts to rain. She created an analogy of a cloud being like a pocket of water which looks fluffy but really isn't. Margaret spoke of learning about clouds and the water cycle, but didn't remember when she had learned it. She mentioned learning about evaporation in fourth grade and vividly described an experiment her class had conducted using solutions and letting them sit uncovered for several days. The most remarkable part of her account of the experiment is her differentiation of what happens to water that evaporates indoors and water that evaporates outdoors. She believes that water that evaporates indoors is stopped by the roof from becoming anything but just part of the air, but water that evaporates outside goes into the sky and forms a cloud.

Letitia, the third student I interviewed, chose "It is in the air in an invisible form" as the best explanation. She thinks that warm air helps water evaporate into an invisible form. She also stated that the water particles grab on to the warm air particles and travel upwards. Eventually, they fall off or come off and go to different places, such as into clouds. She believes that water can turn into a gas and that it was invisible. Letitia knows that water vapor is small, actually invisible to the naked eye, and she thinks that it is like fog and mist. Letitia's memory of learning about evaporation stems from an experiment she had conducted in fourth grade.

Labeled student drawings

Two months after I administered the probe, I asked the students to create labeled drawings of what they believe happened to the water in the wet jeans. Out of 70 drawings, 54 contained clouds. Most drawings showed the sun and, although several students attributed evaporation to wind, most explained that the sun had dried the jeans. A majority of students showed large or microscopic water droplets, not water vapor, going upwards through the air into a cloud. A few drawings appeared to attribute the term "evaporation" to the substance going up to the clouds. One other drawing besides Margaret's exhibited the belief that water turns into a new substance called cloud. Writing on one drawing states that the sun sucks up the water to the clouds. Five students specifically used the terms "gas" or "water vapor" to differentiate between the substance in the jeans and the substance in the air. Interestingly, although the probe contains an image of the jeans hanging on a clothesline, more than one student drew the picture Alex had drawn with a mountain, river, ocean and clouds, not an image of the jeans. (See Appendix B for samples of the student drawings.)

Data analysis

The cognitive research indicates that by the end of eighth grade, students should be quite familiar with the three states of matter and the idea of phase changes. The research in *Making Sense of Secondary Science* shows that between the ages of 12 and 14, most students understand the three concepts on which evaporation is based. My research suggests that the vast majority of 11 and 12 year olds on my team are unaware that water undergoes a phase change during evaporation and becomes part of the air. They show a belief that water travels through the air to become a cloud, but their understanding of how the water gets into the air and the difference between water vapor in the air and a cloud in the sky is, at best, emerging.

Two months after the students saw the probe, they were more attuned to their new school and had some experience creating quality, labeled illustrations. The richness of the labeled student drawings about evaporation surprised me. Because students could draw and write instead of just write, I appeared to get more information from my reluctant writers. Based on the few illustrations I saw and the three student interviews, it would be premature to speculate what educational experiences contributed to students' beliefs about evaporation. It is interesting to note that more than one student mentioned an experiment involving evaporation in fourth grade and that several students from different towns created surprisingly similar water cycle drawings (mountain, river, ocean, and cloud) when asked to illustrate what happened to the water in the jeans.

Significance

So what does all this really mean to my teaching and my students' learning? For one thing, I need to back up and slow down. Teachers assume that if an idea has been covered in previous years, students have learned it. Just because students have learned to use terms such as *evaporation*, *condensation*, and *precipitation* in their science speaking and writing, it doesn't necessarily mean they have a strong understanding of the processes. Additionally, students need more experiences with phase change, especially with the change from a liquid to a gas. They need these experiences, not just in sixth grade, but in lower grades as well. What is challenging about evaporation specifically, and gasses in general, is that they are invisible. Sixth graders are straddling the worlds of concrete and abstract thought. Anything which is visible is more likely to be believed and remembered.

Obviously, I need to give students more opportunities to see, think, and talk about phase changes, and especially to "see" gasses. I need to make the invisible more visible for my students and point out when gasses have been formed. One place this is already occurring is in some of our science investigations where we create and capture carbon dioxide. I specifically need to give students chances to notice when a phase change occurs with water.

The Conceptual Change Model suggests strategies for teachers to address commonly held notions (Stepans, 1999). By administering a probe, I ask students to commit to a belief. This exposes student beliefs to me, but not to the entire class. The next step is to return the probes and have students share their thinking in a small group, and then with the class. My students are becoming more adept at arguing ideas effectively in small and large group settings. We have begun the FOSS® Mixtures and Solutions unit, and students have evaporated a salt water solution. I will give them opportunities to work with condensation to make water vapor in the air more "visible" to them. Students can then seek to accommodate what they see with what they believe to be true. I'll ask them to extend the concept by finding other examples of evaporation in their daily lives and challenge them to create other experiments that show how water becomes a gas when it evaporates.

At that point, students might be ready to confront what started me on this action research journey: their misunderstanding of the differences between evaporating, melting, and dissolving. They will have had a series of investigations using the concept of dissolving. I will ask them to find a way to show the differences between those three processes.

The second volume of *Uncovering Student Ideas in Science* (Keeley et.al., 2007) contains the probe, "What's in the Bubbles?" I would like to give this to students toward the end of the year in order to see what affect the work I've done with students has had upon their enduring beliefs about evaporation. In this probe, a girl notices bubbles forming on the bottom of a kettle of boiling water. She wonders what is in the bubbles. Again, students choose an answer and then explain their thinking. My hope is that students recognize this as a situation where water is undergoing a phase change and becoming water vapor.

I'd like to share my research with the sixth-grade science teachers in my building and the district's K-12 science committee. They may have ideas about what is being done at other grade levels to address phase change and what else may be needed to give students a stronger working understanding of evaporation.

Reflection

I expected to enjoy this action research. I've participated in many professional development opportunities with the Maine Mathematics and Science Alliance and have always appreciated being surrounded by fellow educators who are excited about learning new ideas and unafraid to show their enthusiasm about their content area, teaching, and most importantly, children and how they learn. What I didn't anticipate was just how much learning about action research would energize me and my teaching.

Interviewing my students was my favorite part. With 85 or so students on my team, finding one- on-one time to get to know them is difficult. Although getting the release forms and finding the time to interview was challenging, the ideas kids presented, when I had the time to really listen and probe deeply, amazed me. It was fun and allowed me to interact with students as the receiver of information, not the purveyor.

Conducting and publishing this research exposed fear about putting myself and my ideas under the microscopic lens of my peers. Although conducting the research excited and energized me, pulling together the monograph felt huge and scary. If I had not been part of a team of teachers who met periodically to encourage each other, this monograph may not have happened. It would have been easier to just keep what I learned about my students to myself. Had I not forced myself to undergo this journey, I don't think I would have realized how much my teaching changed in response to my professional development and learning what is developmentally appropriate for students.

I'd like to think that as a teacher I've always been interested in what students think and say. What I've discovered is that becoming a researcher has caused me to be an even closer listener. I am more likely to dig deeper into what a student is saying and not saying. My curiosity about students' commonly held ideas, the sources of those ideas, and what experiences I can offer to dispel misconceptions is increasing. I once believed that teachers could tell when students faked knowledge about a topic. What I discovered is that students become adept at using vocabulary to make it look like they really understand a complex idea. If I had not dug deeper, I could have felt really confident about what students knew. After all, they were using fancy words, such as evaporation, precipitation, and condensation. Unfortunately, their vocabulary misrepresented their understanding. It made their ideas less visible to me.

I've become a big fan of probes. They are cunningly designed. If probes only contained the first tier, giving students a number of possible choices from which to select, students might accidentally choose the correct response or stumble onto it by a process of elimination. A majority of students might choose the correct answer, and teachers, students, and parents would feel reassured about what students know about a topic. But the second tier of the probe, asking students to supply reasons and background knowledge they used to inform their choice, is the true mother lode of information. Here students explain their thinking, and the teacher realizes just what her students do and don't know. Sometimes it can feel discouraging to discover what students don't know, but in the long run, it creates more efficient, effective teaching and learning. Making the invisible visible… it's not just about phase change, is it?

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Appendix A

INTERVIEW QUESTIONS AND PROMPTS

My research is designed to find out what students think about evaporation. I'd like to hear more about what you think evaporation is, how you learned about evaporation, and how you think it happens. The great thing is that there is no wrong answer. What you think is what you think.

- At times I may repeat your answer back to you, not because I want you to change it or because you are wrong, but because I want to be sure that I understood you correctly.
- I may wait after you respond because I want to give you time to organize what you want to say or add anything that you think is important.
- If I don't understand something that you said or if I want to hear a little more about an idea you mentioned, I may ask you more about it.
- I may take notes to help me remember what you've said.

****

I'll reread the probe to you, and then I'd like you to read your response out loud.

Would you please draw what you think happened to the water that was in the wet jeans?

What happened to the water once it left the jeans?

Where did it go?

How did it get there?

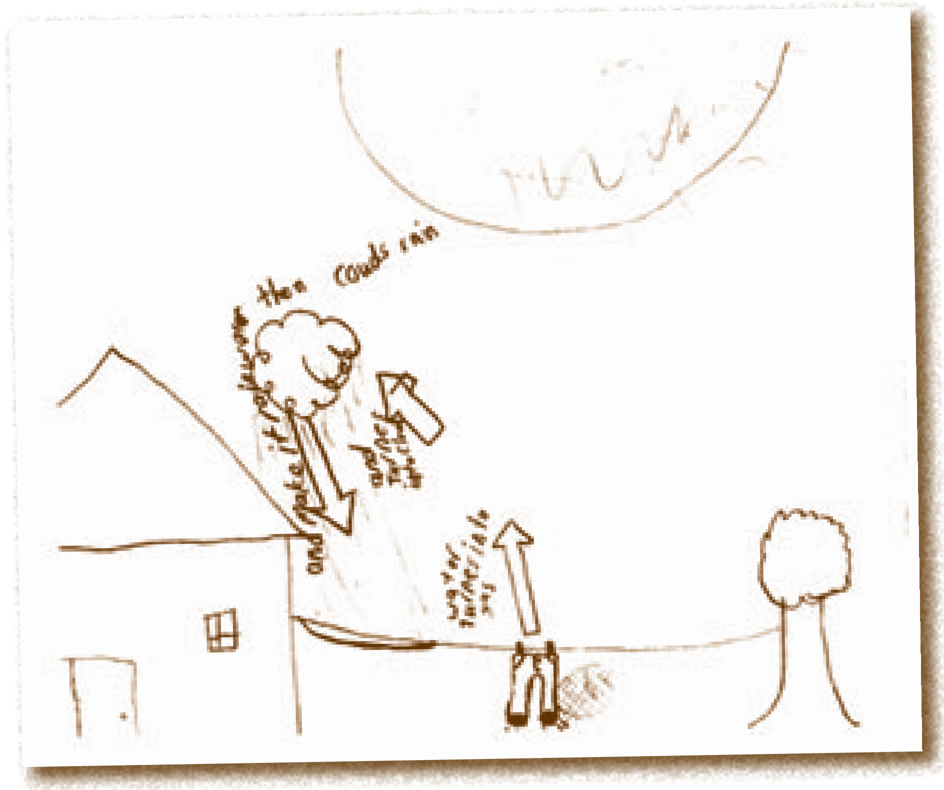
What does it look like now?

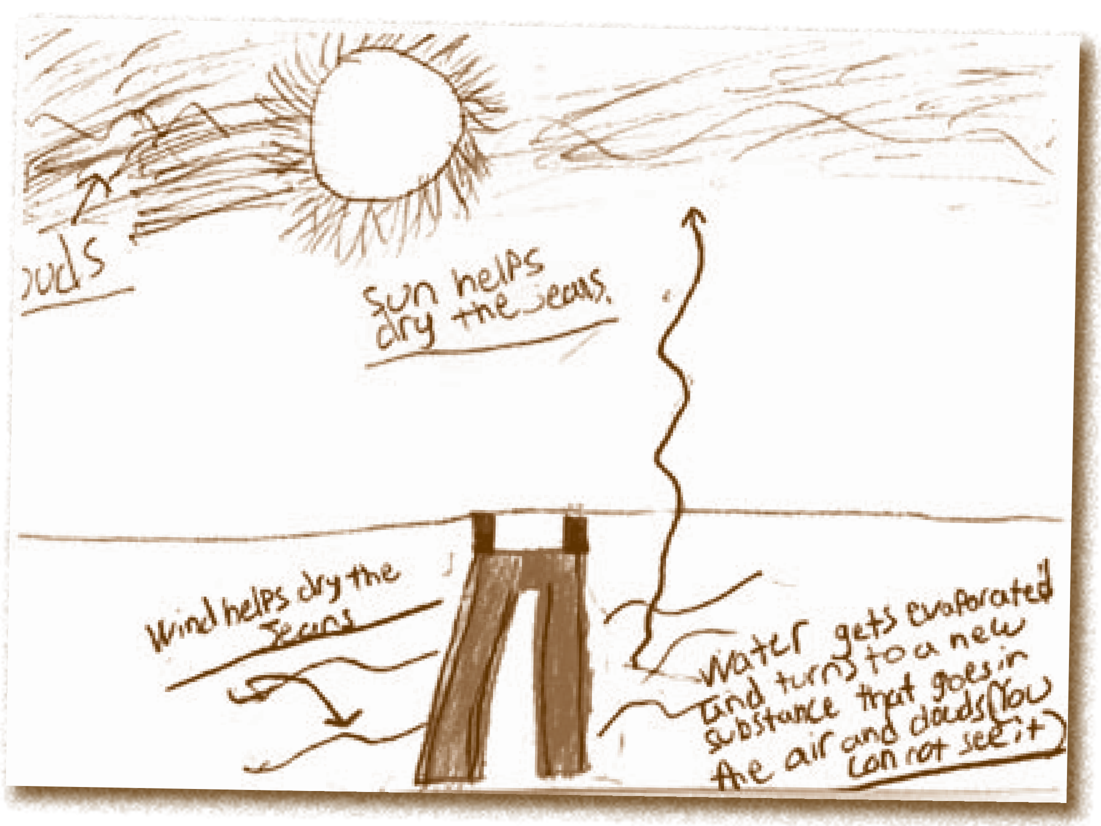
What else can you tell me about evaporation?

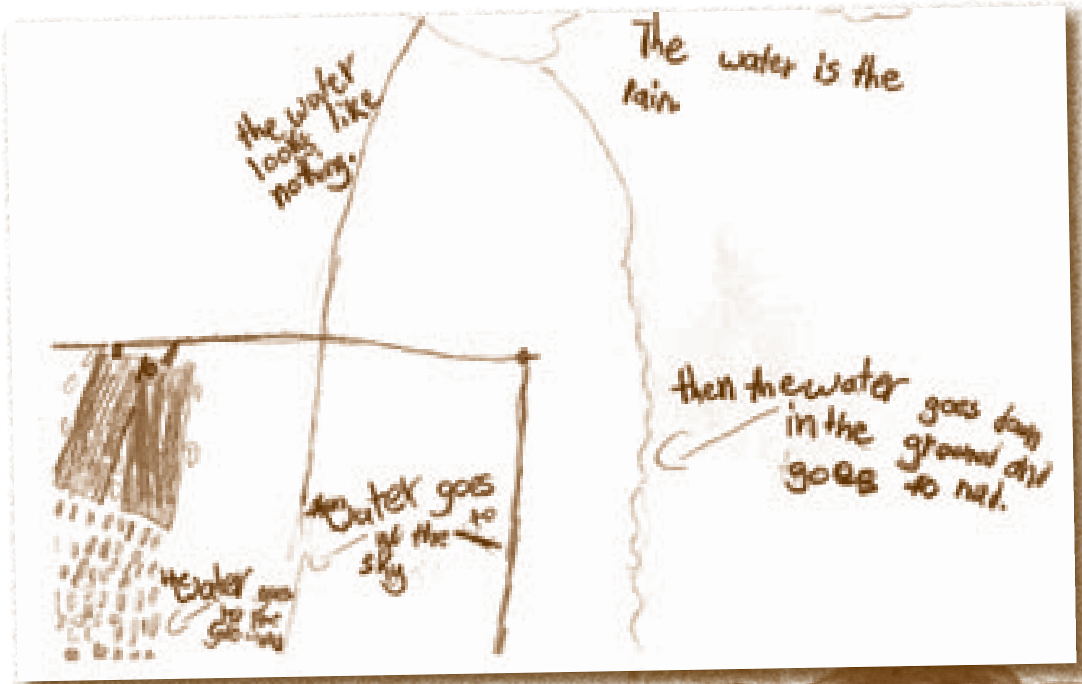
When do you remember first learning about evaporation?

These are the questions I developed to probe the thinking of my interviewees.

Appendix B *Sample Drawings*






The water is the rain.
the water looks like nothing.
then the water goes down in the ground and goes to rail.
water goes up the to sky
water goes to the ground


These Drops are going up to the cloud called perspiration

How do my Fourth Grade Students' preconceived notions about how magnets work impact their understanding of magnetism?

Dawn Robertson

Vivian E. Hussey School

Berwick, ME

Purpose of the Study

The topic of this study is how magnets work, because it is a topic I teach and I wonder if my students are going to struggle. They are familiar with using magnets, but they often struggle when asked to explain how magnets actually work or what magnetism is. I also wonder how much they realize that magnets are used in the everyday world. It's important for students to develop an understanding of this concept because it's a stepping-stone for understanding force, a topic that will continue throughout the students' education. This research process will give me a better understanding of where to start, what to cover, and how to use their preconceptions to guide my teaching of how magnets work.

Research Questions

These are the questions that will help guide my research and, therefore, my future actions in teaching about magnets:

1. What do the standards and research on students' thinking say about how magnets work?
2. What preconceptions do my students have about magnets and how they work?
3. What experiences do students have that contribute to their view of how magnets work?

Curriculum Topic Study (CTS)

Background Research, "Electromagnetism" (p.210) (Keeley, 2005)

Clarification of the content from *Science for All Americans* (*SFAA*) and *Science Matters* (*SM*)

- Gravitational and electromagnetic forces are two types of common forces. (*SFAA*)
- Electromagnetic forces do such things as hold solid and liquid materials together, or act between objects (for example, friction when rubbing a towel on your back). (*SFAA*)
- Magnetic forces are closely related to electric forces because both are thought to act by means of fields. *(SFAA)*
- A magnet has a magnetic field around it that affects other magnets. *(SFAA)*
- Moving electric charges produce magnetic fields. They are affected by magnetic fields just like an electric charge has an electric field in the space around it that affects other charges. *(SFAA)*
- These influence many items of nature such as how an electric current that circulates the earth's core gives the earth a magnetic field. This is the field we use in orientation of our compass needles. *(SFAA)*
- Each magnet, no matter what size, has two poles. (*SM*)
- Magnetic poles always come in pairs and are usually labeled north and south. (*SM*)
- Every time an electric charge moves, a magnetic field is created, and every time a magnetic field varies, an electric field is created and visa versa, although we are not usually aware of electrical effects when we use magnets, nor do we sense magnetic fields when we use electricity. (*SM*)

Student learning goals from *National Science Education Standards* (*NSES*) and *Benchmarks for Science Literacy* (*BSL*)

- Without touching them, a magnet pulls on all things made of iron and either pushes or pulls on other magnets. (*BSL* Grades 3-5)
- Without touching them, material that has been electrically charged pulls on all other materials charged materials. (*BSL* Grades 3-5)
- Magnets attract and repel each other and certain kinds of other materials. (*NSES* Grades K-4)

Student learning goals from *Maine Learning Results, 2007*

- Predict the effect of a given force on the motion of an object.
- Give examples of how gravity, magnets, and electrically charged materials push and pull objects.

Student learning goals from *Full Option Science System (FOSS)®: Magnetism and Electricity*

- Observe the interaction of permanent magnets with a variety of common materials.
- Discover that magnets display forces of attraction and repulsion.
- Measure the change in force between two magnets as the distance between them changes.
- Students will learn that:

1. Magnetic interactions are caused by the magnetic force.
2. Magnets stick to metal objects made of iron.
3. Magnets display forces of attraction and repulsion that decrease with distance.
4. Magnetism can be induced in a piece of steel that is close to or touching a magnet.

Teaching considerations from *Benchmarks for Science Literacy (BSL)* and *Making Sense of Secondary Science* (*MSSS*)

- For many years, force may be treated as an originator of motion. (*BSL*)
- Electric and magnetic forces and the relationship between them should be treated qualitatively. (*BSL*)
- Close attention should be on what conditions produce a magnetic field. (*BSL*)
- Diagrams of magnetic fields may create some misconceptions about "lines of force," because students believe that the force exists only on those lines. Students should be taught that the lines are used only to show the direction of the field. (*BSL*)
- Using solely magnets to teach about magnetism may dissociate pupils from their everyday awareness of magnetism. Approaches, which draw on everyday experience and focus upon the use of magnets, would be advisable. (*MSSS*)

Cognitive research from *Making Sense of Secondary Science* (*MSSS*)

- Although all students are aware of magnets in their everyday lives, they often offer no explanation of magnetism.
- Often students call magnetism "a type of gravity;" they link magnetism with gravity.
- Students tend to think of poles as the ends of magnets.
- Students refer to magnets as sticking to other objects instead of "picking (them) up."
- Students think that big magnets are stronger than smaller ones.
- Students don't always realize that magnetism can act from a distance.
- Students think that magnets work on *all* metals rather than certain metals.
- Students lack experience with repulsion as distinct from attraction.

Classroom Research

Classroom Context

I teach at a rural school in southern Maine with approximately 400 students from kindergarten to fourth grade. There are currently five fourth-grade classrooms in my school. My classroom in comprised of 19 fourth-grade students, eight males and 11 females. During this process, one of my male students left our school and shortly after, one male student joined our classroom, keeping my total student population at nineteen. The male student that left was one of the students that I interviewed. Because of this, I did not add his interview data into my work; there was not sufficient information and I wanted to remain true to dealing with the preconceived notions that the students, in my current classroom had. Our district uses the Full Option Science System (FOSS)® kits as our tool for teaching science; my action research is focused on Magnetism and Electricity the fourth-grade kit. Our district was selected to be part of the SC4 project because it was in need of improvement based upon Maine Education Assessment (MEA) science scores.

Methodology and Data Collection

I decided on three different methods to collect my data: a formal interview, a questionnaire, and a probe.

The interview was comprised of three sections: drawing and discussion, card sort, and magnet manipulation. (See Appendix A for the interview questions.) My goal for the interviews was to get a sense of students' common preconceptions, including those I had noted in examining the cognitive research. At times, I found myself straying from the questions, sometimes eliciting more positive results than other times.

My second form of data collection was a questionnaire. Each student in my class randomly received three of seven questions to complete.

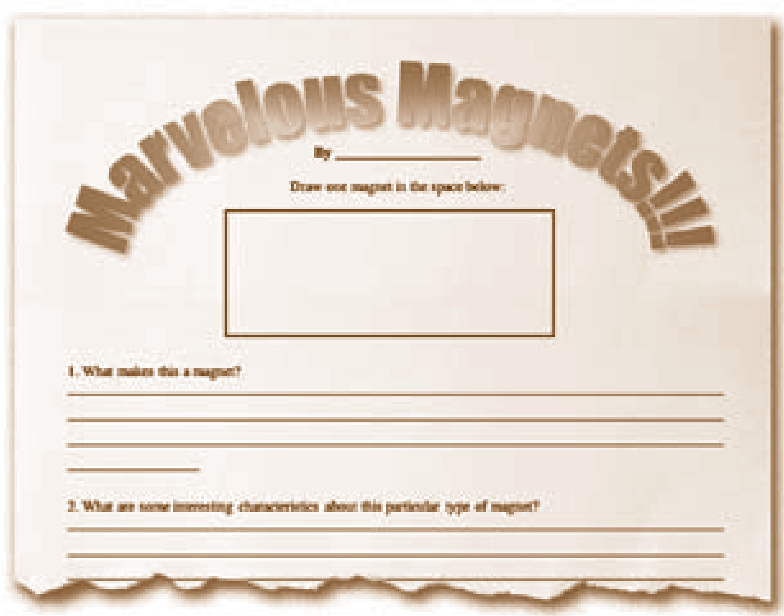
1. What can magnets do?
2. What does it mean when we say an object is magnetic?
3. How are magnets used in our everyday lives?
4. Is the force of magnetism stopped by any materials?
5. Do magnets have to touch an object to interact?
6. Using two or more magnets, describe in pictures and words at least two different ways magnets interact.
7. Do magnets always interact the same way

Through these questions, I was looking for any of the following preconceived notions from *Making Sense of Secondary Science*.

- Magnets "stick" to other objects instead of "picking up" other objects.
- Magnets work on *all* metals rather than certain metals.
- Magnetism cannot act from a distance.
- Magnets only attract; they do not repulse.
- Magnetism is "a type of gravity."

Finally, I needed to collect the same data from each member of my class. Therefore, every student completed a probe comprised of two sections. In the first section, students drew one magnet and described that particular magnet. I added this part because I was seeing some interesting trends in knowledge of different types of magnets from the interview and questionnaires. The second section is comprised of questions, where students not only had to answer if a statement was true or false, but also explain the reasoning behind their answer. Each question was related to the CTS background research about student thinking. (See Appendix B for the "Marvelous Magnets" probe.)

Organization of Data and Findings



I completed formal interviews with seven of my students. Each interview was audio recorded. I then created transcripts of each interview. Because of the vastness of my interview transcripts, I created a summary of information from each student. (See Figure 1.) These captured the essence of ideas in my classroom.

Using the transcripts and photos of how students sorted the magnets, I also created a graph of how students identified each card. (See Figure 2.) I did this to find some trends in knowledge about which pictures students thought were magnets. In fact, all of the pictures were magnets although the students had no knowledge of this.

Figure 3 shows some students' responses to randomly assigned questions from the questionnaire.

The "Marvelous Magnets" probe was broken up into two sections. Figure 4 shows sample drawings from section one. Each student drew one of the types of magnets in Figure 4 with the "horseshoe" being the magnet most drawn. Figure 5 shows a compilation of data from section two of the probe.

Figure 1: Summary of Data from Student Interviews

Student 1:

shared that her experiences with magnets were at school on the whiteboard and at home on the refrigerator. Student 1 mentioned several times that magnets "stick," and once explained magnets as getting "suction-cupped to the metal." Student 1 had experiences with magnets attracting, but not with magnets repelling. Some of her other preconceptions are that a bigger magnet equals a stronger magnet, magnets only "stick" when put together, and magnets stick to all metal.

Student 2:

had preconceived notions about the poles of magnets only being at the ends and a magnet's force field only being on its "lines of force."

Even though the audio was difficult to transcribe and time consuming, I felt it would be worth my time, which indeed it was. The interviews were by far the most useful.

Student 4:

was familiar with positive and negative poles and how opposite poles attract and similar poles repel, although he doesn't use that vocabulary. His preconceptions included magnets sticking and magnets working on all metals, although when asked directly if magnets worked on all metals he replied, "Yeah, except for aluminum and some other stuff."

Student 3 had experiences with magnets on whiteboards and refrigerators and had preconceptions about magnets sticking and working on all metals. She knew that there is a way magnets will go together and a way they won't go together, without mentioning anything about the poles of a magnet. Student 3 also refered to magnets as metal a few times.

Student 5:

used the terms "attach" and "stick" interchangeably, believed that magnets stick to all metals, and offered no explanation or understanding of magnetism when asked, even though she drew the lines of force in her drawings.

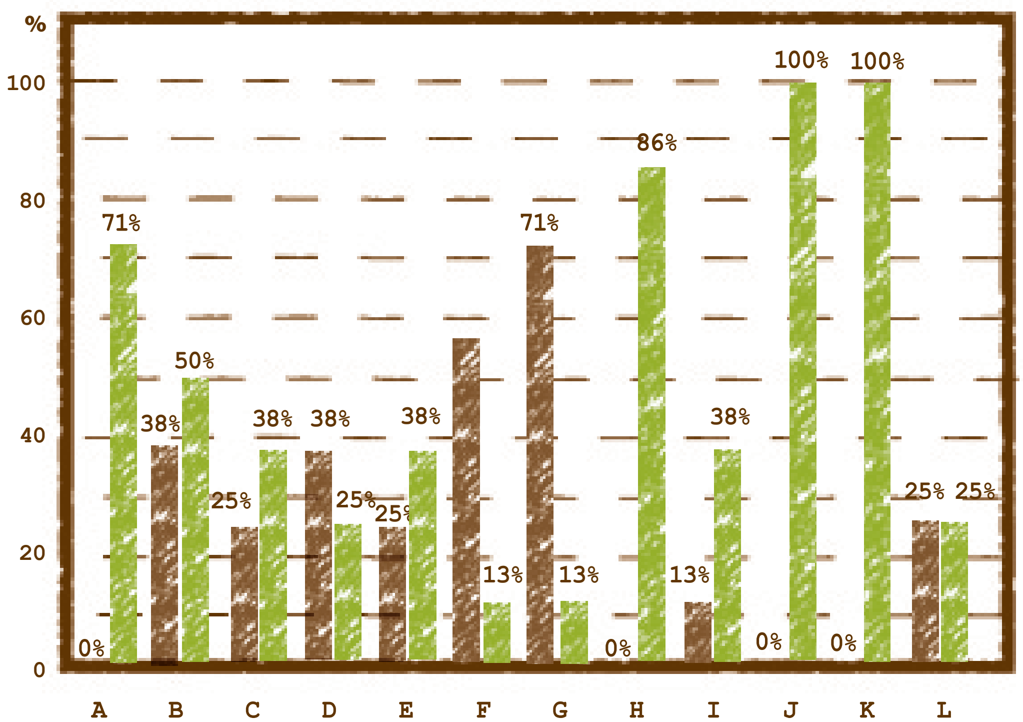
Student 6 had a wealth of experiences with magnets and magnetism. She mentioned that she took a course that dealt with magnetism and had other experiences with magnets at Grammie's house, school, and home. Student 6 had a clear understanding that magnets can be different shapes and sizes. However, her explanation of magnetism in action was, "probably because we moved the cup." Student 6 used the terms "stick" and "attach" interchangeably and had preconceptions about magnets sticking to metal, a bigger magnet means a bigger force, and magnets only attracting. There were also a couple references to magnets being metal.

Student 7 had experiences with magnets at home, including working with Dad in the garage, using magnets on the whiteboard at school, and seeing magnets on cartoons on TV. Student 7 had a good understanding that magnets can go together or push apart, although his explanation of why this happens was because "they're put in the case specially." Student 7 also had preconceived notions about magnets sticking, working on all metals, copper or steel, and a magnet's force only coming out of its ends.

Figure 2: Card Sort Section from Interview Comparison of How Students Identified Pictures as Non-Magnets or Magnets

Non-Magnet

Magnet



Cards A through L were images of a variety of magnets

Card Sort Graph Observations: *No one identified the following picture cards as non-magnets: the real doughnut, doughnut picture, horseshoe, and the Magnetics. (Magnetics is a toy that uses magnets encased in plastic pieces. Children can make designs by putting the pieces together.)*

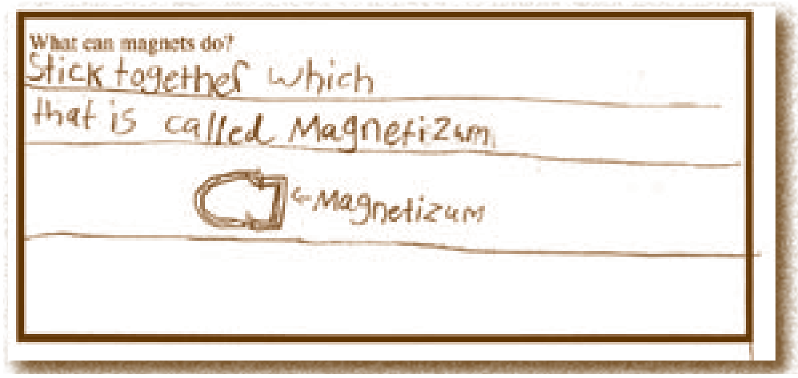
Every student selected and knew the "horseshoe" and Magnetics were indeed magnets. Most students identified the bumpy half-circle as a non-magnet. Each picture card was identified as a magnet by at least one student.

Figure 3:

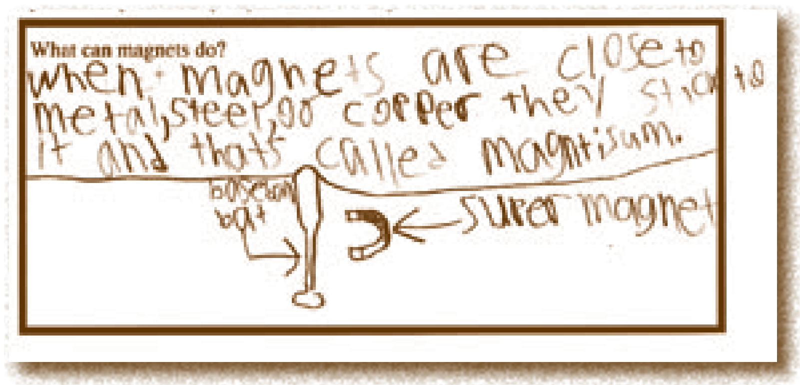
Common Student Answers to Questionnaire

These two pieces of data show the answers that all of my students gave. Most students explained that magnets "stick." Interestingly, student 7 has the preconceived notion that not only do metals become attracted to magnets, but he also differentiates copper and steel from metal. This is the second time this particular student mentions "copper" as sticking to metal, which, in actuality, it does not.

Student 6

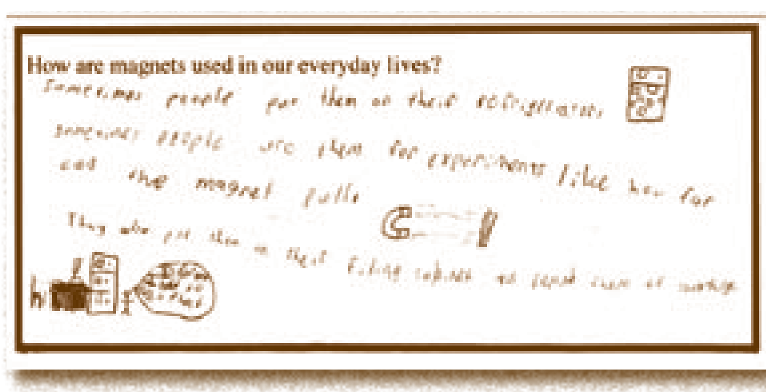

What can magnets do?
Stick together which that is called Magnetizum
←Magnetizum

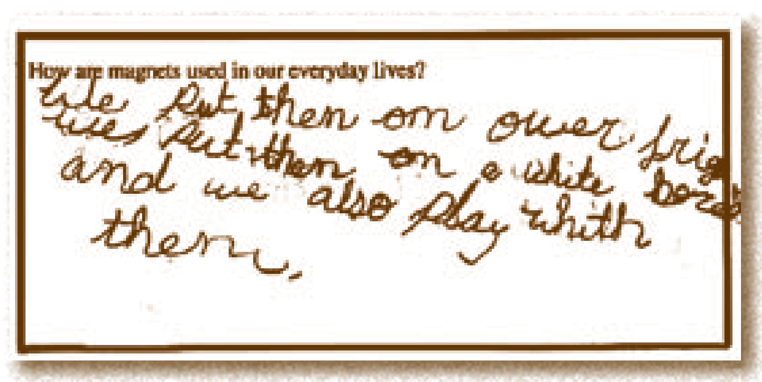
Student 7


What can magnets do?
when magnets are close to metal, steel, or copper they stick to it and that's called magnitism.
←super magnet

Student 2 and Student 8

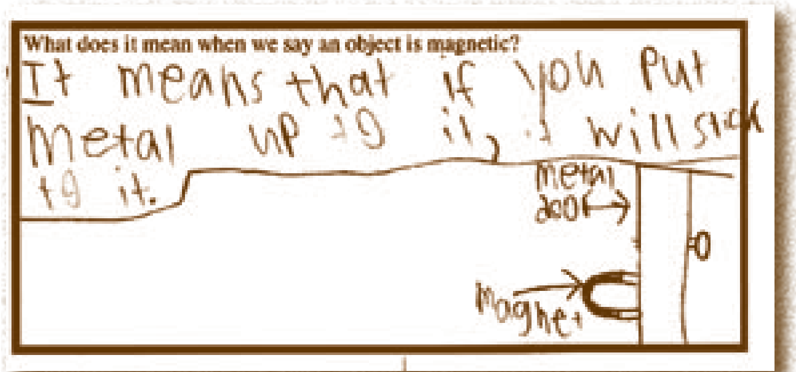
Students 2 and 8 probably gave the best answers to this question. Most students gave one of these answers. This shows how limited their experiences are with magnets in the everyday world. I also noticed that student 2 drew lines for force coming from the ends of the magnets. This is not the first time he has shown this.


How are magnets used in our everyday lives?
Sometimes people put them on their refrigerators.
Sometimes people use them for experiments like how far can the magnet pulls.
They also put them on their filing cabinet


How are magnets used in our everyday lives?
We put then on ower frig
we put them on a white board
and we also play whith them.

Student 7

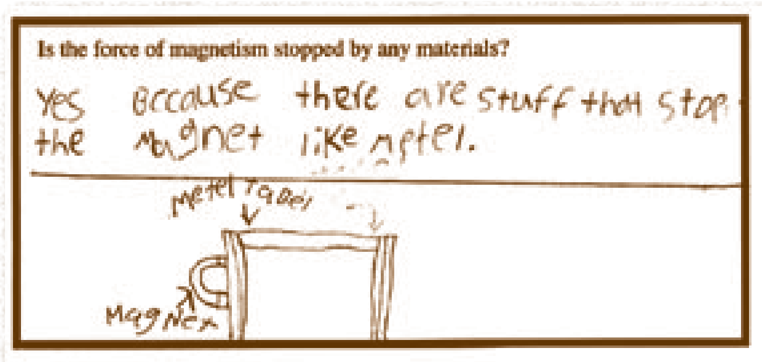
Just like student 7, most students referred to the magnets as "sticking" to metal.


What does it mean when we say an object is magnetic?

It means that if you put metal up to it, it will stick to it.

Student 4

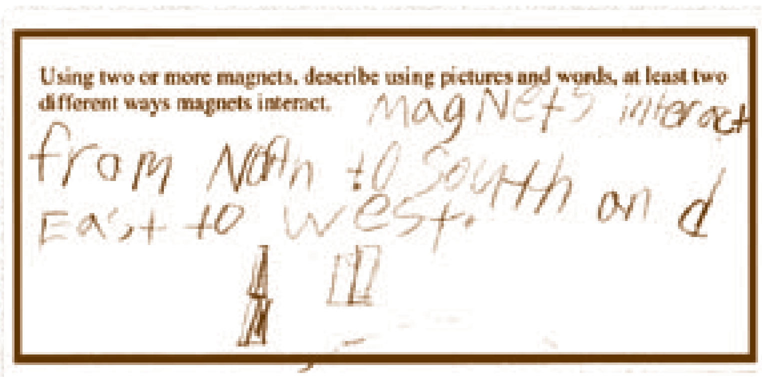
Notice that student 4, like many others who answered this question, believes that the force of magnetism is stopped by all metal.


Is the force of magnetism stopped by any materials?

Yes because there are stuff that stop the magnet like metel.

Student 12

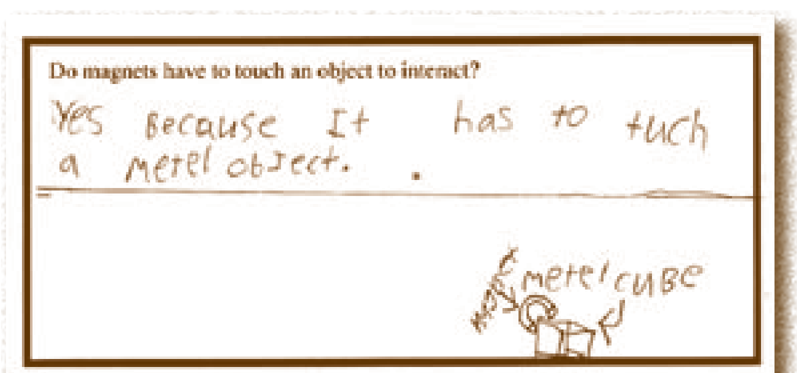
Student 12 is the only student who received this question who answered with two distinct answers.


Using two or more magnets, describe using pictures and words, at least two different ways magnets interact.

Magnets interact from North to South and East to west.

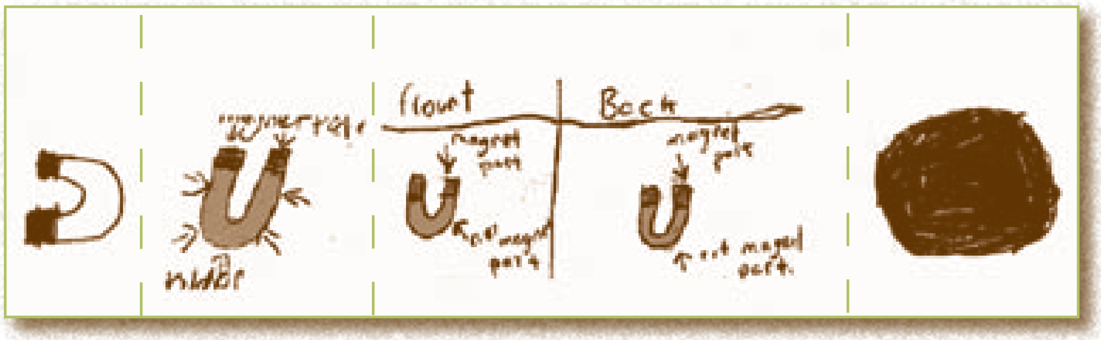
Student 9

Again, with student 9 we see the preconceived notion that magnets are attracted to all metal. This student, along with many others who answered this question, also believes that a magnet has to be touching an object in order for it to interact with the object.


Do magnets have to touch an object to interact?

Yes because It has to tuch a metel obJect.

Figure 4:
Sample Drawings from the "Marvelous Magnets" probe



Fourteen out of 18 students drew the horseshoe magnets. Only two students drew circle magnets and two students drew undistinguishable shapes. One student was absent for several days and therefore did not complete the probe.

Figure 6:
Percentage of Magnets drawn by students as specific shape

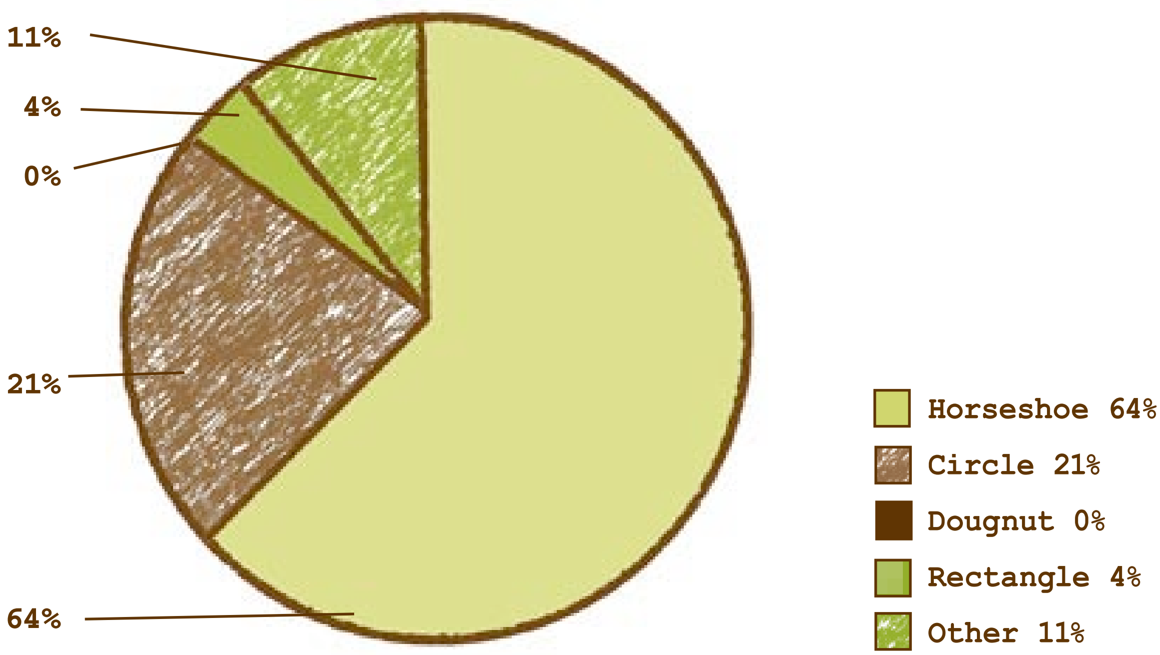
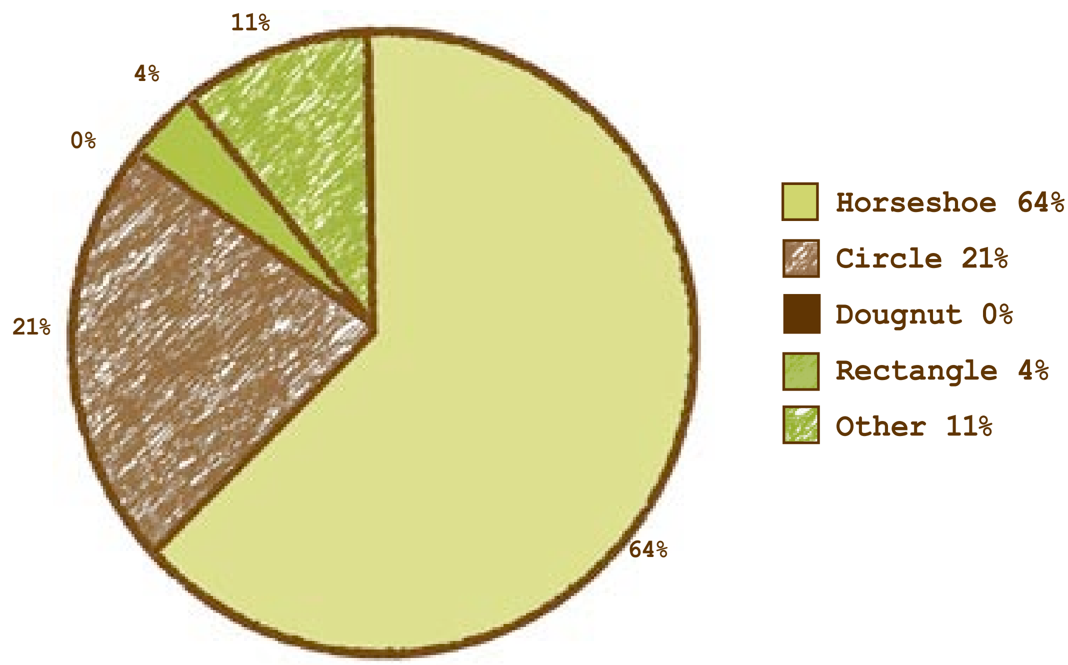


Figure 5: "Marvelous Magnets" Data Collection Table using student answers from section 2 probe

Q#	Real Answer	Real Explanation	# Students Who Answered:			Student Explanations: Students explain why they think their answer is "correct."	% Explain Correct
	T or F		T	F	% Correct		
3	F	Magnets do not stick to objects: certain objects become attracted to the magnets by the magnet's magnetic force.	13	3	19%	FALSE --Doesn't stick to all objects or doesn't stick to just magnets. (Student maybe read statement wrong). TRUE --Most metal, refrigerators, not plastic or wood. --Only metal NOTE: No one mentioned about magnets "sticking".	0/16= 0%
4	F	Only certain metals can be attracted to magnets; items with iron will attract.	6	10	63%	TRUE --"Magnets are metal, can be attracted to anything." --All metal can be attracted to other metals. --Magnets go to all metals. FALSE --Four students correctly explained that some metals don't become attracted: "There are special kinds of metal that magnets don't stick to."	4/16= 25%
5	T	Two magnets can go together even if they are a distance apart from one another.	13	3	81%	TRUE --"It takes some time." --No matter how far away it is, it still comes together. --Two students correctly explained, one of the two students said that they will attract "if they are strong enough." FALSE --One student explained that it depends on the strength of the magnet. I counted this as a correct explanation. --One student explained they won't stick together because of the force.	3/16= 13%
6	F	A magnet's strength does not depend on its size; different magnets can have different strengths.	8	8	50%	NOTE: A student put T/F but explained correctly; he was counted as "F." TRUE --It's true because bigger means stronger. --If it is bigger it has more power + more materials. FALSE --Four students correctly explained: "Sometimes that is correct but sometimes it's not …" --Small magnets can be strong too.	4/16= 25%
7	F	Magnetism doesn't just come out of the ends of magnets; This force is working all around the magnets… see picture.	9	7	44%	NOTE: One student put "both" but explained incorrectly so I counted her as a "T." TRUE --It is true because the ends are where it sticks together. --One student has a misconception that magnetism only comes out of the ends (such as in a horseshoe magnet like the one he drew). The magnets are only on one side and there is only metal on the other so it won't stick. --Only on some magnets can it come out of all ends. FALSE --Four students answered correctly: "It comes out all parts of the magnet." --One student explained that it can come out of the sides too.	4/16= 25%
8	T	Magnets are used in many ways in our everyday lives: to hold refrigerator doors closed and to move scrap metal in a junk yard, and they are used in my toys.	15	1	94%	TRUE --Answers mostly explain how magnets can be used on refrigerators, white boards, desks, or metal. FALSE --"We don't always use them, like we don't use them for writing."	0/16= 0%

One of the interesting pieces I noticed when completing the interviews was that all of the students easily identified the horseshoe and Magnetics as magnets, and most were clear that the doughnut pictures were also magnets. (See Figure 2.) However, when drawing magnets, what would they draw? Would this same trend be apparent? Once all the data was collected, I tallied up the numbers of magnets drawn in each shape. (See Figure 6.)

Figure 6: Percentage of magnets drawn by students as specific shapes



Data Analysis

I found some interesting connections between drawing and identifying magnets. I found the answers to the questions cited above.

- Yes, students, in both drawing and identifying, almost exclusively thought of a horseshoe magnet shape.
- However, oddly enough, students were significantly more apt to identify a doughnut magnet as opposed to drawing it.
- Students were more apt to draw a circle magnet than to identify it as a magnet.

This is one way my students' experiences must have contributed to their views about how magnets work.

Student 2 has a relatively solid base of understanding about magnetism compared to the other students. Student 4 seems to have a pretty strong knowledge of magnets and magnetism, not to mention an excellent definition how magnetism works. I could tell that Student 5 was a little nervous during the interview process and seems to have a relatively limited knowledge of magnets and magnetism, although I do wonder how much knowledge was bottled-up by nerves. Student 5, in the magnet manipulative section, shows a preconceived notion that magnets only attract.

In Figure 5, I noted the real "Marvelous Magnets" answer and explanation as well as how students explained their answers. Interestingly, the percentage of students who could correctly *explain* the right answer was substantially lower than the percentage of students who could correctly *identify* the right answer. For example 81 percent of students wrote the correct answer (true) to question five, but only 13 percent of the students could correctly explain the reason to why it was true. This data was mind-opening. I was extremely surprised most students were not able to explain the answer even though they correctly identified it!

As I gathered my data, I kept a chart of the misconceptions that I noted in the cognitive research. Each piece of data focused on some of the common misconceptions noted in *Making Sense of Secondary Science* (Driver et. al., 1994). I kept a cumulative chart of the preconceptions my students had that I also found in the cognitive research. When completed, the overarching preconceptions that most of my students held were clear to me. (See Figure 7.)

Each letter shows a preconceived notion that one of my students had. I only added a preconceived notion to the list if I was *sure* the student had it. There may be more preconceived notions that I didn't uncover or that I was unsure if they were truly preconceived. Because I didn't uncover any of these preconceived notions from four of my students, they are not on the chart.

Figure 7:

Common Preconceived Ideas held by my students

	Students														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Poles are only at the end of the magnets.		MT	C		T		T								T
Magnets "stick" to other objects.	CQT	T*	DT	CT	DT		DQ			Q			T	T	T
A bigger magnet means a stronger magnet.	C				M	MT		T							
Magnets don't work from a distance.	M		C	Q		M									
Magnets work on all metals.	C		DQ	DQ	D	CT	QT	QT	QT		Q		T	T	T
Magnets only attract.	M				M	M									
A magnet's force field is only on its "lines of force."	D	M			D										
Limited knowledge of how magnets are used in our everyday lives.		QT			C	QT	C	QT			Q	T		T	T
Offers no explanation of magnetism.				D		D									

***Understands the difference, but still uses vocabulary interchangeably.**

Preconceived notions found in:

- **D:** Drawing Discussion section of Formal Interview
- **C:** Preconceived notion found during Card Section of Formal Interview
- **M:** Preconceived notion found during Magnet Manipulative Section of Formal Interview
- **Q:** Preconceived notion found in Questionnaire
- **T:** True/ False section of "Marvelous Magnets" probe

Note: Although almost all students answered correctly, they will have a *very limited* knowledge of how magnets are used.

Conclusions

My students have many of the same preconceived notions that I found in my research. These include:

- Students have limited knowledge of everyday use of magnets.
- Magnets "stick" to other objects instead of "picking up" other objects.
- Big magnets are stronger than smaller ones.
- Students don't always realize that magnetism can act from a distance.
- Students think that magnets work on *all* metals rather than certain metals.
- Students have a lack of experience of repulsion as distinct from attraction.
- Some students tend to think of poles as the ends of magnets.
- A magnet's force only comes out of the ends of magnets (and is often shown by "lines of force.")

Significance

Now that I have identified which preconceived notions my students have, how will this impact my teaching? First of all, it's clear that I can't focus on all of the notions. As can be seen in the prevalent preconceptions summarized above, the list is quite substantial. To affect change in any one of these ideas, it is not as simple as just explaining the "real" answer and reviewing it several times. A student might be able to tell me an answer, but may not truly believe this new information. Instead, I must teach for gradual, conceptual change. This means that several experiences, which conflict with *one* preconceived notion, will have to be given in order for the *one* idea to change in the students' minds. Each of these experiences will require ample time for not only the experience, but for the students to question conflicts and resolve to a new way of understanding. Therefore, it does not make sense to try to change *all* of their thinking in a short two-to-three-week unit where I not only have to teach about magnetism, but electricity as well. Instead I have decided to focus only on these preconceived notions:

1. Magnets work on *all* metals rather than certain metals.
2. Magnets "stick" to other objects instead of "picking up" other objects.
3. Magnets are of little use in everyday life.

Tools of change

How will I go about changing these preconceived notions? My main teaching tools will be the FOSS® kit, scientists' notebooks, and the Conceptual Change Model for Teaching (CCM) (Stepans et. al., 1999). Knowing about my students' preconceived notions makes it clear to me that many of the investigations in the FOSS® kit are valuable activities that help confront these notions. For example, FOSS® does an excellent job giving students experiences with attraction and repulsion. Therefore, teaching about it will happen easily without much extra effort. Because of this, I do not consider this to be one of my focuses even though it will be thoroughly addressed. It is also beneficial that the kit does not include horseshoe magnets. This will be a positive change from what my students are accustomed to and give them more experiences with different types of magnets. However, the kit by itself won't suitably address all of the notions on which I must focus. That is where the CCM comes into play. Students will use their scientists' notebooks as a tool to write down their predictions, findings, questions, confusions, and new beliefs. They will then have their notebooks as an avenue to generate discussions and as the foundation of their developing knowledge. Completing this action research paper has helped me realize how important and worthwhile it is that I use these tools more effectively!

Sharing my research

I am excited to share this new information with my fourth-grade team. Do they know the common preconceptions that most students have about magnets? Are they using similar terminology as I have in the past, which possibly led to some preconceived notions? How can I be of help to them?

Reflection

In completing my action research paper, I have gone through the whole gamut of highs and lows. When I first read the invitation about this action research project, I thought that there is no way I would or could do this, partly because I had enough on my plate and partly because I didn't think I could write a paper this extensive. However, thankfully in this case, I have a hard time saying "No." So when I got another email saying that they were looking for a couple more people and I reread what the project entailed, I thought that maybe it would be interesting to do.

There were a couple of times where I struggled with the process of writing this paper. First, I had a hard time getting my mind wrapped around what I was being asked to do. Once I had struggled through the purpose and research questions and started the very beginning of the CTS background research, I was feeling much more confident and was able to finish the CTS and make decisions on how to collect the data within the school day. From then on, for the most part, it was smooth sailing. I did pieces of the paper here and there when I had time in my busy schedule. I was glad that we had a few meetings for work days to help keep me on schedule. Another time I felt stuck was when I had written almost all of the classroom research. I wasn't sure if the information I had was indeed the type of data I should being adding to the paper, if it made sense, or if I really was heading in the right direction. I am a very visual learner and would have benefited from having an example at this time. One had been available at previous meetings, but I hadn't been at the point where I felt like I needed to look at an example. Luckily, this was just about the time for another scheduled meeting. At the meeting, my work was validated and knowing that I was on the right track made finishing my paper much easier! All-in-all, though, a majority of the time, I found this action research to be very fascinating and a great source of professional development!

Completing the interview was my favorite part of this process, although I definitely would do some things differently next time. All of the students were so excited to be able to work independently with me, even though they weren't sure what they were getting themselves into. It was a gratifying change to be able to have uninterrupted, one-on-one time with my students, as that does not happen often during a busy school day. By the end of the interviewing process, it was clear what preconceived notions each student had. The student that moved away had the most interesting things to explain to me. He talked for twenty-three minutes about what he knew. Before the interview, I would have said that he was a student that knew above and beyond what was required of him about magnets. He had all the vocabulary. However, from his interview it became clear that he had many higher-level preconceived notions about the magnet's force being parallel to the spark of electricity. I think I would have had to read every book about magnetism and electricity to really understand the preconceptions and scientific facts that he knew. Although I was interested in pursuing this, I also knew how much more time and effort that would have taken, so maybe in a way, I was lucky that he left.

Overall, the interviews went well, especially given that it was my first time completing formal interviews, but there are some pieces I would do differently next time. First and foremost, I would have shorter sessions with the students. I completed all three sections at one time, which was fine during the actual interviews, but became slightly problematic when trying to go over them again and transcribing them. Breaking them down into the three sections when organizing the data made me more successful because then I had smaller goals to complete. Another piece that I would do differently is to videotape the interviews, especially the card sort piece, instead of audio recording it. Because I could not see which card the students were talking about, I would have to say which card it was. Many times this happened when the students were talking and so it added an extra challenge to the interviews. If I had videotaped, I could have focused more on what the students were saying and possibly have had better questions at times instead of making sure I would know later which card they were talking about. Lastly, I vacillated over whether to transcribe the audio from the interviews. In the end I decided to do so. Even though the audio was difficult and time consuming to transcribe, I felt it would be worth my time, which indeed it was. The interviews were by far the most useful!

As I come to the end of this paper, I am very glad that I have participated in this action research. I can't wait to teach my magnetism unit!

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Appendix A

QUESTIONS TO ASK IN DRAWING SECTION OF INTERVIEW

1. "Do you know what magnetism is? Tell me about it."
2. "What are magnets? How do they work? Can you draw one and tell me about it?"

PURPOSE OF THESE QUESTIONS:

* To get students thinking about and drawing magnets
* To look for preconceived notions about types of magnets, what they are attracted to, and how they attract

QUESTIONS TO ASK IN CARD SORT SECTION OF INTERVIEW

3. "My friend sent me some pictures. Some are magnets and some are not. Can you help me sort them into the correct piles?" (Note: All cards are pictures of magnets, but the students do not know this.)
4. "How do you know that is a magnet/ non-magnet?"

PURPOSE OF THESE QUESTIONS

* To look for commonalities between "known" magnets and non magnets and the reasoning behind sorting them.
* To look for preconceived notions about how magnets attract, and what at tracts to magnets
* To find student's experiences with magnets and magnetism

QUESTIONS TO ASK IN MAGNET MANIPULATIVE SECTION OF INTERVIEW

5. "Pretend these two pieces of paper are magnets. What would happen if I moved one towards the other?"
6. "What would happen if I turned one magnet around? What would happen then?"
7. "What would happen if I used a bigger magnet and brought it closer to the smaller magnet?"
8. "What would happen if I used a smaller magnet and brought it closer to the larger magnet?"

PURPOSE OF THESE QUESTIONS

* To look for preconceived notions about the force of a magnet, magnets working from a distance, and attraction and repulsion

Appendix B

Marvelous Magnets!!!

By ______________________

Draw one magnet in the space below:

1. What makes this a magnet?

____
____
____

2. What are some interesting characteristics about this particular type of magnet?

____
____
____

***PART II* DIRECTIONS:** In the space provided, write a "T" for true if you agree with the statement or "F" for false if you disagree. Then explain why it is true or false in the space below the statement. Use words and picture to help you explain.

3. ______ Magnets stick to certain objects.

4. ______All metals can be attracted to magnets.

5. ______Two magnets can come together even if they are a distance apart from one another.

6. ______A bigger magnet means a stronger magnet.

7. ______The magnetism only comes out of the ends of magnets.

8. ______Magnets are used in many ways in our everyday lives.

What do students already know about gravity and how will my teaching of this concept be affected by their misconceptions?

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Jan Rollins has been teaching for 36 years, including eight years as an assistant principal (K-8) and director of reading (K-12). She has taught in Maine, Massachusetts, New Hampshire, and Virginia. She also has worked for the US Department of Education as a mastery learning consultant for the State of Maine. She is currently enrolled in a continuing advanced study program. Her most invigorating activity is furthering her learning and teaching of science to her fourth-grade students.

Purpose of the Study

The physical science content area of the *Maine Learning Results, 2007* calls upon teachers to teach students, in grades 3-5, essential concepts in the area of force and motion. Students need to learn how various forces affect the motion of objects. My students' understanding of gravity as a force interested me because I knew from previous experience that the concept would be difficult for them to understand since there is very little that is tangible about it. There is no concrete way for students to create this force. Although magnetism is related in that it is a force that can pull an object from a distance, magnetism can be taught with the use of magnets (tangible objects).

In addition, from having previously taught gravity through the *Force and Motion* and the *Sun, Earth and Moon* units developed by my former district, I knew that gravity was an area where students held some misconceptions. Unless I clearly understood their commonly held ideas, I knew I would not be able to create experiences for them that would change their way of thinking and lead them to accept the scientific explanation of gravity that was cognitively appropriate for their age. I also was curious about the amount of science instruction students received in previous years at my school because I had not taught in the district prior to this year. Once I learned how little the students knew about gravity, I questioned the amount of previous science instruction and wondered how many students had met or exceeded the standards in the state exam. Furthermore, many teachers told me that little science had been taught before fourth grade. With the above issues in mind, I developed four questions to research.

Research Questions

1. What do the standards and research say about gravity?
2. What preconceptions do students have about gravity?
3. How can my teaching of this concept be informed by their thinking?
4. What science instruction did my students receive in previous grades?

Curriculum Topic Study (CTS)

Background Research, "Gravitational Force" (p.215) (Keeley, 2005)

Clarification of the content from *Science for All Americans* (*SFAA*)

- Everything in the universe exerts gravitational forces on everything else.
- The two most common kinds of forces are gravitational and electromagnetic.

Student learning goals from *Benchmarks for Science Literacy* (*BSL*)

- Things on or near the earth are pulled toward it by the earth's gravity.
- The earth's gravity pulls any object toward it without touching it.

Student learning goals from *Maine Learning Results, 2007*
Grades 3-5

- Predict the effect of a given force on the motion of an object.
- Give examples of how gravity, magnets, and electrically charged materials push and pull objects.

Teaching considerations from *Benchmarks for Science Literacy*

- Students think gravitational pull is very strong compared to electric forces on dry hair charged by combing. They can be led to see the opposite. The whole earth is required to pull a hair down by gravity, while only a small amount of charge is needed to force it up electrically against gravity.
- Students need to understand the earth is spherical and people standing at the opposite end of the earth are pulled by gravity in the same way.
- Students need only get a sense of a gravitational force field.
- Research suggests teaching the concepts of spherical earth, space, and gravity in close connection to each other.
- Misconceptions about the causes of gravity persist after traditional high-school physics instruction but can be overcome by specially designed instruction.

Cognitive research from *Benchmarks for Science Literacy* (*BSL*) and *Making Sense of Secondary Science* (*MSSS*)

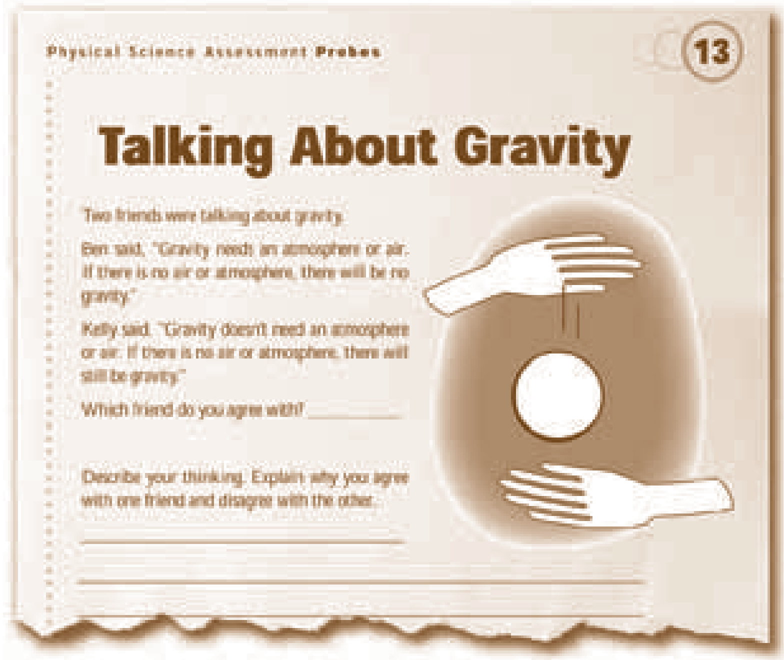
- Student's ideas about the shape of the earth are closely related to their ideas about gravity and the direction of "down." (*BSL*)
- Students cannot accept that gravity is center-directed if they do not know the earth is spherical. (*BSL*)
- Students cannot believe in a spherical earth without some knowledge of gravity to account for why people on the "bottom" do not fall off. (*BSL*)

- Some research indicates that students can understand basic concepts of the shape of the earth and gravity by fifth grade if the student's ideas are directly discussed and corrected in the classroom. (*BSL*)
- Elementary-school students typically do not understand gravity as a force. They see the phenomenon of a falling body as "natural" with no need for further explanation or they ascribe to it an internal effort of the object that is falling. (*BSL*)
- If students do view weight as a force, they usually think it is the air that exerts the force. (*BSL*)
- Students generally appear to think of force as a property of a single object rather than a feature of interaction between two objects. (*BSL*)
- Students of all ages may hold misconceptions about the magnitude of the earth's gravitational force. Even after a physics course, many high-school students believe that gravity increases with height above the earth's surface or are not sure whether the force of gravity would be greater on a lead ball than on a wooden ball of the same size. (*BSL*)
- Pupils, ages from 11 to 17, revealed ideas of gravity "pushing," "pulling," or "holding." "Holding" appeared to be the most common perception of gravity and was bound up with ideas of gravity being connected to air pressing down and an atmospheric shield which prevents things from floating away. (*MSSS*)
- The notion that there must be air for gravity to act appears to be widespread. Relating gravity to air appears to offer an explanation of gravity, which lies outside objects rather than in terms of a property of all objects. (*MSSS*)
- Significant numbers of students think that the force of gravity decreases with the height above the earth's surface, but pupils who hold this view tend to expect a far bigger decrease in the force of gravity with increasing height than is actually the case. (*MSSS*)
- Another study found some 14-year-old pupils think gravity increases with height above the earth. Pupils holding the "higher-stronger" gravity view assume this applies until things get outside the earth's atmosphere. (*MSSS*)
- Some 15-year-old pupils think that gravity only affects heavy things and some think that it is possible to have weight without gravity, saying that astronauts wear moon boots to "give them weight where there is no gravity." Some think it is gravity that keeps birds up. (*MSSS*)
- Some 12- and 13-year-old pupils think that gravity does not operate without weight. (*MSSS*)
- Some pupils and adults see weight as a property of an object and gravity as a property of space. (*MSSS*)
- Some 12- and 13-year-old pupils relate both gravity and weight to air and atmospheric pressure with pupils thinking that air is necessary to keep things on the ground and that weight is affected by, or depends upon, air. (*MSSS*)
- Nine-year-old pupils have a clear distinction between "falling down" involving a loss of equilibrium and "falling" in response to gravity. Pupils did not combine ideas of equilibrium, gravity, and falling. There appears to be a progression from the idea that things fall if nothing holds them up to the idea that things fall because of their weight (without recognizing that weight is the force of gravity on an object) to the idea that weight is a force and that all things fall in the absence of support. (*MSSS*)
- Some pupils think that all objects fall, heavier things fall faster, and barriers stop things from falling. The idea that falling is caused by weight and that not only the earth, but also heaviness, pulls a thing down is found in samples of preschool-age students onwards. (*MSSS*)
- Some children think that gravity begins to act when an object begins to fall and that it ceases to act when the object lands on the ground. In fact, their explanation amounted more to a description than an explanation of falling. (*MSSS*)
- Students think of gravity as relating only to the earth. This notion appears to be bound up with pupils' common belief that gravity is associated with air and that where there is no air there is no gravity. (*MSSS*)
- Students think that gravity needs a medium and that there would be no gravity in places without air. Some appear to think in terms of "molecules of gravity" in air. Many think that there is no gravity on the moon. The idea that not all planets have gravity is common, and many think there is no gravity in space. Science fiction ideas of "weightlessness" may have contributed to this view. (*MSSS*)

Classroom Research

Classroom Context

My research was conducted in a central Maine, urban, fourth grade classroom comprised of 21 nine- and ten-year-old students. This classroom is part of a K-6 school populated by 308 Caucasian, 12 black, four Hispanic, and two Asian students. Of this population 193 benefit from free lunch, 21 from reduced lunch, and 112 pay full price for lunch. Sixty percent of the fourth grade students in the district are at or below poverty level. (Two families are homeless.) The transient rate is 63 percent.


Physical Science Assessment Probes

13

Talking About Gravity

Two friends were talking about gravity.

Ben said, "Gravity needs an atmosphere or air. If there is no air or atmosphere, there will be no gravity."

Kelly said, "Gravity doesn't need an atmosphere or air. If there is no air or atmosphere, there will still be gravity."

Which friend do you agree with? ________

Describe your thinking. Explain why you agree with one friend and disagree with the other.

Used with author's permission (Keeley, Eberle, and Farrin, 2005)

Methodology and Data Collection

Maine requires all students in grades 3-11 to take the *Maine Educational Assessment* (*MEA*) in math, reading, and science. In my school, 40 students took the 2007 *MEA* science assessment. The results were 27 (67.5 percent) met the standards, eight (20 percent) partially met the standards, five (12.5 percent) did not meet the standards, and no one exceeded the standards. Knowing the *MEA* had a science and technology questionnaire for students to complete after finishing the science portion of the assessment, I obtained the results to examine their perception of science instruction and the *MEA.*

I administered a physical science assessment probe, "Talking About Gravity" (Keeley, et.al., 2005), to twenty-one students.

Students were asked to agree with one of the two students, Kelly and Ben, who were discussing whether or not gravity needs air. I also interviewed thirteen students. These students were asked to predict how a rock would fall if it were possible to drop it through a hole drilled all the way through the earth starting and ending on opposite sides of the equator. My third set of data was collected from a group of six children discussing a piece of literature entitled, "Driving on Mars." The book was about a remote-operated vehicle used to collect information from Mars and was read before the gravity probe was administered.

Data Organization and Findings

Table 1 shows the results of the summary sheet of the science and technology questionnaire answered by the students about the science portion of the *MEA*.

As you can see from Figure 1, most students who took the probe agreed with Ben, who erroneously thought that gravity needed an atmosphere or air. Fewer students agreed with the scientifically sound response that gravity exists without air or an atmosphere. When I examined the written explanations, I found that even those students who agreed that gravity can exist without air or an atmosphere provided explanations that were not supported by scientifically sound reasoning. Student interviews further supported that finding. In the discussion of the story, only one student expressed an opinion that gravity would be a force on Mars. In the interview where students predicted how a rock would fall, only four students indicated that there is gravity in the Earth's core. The majority of students did not have this understanding.

Table 1:

Science and Technology Questionnaire

Questionnaire Items	% students in each category	% exceeds	% meets	% partially meets	% does not meet
How well do the questions that you have just been given on the MEA test match what you have learned in school about science?					
A. The questions on the test match what I have learned in science class.	35	0	57	29	14
B. They match some of what I have learned.	35	0	79	7	14
C. They match just a little of what I have learned.	30	0	67	25	8
Which of the following best describes how you rate yourself as a student in science?					
A. Very good	18	0	71	0	29
B. Good	43	0	65	24	12
C. Fair	40	0	69	25	6
How difficult was the science part of this test?					
A. harder than my regular schoolwork	23	0	89	11	0
B. about the same as my regular schoolwork	64	0	76	16	8
C. easier than my regular schoolwork	13	0	0	60	40
How often do you have science classes?					
A. every day	13	0	60	0	40
B. a few times a week	28	0	73	18	9
C. once a week	15	0	83	17	0
D. a few times a month	45	0	61	28	11
Which statement best describes how you learn science?					
A. I mostly read a textbook and answer questions and/or take notes and do assignment. I use science kits for demonstrations and experiments.	41	0	67	20	13
B. I work in groups to design and conduct experiments	22	0	63	25	13
C. I do a combination of A and B, mostly A.	22	0	63	38	0
D. I do a combination of A and B, mostly B.	16	0	83	0	17

Figure 1: Gravity Probe

Seven of the students who responded to "Talking about Gravity" agreed that air or atmosphere is not necessary to have gravity.

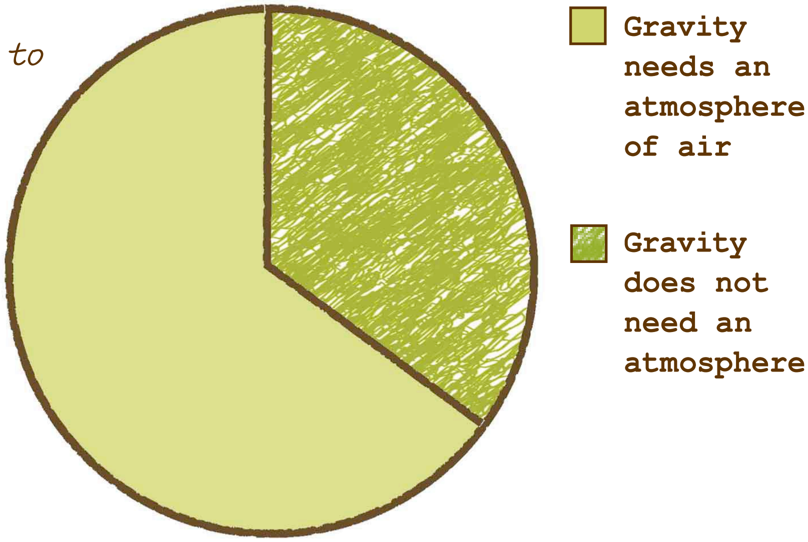


Table 2:
No Air is Needed for gravity response and interview question

Table 2 shows students' responses related to the "no air is needed" answer gravity probe and the interview question.

Student	Response to Gravity Probe and Agreeing that No Air is Needed	Response to Interview Question Predict how a rock would fall if it were possible to drop a rock through a hole drilled all the way through the earth starting and ending on opposite sides of the equator.
1	"Because trees produce air and trees breathe carbon dioxide and they get it from us because when we exhale we breathe out carbon dioxide that proves you don't need to have air to get gravity."	"The object goes through the hole in the earth and continues straight through."
2	"The atmosphere is what you go through to get to space. The atmosphere doesn't have anything to do with gravity. Gravity definitely doesn't need air because there is no air in space."	"The rock would float two to three feet in the hole."
3	Offered no explanation.	"The rock would fall through the hole and keep going."
4	"It does not take air or atmosphere to make gravity."	"The rock would go straight through to the other end because the rock has gravity in it."
5	"Gravity needs no air because 'outer space' is full of gravity."	"The rock would go through the center of earth to the other end and float all over the place."
6	"There is always going to be gravity. There doesn't need to be an atmosphere."	"The rock would go straight through (earth) and destroy the planet because people at the other end would try to push it back up with a machine and the machine would destroy the earth."
7	"Because people go out into space and have no gravity but they'll have air and on a lot of planets there's gravity but no air so you don't need air or atmosphere."	"The rock would fall to the center and stay there."

Fourteen students who answered the probe agreed that air or an atmosphere is needed for gravity to be present. Eleven of these students offered explanations and six were further interviewed. The results are presented in Table 3.

Table 3:

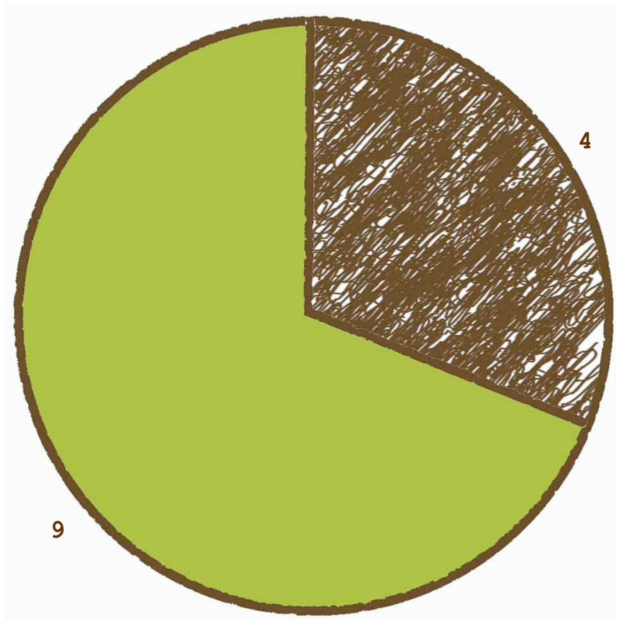
Air Is Needed for Gravity response and interview question

Student	Response to Gravity Probe and Agreeing that Air is Needed	Response to Interview Question Predict how a rock would fall if it were possible to drop a rock through a hole drilled all the way through the earth starting and ending on opposite sides of the equator.
8	"The moon is a planet and it has no atmosphere or gravity. I know that when you walk on the moon, you weigh nothing."	"Gravity will stay in the dirt. Gravity will make the rock have a lot of pressure because it has a lot of gravity around it. The rock will go around because the gravity is pulling it."
9	"Because if you throw a pencil in the air it will fall and there is air here. If you throw a pencil in outer space it will float because there's no air."	
10	"Because the atmosphere keeps the gravity in so we don't float. It also keeps the air in so we can breathe . . . if there is no atmosphere, the gravity will be in space. The air will disappear."	"The rock will fall to the other end [of the earth]."
11	"You do need atmosphere or air . . . you need one or the other."	"The rock goes to the bottom of the hole if there is no gravity and, if there is gravity, it would stay at one side or fall down to the other end."
12	"You need atmosphere for there to be gravity. Also there is no air in space so there is no gravity."	
13	"Gravity can't work without air or atmosphere."	"The rock would go to the center of earth and earth would hold it there because gravity keeps things up and in space there is gravity and earth is in space. If you cut a hole in earth which is in space, the rock would still have gravity because if there was a hole through the earth, it would have like an opening through space then gravity, which is in space, would hold up the rock."
14	"You need air for gravity."	"It [gravity] would hold it [rock] in the center of the earth in the hole."
15	"Because if there was no air or atmosphere probably nothing would exist. If nothing existed, gravity probably wouldn't exist."	
16	"No air, no gravity."	"Gravity slows the speed of the object depending on how heavy it is. The lighter the object the faster it falls with no gravity. The object would go slowly, get to the other end of the hole, and go into space."
17	"If there is no atmosphere, there is no planets, and if there is no planets, there is no air, and if there is no air, there is no place for the gravity to go."	

The results of the interview question, "How would a rock fall if it were possible to drop it through a hole drilled all the way through the earth starting and ending on opposite sides of the equator?" are presented in Figure 2.

Figure 2:

Rock Falling through Earth Interview Question



Understood gravity is in Earth's core

Did not understand that gravity is in Earth's core

The following comments are quotes from our class discussion about the story, "Driving on Mars."

Student 3:
"When there is gravity, the car moves easily, and when there is no gravity, the car is harder to move."

Student 1:
"Gravity helps the world turn. Gravity goes in tiny dust and you can't see it or feel it. It goes right through you. Gravity and space men, when they are using the rocket ships, right when they go, just like Student 10 [sic] said, when you throw a baseball it just stays. It will stay right in space. Gravity is in it so it moves just a little. The rocket ship is very heavy. It is hard to move. When they go out they just open the door and they jump out, because they go very slowly down on the planet. They jump and don't get hurt because there is no gravity and they go very slowly. With gravity you go very fast. No gravity, it is hard to move. It is like physical. When you are on Mars, you can't walk. You literally have to jump. Walking is difficult because the space suit and boots are very heavy so you have to jump."

Data analysis

Do my students have commonly held misconceptions about gravity? Results from this research indicate that they do. Some students understand that gravity exists without air, but they do not know why, do not understand how to answer a "why" question, do not have enough expressive language, or answered in a manner that exemplified further misconceptions. As a teacher, I found it interesting to find shallow and incomplete explanations, which confirms my practice of looking beneath an obvious "right" answer for supportive evidence that the students understand the essential concept. In the story discussions, students revealed many interesting ideas about gravity in space. It will be beneficial to the students to confront and express their own ideas about gravity in future reflections. I found this free-flowing conversation full of insightful (if incorrect) ideas. This is a strategy that I will use in future science units. Interestingly enough, I also learned from the results of the *MEA* science questionnaire portion of the test that most students view themselves as fair to very good science students, although one third of the students failed to meet the standard.

Significance

What went well? What could be done better? What can I continue to expect? What further questions do I have?

- I am curious to know if any questions about gravity were on the *Maine Educational Assessment,* what the questions were, and what answers did my students choose?
- I can conclude that students have not developed the correct concepts regarding gravity.
- I need to use the inquiry approach and a combination of demonstrations and hands-on experiments.
- I would probe further with students about their prior experiences to gain insights as to how they developed their ideas.

Student 4:
"That if there is no gravity you have to jump to move. Gravity makes you stay on the ground, and I don't know how that does that. The car on Mars has gravity inside it. So it keeps it on the ground and so it moves around."

Student 7:
"Gravity is a force that holds stuff to the ground. It is everywhere. You can have air and no gravity like in a rocket ship. You can breathe when there is no gravity. There is gravity on Mars."

Student 19:
"Gravity is in the air. Gravity is kind of like air like on Earth. On Mars there is not much earth or air and suits have air in them so they can breathe so, no air, no gravity."

Student 10:
"There is no gravity in space." When asked how the Land Rover stayed on Mars, Student 10 responded, "It's probably so heavy it will just stay there. There is something sticky on the wheels. So sticky that gravity pulls it off and the Rover just stays there." When asked about the gravity shield he mentioned earlier in the discussion, Student 10 replied, "Maybe there is a gravity shield around the rover so it doesn't float away."

- During the data collection, I thought four students correctly understood the concept of gravity. Not until I started looking more closely at their answers did I find that those students had misunderstandings as well. I thought for sure Student 8 had a complete understanding, until he used the word "hold." In addition, he said that there was no gravity in space.
- I am very surprised at how many students had misconceptions.
- Clearly one method of assessing prior knowledge is not sufficient.
- With two choices for an answer, as with the gravity probe, there is a 50 percent chance of guessing correctly. The explanations children offered highlighted their misconceptions and are most important.
- I need to make sure students understand the question "Why or Why Not?" It is the reason they give that enlightens me as to their commonly held ideas. Some students did not provide any reasons.
- It is difficult to really probe in a classroom atmosphere. Students can hear others' responses. One-on-one interviewing in a private setting requires additional supervision.
- Some students do not express themselves in complete sentences nor with sentences that are connected to one another. I have to be prepared to listen very closely and ask clarifying questions without leading the student to a correct concept. Some students talk and talk and talk to the point where nothing they say makes sense.
- At no time did any student say he did not know or understand gravity. Students gave the appearance of knowing something and expressed themselves with confidence, implying they were correct.

Impact on my teaching

- Students need hands-on experience, much discussion, and science notebooks for recording experiments and thoughts to be shared with other members of class.
- No students think of themselves as poor science students. I need to continue to support that self concept.
- I need to teach science at the very least once a week.
- I need to clearly teach and reinforce to students that claims written in their science notebooks need to be supported with evidence.
- Sharing students' written responses from their science notebooks with their peers will help reinforce the need for supporting evidence, assist with student reflection, and support further inquiry by students.
- I need to keep a record of all student responses during the research phase so I can intermittently and in a timely fashion refer back to them to assist my students with discriminating between fact and opinion.
- One of the last acts my students and I will do is revisit the gravity probe again, and I will interview each student once again with the same question.

Reflection

The process of doing action research was an enjoyable and intellectual experience. Knowing my work would be published was an exciting motivator, as well. The vast amount of excellent professional support and resources provided by the Maine Math Science Alliance, my school administrators, and my cohort totally freed me to concentrate, learn, and enjoy the experience from start to finish. All the pieces needed for success were in place and my plan of action, as a result of all the support, was articulate and well organized. This foundation freed me to look forward to the 'action' part of the research.

I began in the fall with my new fourth-grade class. I didn't know what answers I would get from my verbose group. From the very beginning, these students loved to talk and tell me what they knew. Their participation peaked when I explained to them that I was researching what they knew about gravity before we studied it in class and they were part of my experiment.

The difficulty of the process was getting students' responses recorded accurately and collected in a manner that did not influence the responses of other students in the room. The group discussion was the most frustrating because

I did not use a hand held microphone attached to the tape player. I used the built-in microphone. The background noise was the culprit. When I listened to the tape to record my students' responses verbatim, I had to stop and start that machine dozens upon dozens of times to catch every word accurately. In this facet of my data collection, students' responses may have influenced one other so the personal interviews were important to my study.

The interviews posed difficulties in three ways. First, I needed to remove each student from the group so their overheard remarks would not influence other students' responses. Second, the only time students could be interviewed individually was during art, library, music, physical education, or technology classes because children cannot be left unsupervised. Third, it was difficult to frame the interview so students would be relaxed, focused, and thoughtful with their answers, because most students do not want to leave their once-a-week special classes.

The data I collected was a revelation and minimized the hurdles that needed to be overcome. I shared the results with my students, and they often appeared and responded with surprise as they explored gravity as a force and attempted to make sense of the new concepts.

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A Spin on Variables

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Jennifer has been teaching for 14 years at the Kindergarten and Grade 1 level. She received a BS in Psychology from the University of Southern Maine (USM) in 1993 and entered the ETEP program, where she began graduate courses to become a certified elementary teacher. In 1994, Jennifer started teaching first grade in North Berwick, Maine. She received an MS in Teaching and Learning from USM in 1997. She resides in Sanford, Maine, with her husband and two daughters. They enjoy reading, camping, kayaking, snowmobiling, and skiing.

Purpose of the Study

In the past five years of teaching the FOSS® Balance and Motion unit, it has been my experience that first graders tend to use a lot of trial and error in their explorations of building tops. As they construct their tops, they tend to change too many things all at once. This makes it difficult for them to identify the factors that influence the motion of their tops.

They understand that they have to experiment in order to build tops that spin. They know that they have to test variations of their designs. And, they have good ideas to test. The problem is that they go about it in such a random, haphazard way that it's difficult for them to connect their manipulations of the tops to how such manipulations change the motion. They're usually very excited about the activity and remain engaged in it for the entire session. This makes for fun, but chaotic "science" sessions, and it often leaves me wondering if they have gained a true sense of what it really means to engage in the scientific process of inquiry.

Research Questions

1. What do the standards and research say about how young children identify and control variables?
2. What strategies do my students use as they go about identifying and controlling variables using tops?
3. What issues do my students have identifying and controlling variables using tops?

Curriculum Topic Study (CTS)

Background Research, "Experimental Design" (p.235) (Keeley, 2005)

Clarification of the content from *Science for All Americans*

- People need to decide what evidence to pay attention to and what to dismiss.
- People should be able to distinguish careful arguments from shoddy ones.
- People should be able to apply those same critical skills to their own observations, arguments, and conclusions, thereby becoming less bound by their own prejudices and rationalizations.
- Everyone can learn to detect the symptoms of doubtful assertions and arguments.

Student learning goals from national standards from *Benchmarks for Science Literacy*

Grades K-2

- When a science investigation is done the way it was done before, we expect to get a very similar result.
- Sometimes people aren't sure what will happen because they don't know everything that might be having an effect.
- People can often learn about things around them by just observing those things carefully, but sometimes they can learn more by doing something to the things and noting what happens.
- Ask "How do you know?" in appropriate situations and attempt reasonable answers when others ask them the same question.
- Describing things as accurately as possible is important in science because it enables people to compare their observations with those of others.
- Draw pictures that correctly portray at least some features of the thing being described.
- Describe and compare things in terms of number, shape, texture, size, weight, color, and motion.
- Raise questions about the world around them and be willing to seek answers to some of them by making careful observations and trying things out.

Student learning goals from *Maine Learning Results, 2007*

Grades Pre-K-2

- Plan and safely conduct a simple investigation to answer questions.

Learning goals from *Full Option Science System (FOSS)*®*:* Balance and Motion

- Develop a growing curiosity and interest in the motion of objects.
- Investigate materials constructively during free exploration and in a guided discovery mode.
- Solve problems through trial and error.
- Develop persistence in tackling a problem.
- Discover different ways to produce rotational motion.
- Explore and describe some of the variables that influence the spinning of objects.
- Construct toys that demonstrate spinning.
- Acquire the vocabulary associated with balance and motion.
- Gain early experiences that will contribute to their [students'] understanding of several pervasive themes that relate one scientific idea to another: change and interaction.

Teaching considerations from *Benchmarks for Science Literacy* (BSL) and *National Science Education Standards* (NSES)

- The process of inquiry is more demanding than "making a great many careful observations and then organizing them." Yet, it is more flexible than the rigid sequence of steps commonly depicted as "the scientific method." (*BSL*)
- Students need to participate in scientific investigations that progressively approximate good science. (*BSL*)

- All students should develop abilities necessary to do scientific inquiry and understanding about scientific inquiry. (*NSES*)
- Students should also learn through the inquiry process how to communicate about their own and their peers' investigations and explanations. (*NSES*)
- Full inquiry involves asking a simple question, completing an investigation, answering the question, and presenting the results to others. (*NSES*)
- Children can design investigations to try things to see what happens. They tend to focus on concrete results of tests and will entertain the idea of a "fair" test in which only one variable at a time is changed. (*NSES*)

Cognitive research from *Benchmarks for Science Literacy* (BSL) and *National Science Education Standards* (*NSES*)

- Students of all ages may overlook the need to hold all but one variable constant. (*BSL*)
- Students tend to make causal inferences based on a single concurrence of antecedent and outcome. (*BSL*)
- Students have difficulty understanding the distinction between a variable having no effect and a variable having an opposite effect. (*BSL*)
- Students tend to look for or accept evidence that is consistent with their prior beliefs and either distort or fail to generate evidence that is inconsistent with these beliefs. (*BSL*)
- Children in grades K-4 have difficulty with experimentation as a process of testing ideas and the logic of using evidence to formulate explanations. (*NSES*)

Classroom Research

Classroom Context

I gathered data from a small group of six students comprised of three girls and three boys, randomly chosen out of a first-grade classroom of sixteen. (No one in the small group was identified as having special needs.) The class is self-contained in a small rural school of about 298 students spread over two campuses. It is situated in a "small-town America" community in southern York County, Maine, an area that is rich with early settler history. The class is nearly gender balanced with nine boys and seven girls. There is a full-time teacher and a half-day, Title I, literacy and mathematics education technician.

Methodology, and Data Collection

I conducted 15-minute videotaped interviews with each student over a span of two days in the fall of 2007. I gave each of them a plastic bag of materials consisting of a narrow green straw, two small yellow disks, and two larger red disks. The yellow disks have one hole in the center and four perpendicular grooves on the edges. The red disks have three holes in the center and the same grooves. I instructed each student to "use these materials to build a top that spins." I also gave them some blank paper and a pencil and specifically stated that they could use them in case they wanted to write anything down that might help them.

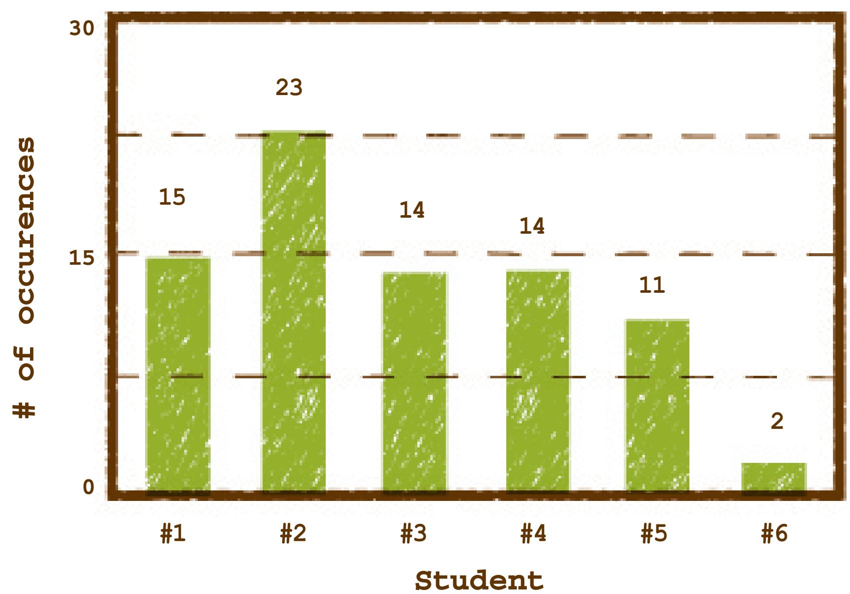
Most of them eagerly emptied the bag and went right to work. I observed them as they worked and asked them pertinent questions about their strategies and thinking as they built their tops and manipulated the pieces in attempts to make them spin successfully. I tried to access their prior knowledge and experience with tops by asking them if they had ever used one before. Half of them reported that they had. As they continued experimenting, I recorded each child's approach to the task, whether it was random, systematic, or effective. (See Appendix A for Approach Chart.) I defined random as using lots of variables and limited or no recording strategies; systematic as using some type of organization and some recording strategies; and effective as controlling one variable at a time and recording how they do it. When the interviews were completed, I watched the tapes again and transcribed the conversations.

Data Organization and Findings

As I suspected, based on my prior experience with first graders and this activity, none of them used the paper and pencil to record anything, and they all approached it very randomly through trial and error. That prompted me to go back through the transcripts and tally how often each student used the trial and error strategy; the group average was thirteen times. (See Figure 1.)

Figure 1:

Frequency of Trial and Error Usage



I also found evidence that five of the children relied only on their memories of previous constructions while the sixth one achieved a working top in only two trials, so she didn't have a lot of information to keep track of. I asked her why she thought it wasn't spinning on her first try, and she applied her knowledge of top-heaviness to change her construction and made her top work in a much shorter amount of time than the others. As the other five encountered initial problems with getting the top to spin, they mostly were able to identify top-heaviness as a factor through a few probing questions (as evidenced by their quotes listed in Table 1). All of them eventually arrived at the conclusion that the disks needed to be located towards the bottom of the straw in order for it to spin well. About half of them identified several other variables that made a difference in how the tops spun. One was how they grasped the straw as they initiated the spin—either with a finger and thumb pincher grasp or a "between the hands" method. Another was how much energy they put into the top to get it started and whether the top started on a table, a smooth tile floor, or a carpeted floor.

Data Analysis

As I look back at my original questions in this puzzle, I observed that some students were overwhelmed with the open-endedness of the task and lacked confidence in their ability to build a working device, whereas others eagerly dove in and began testing their ideas. I also got a sense that most of them just viewed the task as playful and fun. They didn't naturally recognize the scientific importance of recording their variations, so they could keep track of which designs they tried and whether they worked or not. It appeared that they thought their memories were an adequate and reliable source of information. It did not occur to them that real-world scientists only change

Table 1:

Identifying Top-Heaviness

Students also provided unclear explanations as they went about the task, as indicated in Table 2.

Student #1 "Maybe if I used, um, put this a little farther down so it wouldn't fall as much." "It wouldn't spin too good if I did it like this because there's too much pressure at the top, not the bottom." ". . . because there's too much pressure underneath and on the top."	**Student # 4** "With this one on, it's too heavy." "The little ones weren't too heavy as this one." "Put them right, a little more down."
Student # 2 "When I move it down, it spins better." "...but I think I just moved it down."	**Student # 5** "Probably because the weight on top is heavier." "I had to move it down because the weight was too heavy on the top . . . Everything is down lower."
Student # 3 "Because it's too heavy."	**Student # 6** "It needs to be down a little bit more . . . so it can spin."

Table 2:

Unclear Explanations

Student # 1 "I was thinking that if you put it on the side it would probably go, wobble, and would help it keep balanced a little more, but when you do it just side in a pattern it works more so you can spin it 'cause it's better gripped on each other so it can spin better."
Student # 3 "Um, the, this whole entire thing. It's more heavier than it makes it. It's like if I put one arm out then I just swing around then, then I'll try to escape and that's what is making it move."
Student # 4 ". . . 'cause they were right, this one was there, this one before was right here and this one was right here, and these ones were right here." (Pointing and showing instead of explaining.)."

one variable at a time so they know an observable change in the motion of an object can be attributed to that one variation. Those skills need to be explicitly taught.

The last major issue is developmental. Once again, I have first-hand experience that young children tend to lack the more sophisticated language and vocabulary necessary to accurately and effectively explain their reasoning. Student # 1 illustrates this point when she misuses the word "pressure" on two occasions. But, as indicated in Table 2, she wasn't the only one to offer unclear explanations.

Significance

These findings are consistent with the cognitive research. Young science learners do have issues with identifying and controlling variables that need to be addressed directly in the classroom. This study shows that children are natural explorers. Teachers should capitalize on this trait and use it to their fullest advantage. Children also are able to identify some variables, but don't control them because they aren't familiar with the protocol of scientific inquiry that deals with the need for such control. These skills need to be explicitly taught. Year after year, they will need to be led through the process of gathering, recording, and organizing data and sharing results to complete the cycle of answering their original questions that launched the investigations in the first place. Students' beliefs about science being fun and playful will be confronted during hands-on testing as they're taught that science also is working to find answers to specific questions. Then, once an answer is found, they should be expected to take the next step and share the results with others in a logical, organized way. They won't just do it on their own if it's not a regularly expected routine. Teachers at all levels of science instruction should include some type of written communication component and time for students to share their results in order to "progressively approximate good science." (*Benchmarks for Science Literacy*.)

This project has had a significant impact on my teaching practice. An immediate short-term benefit is that I've learned about "inquiry boards" (Buttemer, 2006), a practical tool that can be used with the whole class. They provide a way to scaffold the process of controlling variables during scientific investigations. They can be used in the classroom to lead children of all ages into scientific inquiry in a controlled and sequential manner. Hopefully, their use will decrease the "chaotic science" that seems to creep in so easily when children conduct their own investigations. This tool may help me teach my students not only how to control variables but also to complete the full-inquiry model.

I'm at the beginning of the entire educational process for my students. Potentially, a long-term benefit is that, as a first-grade teacher, I'm in the position to facilitate the early development of scientific habits of mind that my students will be required to use for many years to come. If they can become familiar with the full-inquiry process this soon, how much more productive will their investigations be in the upper grades, especially if it's considered best educational practice? If the process becomes ingrained in them sooner, how much more will they be able to learn later?

When the time arrives to do the spinning tops investigation in the next few weeks, I'd like to try using the inquiry boards scaffold with my class and see how it goes. The first-grade teachers in my building team teach the science units, so it will be easy to share this new technique with them. Then, I can make plans with my principal to share the results with the rest of my colleagues.

Reflection

It was great being a researcher in my classroom. I loved it. I felt like a true professional especially in these RTI (Response to Intervention) times where my professional opinion seems largely ignored in favor of legislatively supported rules and regulations. In this age of accountability in education, I'm concerned about using my instructional time as wisely as possible. The background research and program goals allow me to relax, given the idea that some degree of disorganized, playful exploration is acceptable and should be expected at this grade level.

I discovered that I need to shift my instructional strategy. I don't have to be so concerned about making sure all the variables are controlled during the investigation because learning happens in the "doing" of science. I was thrilled to find out that my teaching practice is supported by the research; when the students complete an investigation, we do come back together as a large group to share our discoveries with each other. I also have students document their experiences and observations in their science notebooks. The process of scientific inquiry is being completed in a developmentally appropriate manner for first graders.

I've been on a steep learning curve in many ways this year. It's been an incredible amount of work, but this project has made this whole year worth it. Some of my own beliefs and misconceptions were uncovered. I learned that I had prejudged some of my students. I was pleasantly surprised at what some of them were capable of. I may have missed those subtleties in a full classroom setting. Yet, I was equally surprised by which students had difficulty with the task.

I had a "light bulb" moment during the fifth interview. I realized that I was using vague language in my questions. As I sat painfully watching this child struggle with a construction that just wasn't working, I tried to keep encouraging him by asking him how else could he "change his design." As I continued watching, I kept asking myself, "How can I rephrase what I'm saying to help him figure this out?" Then, I finally realized I had to be more specific and ask him how he could "transfer the weight" of the disk on the straw so it wouldn't keep tipping over. As soon as I asked him that question, he moved the weight toward the bottom and had the top spinning in no time. I can't help but wonder how much of what I say and the manner in which I say it hinders learning more than it promotes it.

It was fascinating to spend one-on-one time with each student. The dynamics of a classroom full of strong personalities can dramatically influence children's behavior, thinking, and learning in a group setting—not always for the best. It was a privilege to observe and interact with them individually. I caught a glimpse of them that I wouldn't have been able to see otherwise.

Now that I have answers to my questions, I know how I will proceed when this lesson is taught. I have a much better understanding of what I'll be asking my students to do when they engage in scientific inquiry because this project gave me the opportunity to experience the whole process for myself. In this case, the experience was the best teacher for me, but without the guidance and support of the MMSA staff and the SC4 Project, this never would have happened.

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Appendix A *Approach chart*

Identifying and Controlling Variables While Building a Top That Spins

Student	Random	Systematic	Effective

May the Force Be with You

Kristina Thompson

Sherwood Heights Elementary School

Auburn, ME

Kristina "Krissy" Thompson graduated from the University of Maine at Orono with a BS in education and a minor in dance. She has taught at Sherwood Heights School as a second grade teacher for the past three years. Incorporating science and dance into her daily lessons are methods Krissy uses to help her students understand themselves and the world they live in. When she isn't teaching, Krissy enjoys spending time with her husband and two boys.

Purpose of the Study

This statement from *National Science Education Standards* reflects what I would like to gain from this work: "*Students' first encounter with physical science should come from natural curiosity.*" The question is how do I best encourage that in my science lessons?

The Auburn School Department has created three science kits for grades K-6. All of the kits have been built through teacher collaboration with reference to the newly revised *Maine Learning Results* and aspects of other science kits. The Auburn science program has been built through these kits. Given that those building the Auburn science program are open to making changes and re-evaluating what is in our kits, I have been thinking about how I could add more to the second-grade motion kit. In my past experiences with teaching this kit, I felt that it could have more variety and depth, but I didn't have the full understanding of what was developmentally appropriate or how it would fit into the bigger picture.

Through this study, I hope to gain a better understanding of what ideas my students bring to the classroom in reference to understanding forces and motion. I would like to look at both their understanding of forces and motion and the effects forces can have on the motion of an object.

Research Questions

1. What do the *National Science Education Standards* and research on student learning say about students' understanding of forces and motion?
2. What preconceived notions do my students have about forces and motion?
3. Through instruction, how can I address my students' abilities to think about and see the relationships between forces and motion?

Curriculum Topic Study (CTS)

Background Research, "Forces" (p.214) and "Motion" (p.220) (Keeley, 2005)

Clarification of the content from *Science for All Americans (SFAA)*

- Everything moves. Nothing in the universe is at rest.
- Changes in motion—speeding up, slowing down, changing direction—are due to the effects of forces.

Student learning goals from *Benchmarks for Science Literacy (BSL)* and *National Science Education Standards (NSES)*

Grades K-2

- Things move in many different ways, straight, zigzag, round and round, back and forth, and fast and slow. (*BSL*)
- The way to change how something is moving is to give it a push or pull. (*BSL*)

Grades K-4

- An object's motion can be described by tracing and measuring its position over time. (*NSES*)
- The position and motion of an object can be changed by pushing or pulling. The size of the change is related to the strength of the push and pull. (*NSES*)

Student learning goals from *Maine Learning Results, 2007*

Grade Pre-K-2

- Students describe how objects move in different ways. Describe different ways things move and what it takes to start objects moving, keep objects moving, or stop objects.

Learning goals from *Auburn Motion Science Kit*

The guiding questions are:

- What causes motion?
- What are the different ways an object can move?
- The unit is focused on students' learning the terminology of what a force is as well as directionality and speed.

Teaching considerations from *Benchmarks for Science Literacy* (BSL) and *National Science Education Standards* (NSES)

- Students need experiences and opportunities to view, describe, and discuss all kinds of moving things such as themselves, insects, birds, trees, doors, rain, fans, swings, volleyballs, wagons, etc. These opportunities should include keeping notes, drawing pictures to suggest their motion, and raising questions, such as "Do they move in a straight line?" "Is their motion fast or slow?" and "How can you tell?" (*BSL*)
- The question (that students come up with) counts more than the answers at this stage. (*BSL*)
- Students should gain varied experiences in getting things to move or not to move and in changing direction or speed of things that are already in motion. (*BSL*)
- They need to know that push and pull is a force and to be able to describe different types of motion. (*NSES*)

Cognitive research from *Making Sense of Secondary Science* (*MSSS*) and *Benchmarks for Science Literacy (BSL)*

- Younger pupils, between seven and nine years old, were found to think of force in terms of anger or feelings. (*MSSS*)
- Pupils, ages seven to eight, tend to view forces getting things going rather than making things stop. (*MSSS*)
- Pupils sometimes suggest, when describing the act of forces, that objects are 'trying to' bring about a particular action. (*MSSS*)
- Primary children did not associate "kick" or "throw" with "push." (*MSSS*)
- Pupils' ideas about motion seem to be well established by the age of nine and hard to change after this age. (*MSSS*)
- Children need to develop the language tools to describe motion appropriately (including vocabulary and graphical representations) prior to developing an understanding of the principals of motion. (*MSSS*)
- Younger students associate the word "force" with living things. (*BSL*)
- Students tend to think of force as a property of an object rather than as a relation between objects. (*BSL*)

Classroom Research

Classroom Context

My classroom ratio is well-balanced with 11 girls and 11 boys, making a total of 22 second-grade students. Four of the 22 students have special needs and nine of the general education students require Title 1 services. The group is educated with a variety of support including a full-time classroom teacher, a one-on-one educational technician, a Title 1 teacher and her educational technician as well as a special education teacher. Mine is one of two second-grade classrooms in a pre-K-6 elementary school in central Maine. The school's students are from a variety of socioeconomic backgrounds ranging from homeless to well-off.

Methodology and Data Collection

For working with my students to find out what they know, I picked three different types of data collection to help me understand what they may be thinking about motion and forces.

My first piece of data came from a Concept Cartoon that I altered to match what I was looking for (Keogh and Naylor, 1991). The Concept Cartoon program can be used to uncover science concept misconceptions that students may have. Concept Cartoons are divided into different science categories and show a science situation along with choices of typical thinking that students may have. Collecting this piece of data was quick enough that I was able to garner the thinking of my entire class. The cartoon I used was a picture of a girl riding a skateboard. There were different prediction "bubbles" (of what children thought would happen) around the skateboarding girl. The four predictions shown on the cartoon were (see Figure 1):

1. "There must be a force that keeps her moving;"
2. "Gravity and friction will stop the skateboard;"
3. "She will stop because all of the power will get used up;" and
4. "The skateboard will keep going."

The second piece of data was designed to give me a deeper understanding of what my students were thinking and why. I decided to do a recorded interview of five students, two boys and three girls. They all had varied academic skills and family backgrounds. During each interview, I asked the students the same questions: "What things move?" "What makes things move?" "What makes things stop?" and "What is a force?" (see Table 1)

Lastly, I wanted to see my class at work trying to solve a motion "challenge." The entire class was presented with the challenge of getting a small car to move across a variety of "zones" or areas. Each zone covered a different distance making each challenge easier or more difficult. The rules for the challenge were: "No pushing the car" and "Keep

Figure 1:

More than half of the students chose answer 1 or 3 to predict what would happen to the skateboarding girl, but there was no one idea that was overwhelmingly chosen.

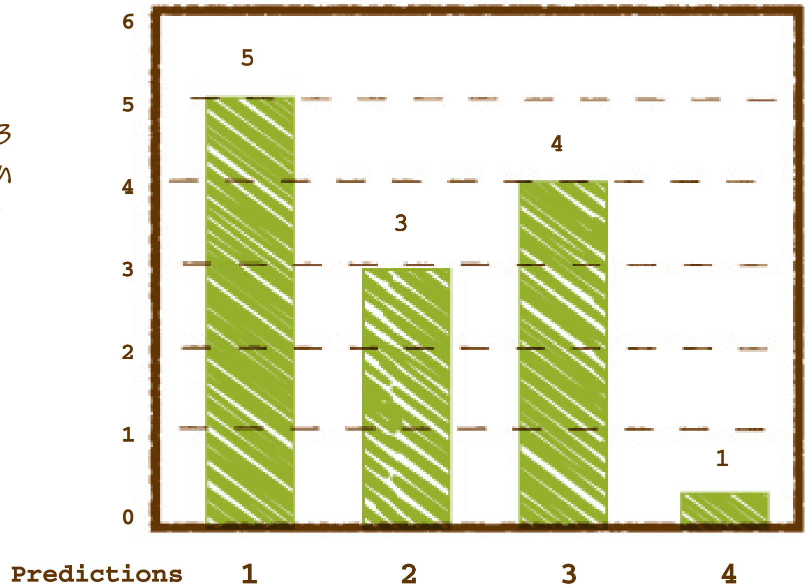

Table 1: *Through the interview process I found that none of the students could truly tell me what force was. The chart below that lists their responses.*

Interview Questions	Student Response
What are some things that move?	• Cars • Wheels • Humans/People • Arms • Animals • Trees • Ball
What makes things move?	• Battery and gas • Roll • Push • Bounce • Wind • How strong you push • Throw up in the air • Swing • Use a remote control
What makes things stop?	• Catch it • Wind • Not helping it move • It runs out of power • Everything stops • Too heavy • Grab it • Hold it with two hands • Fall over • Bounce into something
What is a force?	• I don't know. • The force of the wind. • A person can force you to do something but I don't think that's what you mean. • I know what it is on Star Wars. It's this thing that the Jedi have. • The student pushed my arm. He said, "I'm forcing you to move."

The final piece of evidence I collected that helped demonstrate my students' thinking in regards to motion was the car challenge. Below are the students' drawings that show the solutions to the challenge. Some words that the students used to describe their drawings were push, pull, and ramp.

Figure 2:

I tied string to the car and I was at the other side, so I could wheel it over.

Figure 3:

We're trying to put the cardboard on the ground and part of it is up. Then we slide the car down there. It worked.

Figure 4:

I tied string to the chair. I stuck the car on the chair and pulled the chair to the other side.

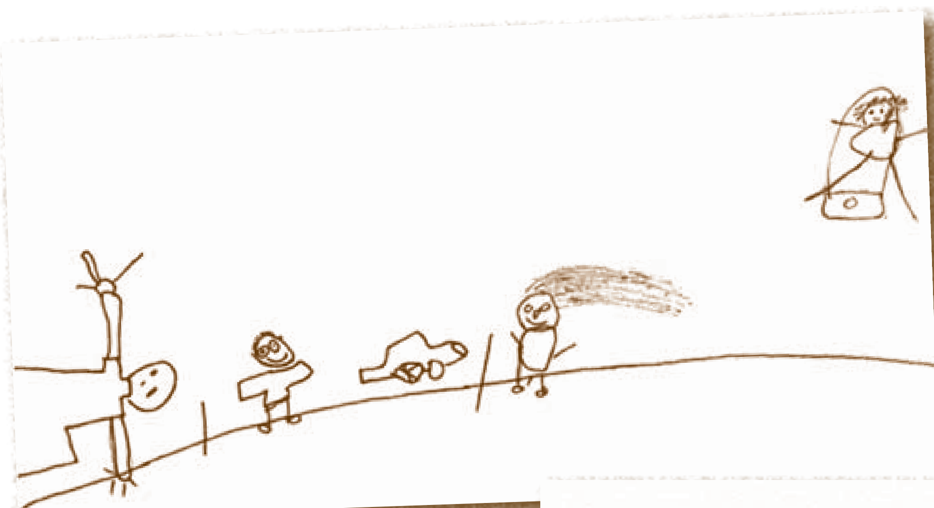

Figure 5:

We pushed the car and we let go. It went past the finish line because it had an engine.

Figure 6:

We made a boat with the string and the cardboard. We blew on it. It didn't work.

your body out of the zone." Once we started the activity I realized that I needed to add another rule: "The car needs to stay on the ground all the way across the zone." In order to complete the project, students were given a piece of string, tape, and a section a cardboard. While students were doing their challenge, I was walking around taking pictures of their solutions and ideas. I then had the students tell me their thinking and create drawings. (Figures 2-6)

Organization of Data and Findings

Data Analysis

After collecting my first piece of data from the *Concept Cartoon*, I found that the questions and reasoning the students used while trying to make their choices were more valuable then the actual answers. A question that came to me from this activity was: "Do my students know what the words friction, gravity, and/or force mean?" Over half of the class had picked A or B which had the more complex vocabulary. The interesting aspect of this data is that through the interview I found that none of the students could truly tell me what force, friction, or gravity was. Just because they picked A or B did not mean they understood the meanings of those words. This led me to the second piece of evidence, the interview.

During the interview process, it was surprising to see how much the students knew and, at the same time, I noted that what my students said during the interviews matched the research on student ideas. The piece that really stood out to me was the fact that not one student had a strong understanding of what a force is. They all seemed to be starting to form a meaning of the word but still needed more explicit teaching as well as more time to experiment with the concept of force and its relationship to motion. Another interesting finding was based on what I heard on several occasions from the three girls I interviewed. They mentioned "wind" as playing a major role in causing or stopping motion. This was particularly interesting because in all of my readings it was not talked about. Yet, it was such a common explanation for each of the girls that I interviewed.

Through the motion experiences the students were able to think about what they knew about motion and apply it to getting their car to move across the zone. During this motion challenge, some students ran into difficulties with their plans but continued to try new strategies until they found a solution. For example, one group wanted to tie the string to the cardboard, put the car on the cardboard, and pull the car across. They found that the car kept rolling off the piece of cardboard. They were not sure why but they quickly decided that they should tie the string directly on to the car without the cardboard and that would work. This activity showed me the value of how meaningful and challenging experiences can give the students the opportunity to build a better understanding of motion and its relationship to forces.

Significance

The findings of the research I completed in my classroom have shown me that there are a variety of misconceptions that my students have regarding motion and force, including the effects of push and pull. It is clear that just because my students use words like "force" and "motion" it does not mean that they understand those words. One goal I now have, based on this research, is to slow the pace of my instruction down and make sure that I provide a variety of experiences for my students, including opportunities to play with motion and forces as well as discuss and write about them. It is important that I focus more on the conceptual understanding than the use of the technical vocabulary.

Another change that my research has led me to make is to try to teach the class that there are passive forces such as friction that are pushing on things. This idea brings me to the biggest "ah hah" that this research process has had for my teaching of motion. That is in how I teach gravity and friction. In order to aid my students in their explanations of how things stop, I will incorporate experiences utilizing friction. This will provide my students with opportunities to test how well something smooth, like a marble or coin, moves and stops when going across a variety of textured surfaces, such as rough and smooth ones. My students thought that objects just stop. (The research supports this.) The inclusion of friction and its relationship with motion will take my students to a deeper level of their own understanding of the relationship between force and motion

The Auburn School Department is very lucky to have two full-time teachers who work on the science kits for the district. I now plan to talk with them to see what they think about adding friction experiences to our motion kits. I also would like to see a few more creative and open-ended student-directed opportunities. Such opportunities will help to uncover the misconceptions that I have seen first-hand and will aid students with building their conceptual understanding of the variety of aspects of push and pull.

Reflection

This research project began with the frustration I experienced while teaching my district's motion kit. Initially, I felt that teaching my students the words "push and pull" was too basic and boring. I have come away with a better understanding of the different types of pushes and pulls that my students don't yet understand and the relationship of those forces to different types of motion. I am now ready to take a step back and try to truly understand what it is my students think and use that thinking to design my instruction. I especially enjoyed using the Concept Cartoons to get a quick understanding of what my students think in reference to motion. To make better use of the Concept Cartoons I will not only ask what answers the students agree with but also why they made those choices. Asking why gave a lot more depth to the information that I was collecting.

Hands down the interviews were the most eye-opening form of data collection for me. Even with the very busy schedule of teaching I now see the importance of interviews before starting new units. I will try to build in time at the beginning of each unit and give my students an opportunity to discuss their thinking. The concept of interviewing or having discussion groups could be stretched across the curriculum. Why not use interviewing through various math, writing, and reading times to gain a deeper understanding of science concepts we are focusing on?

My feeling is that, while I incorporate conceptual changes to my teaching of science, I want to make sure that I don't lose sight of the need for my students to view science as fun, engaging, and challenging. By remembering to let kids be kids, I can allow them to actively explore, ask questions, and be creative.

Overall, I feel like this learning opportunity has opened my eyes to a new way of thinking and teaching. Building in opportunities for my students to bring in their own ideas to the classroom and taking the time to find out what those are will allow me to build instruction around them. Finding out what they are thinking is so intriguing. Now I can feel like a curious learner along with my students!

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Where did it come from? Where did it go? Students' ideas about energy

Amy Troiano

Bruce M. Whittier Middle School

Poland, ME

Amy Troiano is a middle-school teacher in Poland, Maine. She graduated from the University of Southern Maine with a degree in biology. She has been teaching three years and teaches both seventh and eighth graders.

Purpose of the Study

Last year, when I taught the energy standards to an eighth-grade class, I had students who provided all of the correct answers on a test about forms of energy and energy transformations. Later on in the year, when discussing the process of photosynthesis, I discovered that they did not have a conceptual understanding of energy transformation. As a brand-new teacher, this was an eye-opening experience for me. This year, I decided to dig deeper into my students' ideas and draw out those commonly held and deeply rooted ideas that are going to become barriers to their accommodation of these concepts.

I chose to research this topic because a conceptual understanding about energy is essential to my students' ability to comprehend the themes that are taught in seventh and eighth-grade science. Whether they are learning about states of matter or they are learning about photosynthesis and cellular respiration, they will need to know what role energy transfer and energy transformations play in these physical processes. In order to plan lessons and classroom experiences that will effectively increase my students' conceptual understanding, it is essential to uncover their current thinking. In doing this study, I hope to uncover the ideas that my students have about the nature of energy so that I may provide them with experiences that confront their ideas, causing them to adjust their beliefs to fit their observations, classroom experiences, and discoveries and, ultimately, leading them to conceptual change.

Research Questions

I conducted a Curriculum Topic Study (Keeley, 2005) to decide where to begin. By examining the standards and research on energy transformations, I can identify the commonly held ideas that middle-school students have about energy transformation, narrow my focus, and clarify for myself what I am hoping to uncover. Do my students think that energy is a substance that gets "used up?" Do my students think that energy is something that you get, use, and then it is just gone, as the research suggests?

Where and how do these ideas develop? In summary, my research questions are:

1. What are my students' ideas about energy that will affect their understanding of energy transformation?
2. Where and how do their ideas develop?

Curriculum Topic Study (CTS)

Background Research, "Energy Transformation" (p.213) (Keeley, 2005)

Clarification of the content from *Science for All Americans* (SFAA) and *Science Matters* (SM)

- Energy appears in many forms. (*SFAA*, *SM*)
- One form can change into another. (*SFAA*, *SM*)
- Most of what goes on in the universe involves one form of energy being transformed into another. (*SFAA*)
- Transformations of energy usually result in producing some energy in the form of heat, which leaks away. (*SFAA*)
- Almost all life on earth is ultimately maintained by transformations of energy from the sun. (*SFAA*)
- Each successive stage of the food web captures only a small fraction of the energy content of organisms it feeds on. (*SFAA*).
- There is an irreversible flow of energy from captured sunlight into dissipated heat. (*SFAA*).
- Energy is the ability to do work or the ability to exert a force. All forms of energy have one thing in common; they involve a system that is capable of exerting a force. (*SM*)
- Conservation of energy is one of the deepest and most widely applicable principles in the sciences. It is one of the great integrating principles of science. (*SM*)
- Energy that is transferred into heat energy, sound energy or vibrational energy is lost to the environment. (*SM*)
- The trophic level in the environment, consisting of plants and photosynthetic organisms, is the level that supplies the energy to all living things. (*SM*) There are two basic laws about energy: (1) Energy is conserved; (2) Energy always goes from more useful to less useful forms. (*SM*)

Student learning goals from *Benchmarks for Science Literacy* (BSL) and *National Science Education Standards* (NSES)

Grades 5-8

- Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. (*NSES*)
- Energy is transferred in many ways. (*NSES*)

Grades 6-8

- Energy cannot be created or destroyed, only changed from one form into another. (*BSL*)
- Most of what goes on everywhere involves some form of energy being transformed into another. (*BSL*)

Student learning goals from the *Maine Learning Results, 2007*

Grades 6-8

- Describe several different types of energy forms including heat energy, chemical energy, and mechanical energy.
- Use examples of energy transformations from one form to another to explain that energy cannot be created or destroyed.
- Describe how matter and energy change from one form to another in living things and in the physical environment.

Teaching considerations from *Benchmarks for Science Literacy* (BSL), *National Science Education Standards* (NSES), *and Atlas of Science Literacy, Volume 2* (ASL, 2)

- Students should be introduced to energy primarily through energy transformations. (*BSL*)
- Students may have some confusion at this age between energy and energy sources. It is important for them to learn that energy does not disappear, rather that it changes into other forms. (*BSL*)
- Quantitative ideas about energy transformations and conservation should wait until high school, focusing instead on a more semiquantitative idea that whenever some energy disappears from one place, some will show up in another. (*BSL*)
- Understanding of energy in grades 5-8 should build on K-4 experiences with light, heat, sound, electricity, magnetism, and the motion of objects. (*NSES*)
- Students at this age may view energy as a fuel or as something that gets used up. Students can improve their understanding of energy by experiencing many kinds of energy transfer. (*NSES*)
- Understanding of basic ideas about energy transformation is needed for making sense of a wide variety of phenomena and for making informed decisions involving energy use. (*ASL, 2*)
- Middle-school students should be able to describe different energy forms, transformation, and transfer. (*ASL, 2*)
- Students should know the definition of a system as "placing boundaries around collections of interrelated things," and since systems often interact with their environment, students should also know the importance of keeping track of what enters or leaves the system. (*ASL, 2*)

Cognitive research from *Benchmarks for Science Literacy*

- Students' meaning for energy, before and even after instruction, may be considerably different from the scientific meaning.
- Common conceptualizations about energy include: energy is associated only with animate objects; it is a causal agent stored in certain objects; it is linked with force and motion; and it is a fuel-like substance, ingredient, or product.
- To students, where energy comes from is much more evident than where it goes.
- Students tend to associate energy only with living things, in particular with growing, fitness, exercise, and food.
- Even as students develop skill in identifying different forms of energy, in most cases their descriptions of energy change focus only on forms that have perceivable effects.
- Students intuitively reason that energy is lost or "used up," rather than using conservation-of-energy ideas.
- Students tend to confuse energy and other concepts such as food, force, and temperature.

Cognitive research from *Making Sense of Secondary Science*

- Energy is seen as being:
  - --Associated only with animate objects;
  - --A causal agent stored in certain objects;
  - --Linked with force and movement;
  - --Fuel; and
  - --A fluid, an ingredient, or a product.

Classroom Research

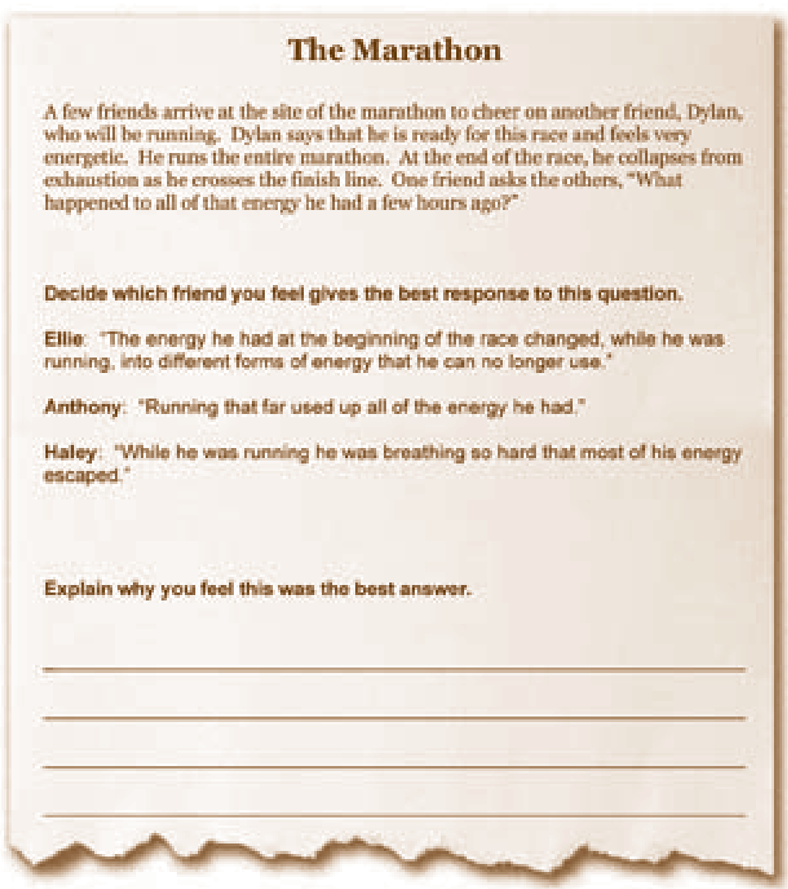
Classroom Context

The students in this study are seventh graders in Poland, Maine. A probe was also given to a group of seventh-grade students in Minot, Maine, which is one of three towns along with Poland and Mechanic Falls that make up School Union 29. Poland is a rural town in Androscoggin County. The size of the middle school is about 145 students, with 73 seventh graders.

Methodology and Data Collection

In order to collect data about my students' thoughts on energy, I administered a formative assessment probe. When I looked through books that I found to be indispensable for this kind of research, there were a few probes on energy, but I did not find one that targeted the commonly held idea that energy is a substance that gets "used up." I created my own probe using the "friendly talk" probe model (Keeley et.al., 2005).

The idea behind this probe is that students read "The Marathon" and, from three statements, choose the one with which they agree. Then students explain the reasoning behind their decision. At the time the probe was administered my students had no prior experiences in my classroom with the transformation of energy. I explained that the probe was for data collection purposes and would not be graded or count towards their grade. I explained that I was only interested in what they were thinking, so it could inform my planning for a unit on energy. I gave students about 15 minutes to complete the probe. From it, I gathered the Tier 1 responses (the multiple choice piece) and the Tier 2 responses (the explanations the students gave for their choices).



The Marathon

A few friends arrive at the site of the marathon to cheer on another friend, Dylan, who will be running. Dylan says that he is ready for this race and feels very energetic. He runs the entire marathon. At the end of the race, he collapses from exhaustion as he crosses the finish line. One friend asks the others, "What happened to all of that energy he had a few hours ago?"

Decide which friend you feel gives the best response to this question.

Ellie: "The energy he had at the beginning of the race changed, while he was running, into different forms of energy that he can no longer use."

Anthony: "Running that far used up all of the energy he had."

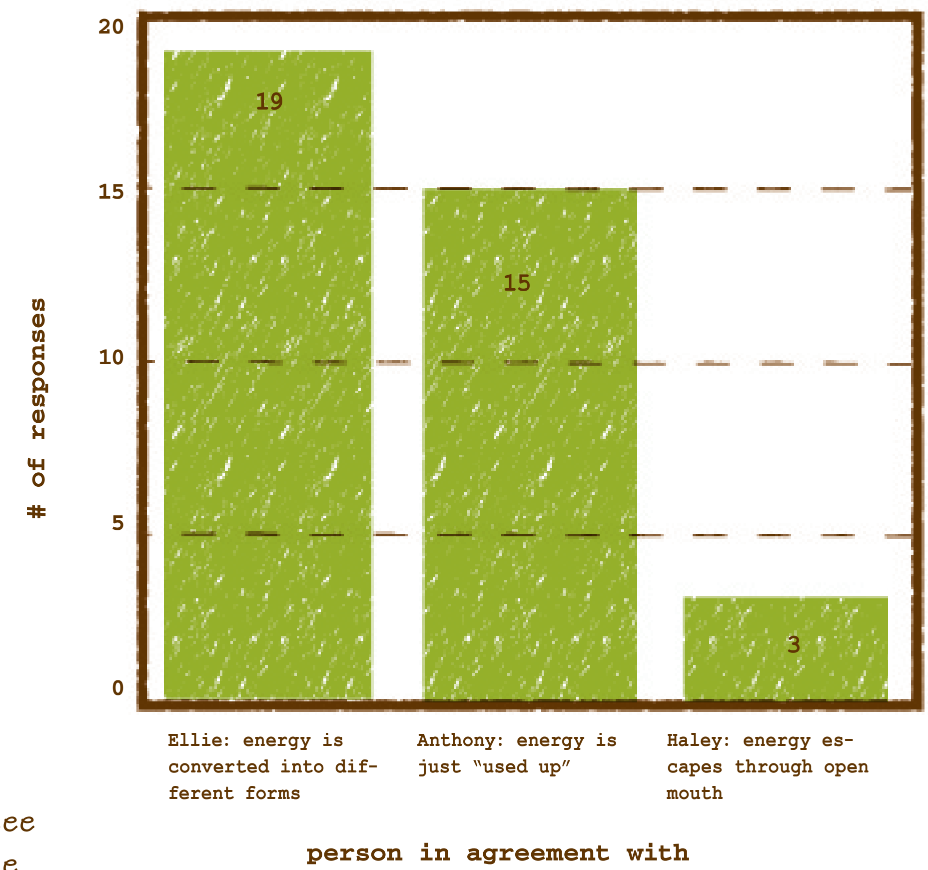
Haley: "While he was running he was breathing so hard that most of his energy escaped."

Explain why you feel this was the best answer.

In order to triangulate the data, I conducted interviews to examine my students' thoughts on energy. I interviewed two students selected at random. The interviews were held in my classroom after school. There were no other people in the room at the time of each interview, and they were conducted as friendly conversations while being recorded with a digital recorder. The students were told that they were being interviewed to examine their thoughts on energy and that they were not

Figure 1:

In order to visually represent my data and make the analysis easier, I created a bar graph (See Figure 1) to represent the Tier 1 responses. To do this, I simply counted up how many students agreed with Ellie, Anthony, or Haley.



I also created a graph (See Figure 2) to represent the Tier 2 responses. I looked for categories of reasoning, and there were into which most students' responses seemed to fall. One was the commonly held idea that energy just gets "used up" and the other was the scientifically sound idea that energy is being transformed into other forms of energy. I chose a pie chart to represent these responses, as it was easier to display clearly the percentages of students who fell into each category. Table 1 shows some of the responses the students gave as explanations for their reasoning.

Figure 2:

Tier 2 responses

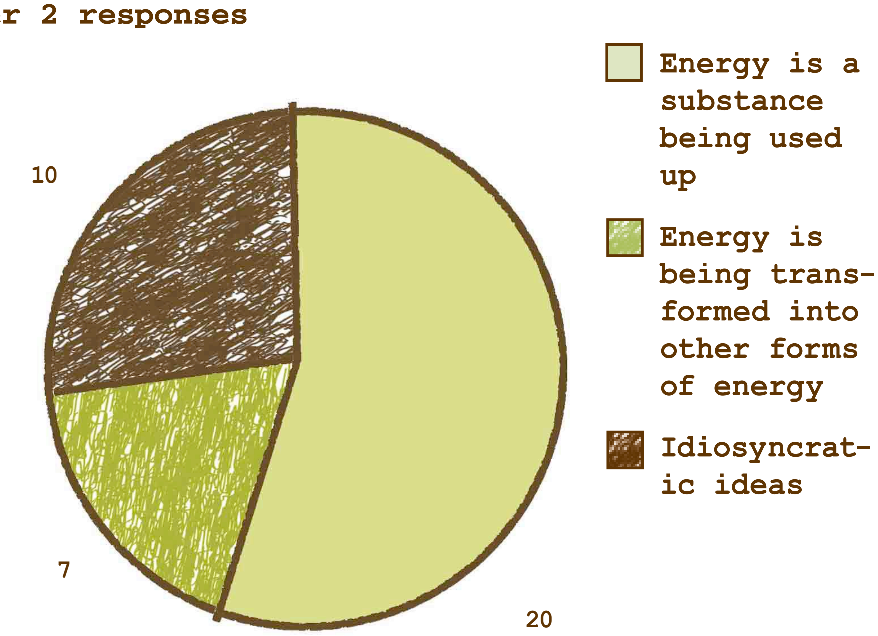


Table 1: Sample responses from each of the above categories

ENERGY IS A SUBSTANCE BEING USED UP	"I believe this because the more he ran the more energy he needed and he ran so much that any energy he had got used up and that's why he collapsed, after all his energy was gone."	"I think that as he ran all his energy was burnt up to fuel his muscles."
ENERGY IS BEING TRANSFORMED INTO OTHER FORMS OF ENERGY	"I think that Anthony had the best answer because you can eat good snacks before the race to give you energy, but when you run for a long time you get tired and you sweat, so you used some of that energy that you had earlier."	"Energy can change from AC to DC, or, if he was running for a long time, his food or water energy could have been depleted. Energy does come in different forms some of which I don't even know."
IDIOSYNCRATIC IDEAS	"I feel that Ellie had the best answer because she used detail in her response. Also, when a person or animal runs, then they do end up getting tired after a while."	"I agree with Anthony because he gave the simplest answer that made 100% sense. Because your energy doesn't escape, it gets used up and it doesn't change into different types because you would still use it."

going to be held accountable for their responses. They were aware that they were being recorded and that the interviews were for gathering data about their current understanding of energy.

Organization of Data and Findings

The interviews I conducted were recorded on a digital voice recorder. I transcribed these interviews to further analyze their content. (See Appendix A for transcripts of student interviews.)

As indicated in Figure 1, most students agreed with Ellie. Ellie did have the scientifically sound response that the energy Dylan had at the beginning of the race was converted into other forms of energy that he could no longer use. The interviews gave me different results. Not many of the students were able to articulate or seemed to have an understanding of the concept of energy transformation. In fact, many of the students who chose Ellie admitted to choosing her because they thought she sounded like she knew what she was talking about, but they really had no understanding of the concept of energy transformation. They believe it is a substance that one can just get and then use up. They do not think of energy as something that is conserved and transformed.

Data Analysis

It was surprising to me, based on the cognitive research, to discover how many students appeared to know that energy is converted to another form. I expected more students to choose Anthony, who said that the energy was simply "used up." It was not until I dug deeper into their thinking in their Tier 2 responses that I found what I had expected to find. Most of the students do hold the idea that energy is a substance that you "get" and then it's gone" or "used up," but where and how did this idea develop?

In summary, what are my students' ideas about energy that will affect their understanding of energy transformation? How did their ideas develop? These were the questions I posed as I began this project. The use of the formative assessment probe gave me the data I needed to be able to answer the first question. My students think that energy is a substance that gets used up and that energy is something that you get, use up, and then it's gone. What I found in my data correlates with what I discovered in the cognitive research. As *Benchmarks for Science Literacy* suggests, my students believe that energy is a fuel-like ingredient, product, or substance. They do intuitively think that energy is lost or "used up" rather than using conservation of energy concepts. Had I only given them the Tier 1 multiple choice component, I would not have found this out. It was in the tier 2 responses that I was better able to see what they were thinking. Many of them had the right response but the conceptual understanding wasn't evident in their reasoning. On the flip side, there were a few who had the incorrect choice, but, surprisingly, demonstrated some conceptual understanding in their reasoning. This leads me to believe that I need to revise the probe, so that the choices better represent the students' commonly held ideas. The students also, as is suggested in *Benchmarks for Science Literacy*, confuse energy with other concepts such as food and force.

It wasn't until I conducted the student interviews that I was able to find the answers to the remaining questions that I had. Where and how did their ideas develop and how will these ideas affect their ability to understand energy transformation? In both the formal recorded interviews that I conducted and informal conversations with students, I discovered that their ideas were coming from statements they were hearing from adults. For example, "You are too hyper, go outside and get rid of some of that energy." You just don't often hear an adult say to a child, "You seem to be fidgety. Why don't you go outside and run around so that you can convert some of that chemical energy into heat and kinetic energy?" Or, "Make sure you eat a good breakfast this morning so that your body can convert that chemical energy into kinetic energy and keep you going throughout the school day." It makes sense to me that they would have these preconceived notions of what energy is and how it works.

Another thing that was mentioned was the new trend among students, the energy drink. All the commercials and advertisements for these products seem to feed the misconception that they contain a fuel-like substance, so that when you run out of this substance, you just need to drink more of it. Students seem to believe that drinking the energy drinks is adding "fuel" that they will burn and use. They do not seem to understand where this energy is coming from. They never mention the sun as being a source of energy and certainly do not have the concept that this is where all their energy is coming from.

Significance

The significance of my findings reinforces for me the need to look out for and be sure to give students the opportunity to experience energy transformations, not just read about them. I need to diversify those experiences to include energy transformations in both living and non-living situations. In teaching photosynthesis or ecology, students should trace the path of energy and identify all of the conversions from one form to another. Also, when learning about simple machines or force and motion, we can do the same thing. I also envision them being able to track energy as they experience and learn about chemical reactions. I see a need to connect this very important concept in every unit that we do throughout the two years in middle-school science. This would give students many opportunities to experience energy transformations in several different scenarios and lead them to change their conceptual understandings of energy. This may lead to a better understanding of the conservation of energy ideas presented in high-school science. The possibilities are exciting to me as a teacher.

Reflection

This project turned out to be an incredibly rich and valuable professional development experience for me. I have discovered not only the value of formative assessment, but I have had a glimpse of the dangers of only asking kids to come up with the answers to the questions and not digging deeper into their thinking. I feel inspired and excited at the opportunities that are presented as a result of conducting student interviews. I would love to be able to have an "Interview Day," where I could ask a few volunteers to stay after and chat with me for five minutes about a specific topic in science and collect data from several students about a variety of topics that might help to inform planning. I feel a responsibility to my students to not just ask them the questions, but to dig deeper and find out what they are thinking so that I can provide them with experiences that will lead them back to the path of gaining conceptual understanding.

Being able to conduct this action research was a great experience because of the collaborative nature of going through it as a group. It was very important to have the set meeting days, the due dates, and the support of just knowing there were others out there doing the same things I was doing. I think without this collaboration, it might not have happened for me. Once the school year starts, it's easy to get lost in all that comes with teaching and advising students and lose sight of the clarity and plethora of ideas that come to us over those summer breaks. Having the accountability piece of doing this project as a group in place is what helped me to not give it up when the year got hectic, as it always does. I am so grateful to have had those days to focus on this work and to have had the knowledge that this group was out there for support. Without that I am not sure that I would have had this tremendous professional growth experience. It's important as educators that we continue to grow professionally, and I have found through this project that this is best accomplished through collaboration with others sharing a common goal.

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Appendix A *Student Interview Transcripts:*

Student 1:

Q: What is energy?
A: Energy is either an electronically or water-based substance that is also in lightning and runs electronics.
Q: You said that energy is in electronics. Where do you think the energy in your electronics is coming from?
A: Ummm…from a battery?
Q: Where is the energy in the battery? Can you describe this?
A: Well, I remember something from like way back in fourth grade. Something about like…the poles. How they have, like, energy connected to them, they have like this magnet-based thing. But, other than that, I really cannot remember.
Q: OK, what about other types of electronics? What about electronics that plug in to an outlet, where is their energy coming from?
I want to say that it is coming from the center of the Earth, but when I say that it sounds so wrong because I don't think it does, but yet I do, if that makes any sense.
Q: When you said that energy is electronical, can you give me an example of an electronic device that you think has energy?
A: An iPod.
Q: Where is the energy in your iPod?
A: It's in the computer chip that has the battery in it.
Q: Going back to this idea that energy is this "substance," what do you think the energy in the battery is? Where does it come from? Where does it go?
A: I want to say that it has something to do with matter, but I don't know what type. And…it's…I don't know…I really don't know.
Q: That's OK. Let's look at it a different way. What happens to the energy in the battery when you turn on the power on your iPod?
A: Well…it just runs out after a while.
Q: Where do you thunk it goes?
A: Hmmm…hmmm…(Giggles)…Where does it go? I don't know.
Q: Where do you think it went when it left the battery?
A: The air? Or maybe it just stayed right in the battery, but was no longer able to be used? (Possible reference to probe?) Or just unable to produce electronical things? (Giggle)
Q: What other examples can you think of where things use energy?
A: Well, we do.
Q: OK, so where do you think our energy comes from?
A: What we eat.
Q: What happens to the energy in us?
A: Well, I think…I think that air is energy, but I don't really know. When we breathe the air, it comes out as like, carbon dioxide, or myoxide, or however you pronounce it, and I think that there is energy in water because I know when lightning hits the lake and everything, and I'm not quite sure where that energy goes.

Student #2

Q: What is energy?

A: It's like when you eat food and then all of a sudden it breaks down and like turns into energy because like you need energy to like, stand up.

Q: What do you think it is about food breaking down that gives you energy?

A: Huh?

Q: Where do you think the energy was before the food broke down?

A: In the food. You eat it and you chew it and then the food turns into energy.

Q: Do you think that the energy was already in the food or do you think that the food turns into energy?

A: It was already there.

Q: OK, so the energy was already in the food. How did it get there? Where did it come from? What form is it in?

A: I think it is in the stuff that makes up the food. Like in mac and cheese the energy would be in like the cheese.

Q: So, what you are saying is that energy is in the stuff that makes up our food and when we eat it and it gets broken down we get our energy from that. What happens to the energy then?

A: I burn it off. Well, sometimes you can burn it off, but sometimes you need it so you can like, stay awake and like, to walk around.

Q: Can you describe what you mean when you say that you "burn it off?"

A: Yeah, like when you have too much energy someone will say like, "Go burn off some energy."

Q: What do you think they mean by that?

A: That you are too hyper. They will say, "Go outside and burn off some energy," so you run. You go outside and run around and then, like you're tired, so you don't have much energy.

Q: So, what you are saying is that energy is in the stuff that makes up our food and when we eat it and it gets broken down we get our energy from that. What happens to the energy then?

A: I burn it off. Well, sometimes you can burn it off, but sometimes you need it so you can like, stay awake and like, to walk around.

Q: Can you describe what you mean when you say that you "burn it off?"

A: Yeah, like when you have too much energy someone will say like, "Go burn off some energy."

Q: What do you think they mean by that?

A: That you are too hyper. They will say, "Go outside and burn off some energy," so you run. You go outside and run around and then, like you're tired, so you don't have much energy.

Q: Where did it go?

A: Ummm…like…I have no clue.

(Student 2 transcript continued)

Q: Is there anything else you associate with energy?
A: Sometimes it has to do with like electric stuff. Oh, wait, no that's electricity.
Q: Do you know of any examples of things that are electric that use energy?
A: My laptop?
Q: Where do you think your laptop's energy come from?
A: I think it comes from my charger and from the power lines.
Q: What about the energy in the power lines? Where do you think it comes from?
A: I am about to say something real weird…outer space?
Q: Let's go forward a little bit. After the energy comes through the power lines and goes into your laptop through the charger, what happens to it after a while?
A: The battery goes dead.
Q: What do you think this has to do with energy?
A: Nothing.

What's shaking? First-grade students reflect on the source of sound

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Jean Vadeboncoeur is a first-grade teacher in Auburn, Maine. She has 18 years teaching experience in grades K-2, reading recovery, music, and as a library specialist. She earned a BS in Music Education from Wilkes College and a BA in French from the University of Massachusetts. She holds a graduate certificate in Literacy from the University of Southern Maine and a MSEd from the University of New England. In addition to Maine, Jean has taught in Colorado, Massachusetts, and Pennsylvania.

Purpose of the Study

As first-grade students become familiar with the inquiry process through simple investigations, they need to develop an understanding of what constitutes "evidence" to support their conclusions. It is important to investigate whether the students are basing their decision- making on observable evidence or drawing their conclusions from other sources. Using an investigation of the relationship between vibration and sound, can first graders develop an understanding of what constitutes "evidence," and apply this understanding to their other investigations in the study of weather and plant experiments?

The world of sound is a fascinating and rich area of exploration for six year olds. They are naturally eager to immerse themselves in sound-producing activities and can readily compare, describe, and reflect upon sounds they hear. They experience sound both with and without the aid of other senses such as touch and sight. Unfortunately, sound exploration can leave them with some rather magical thinking because the evidence available to them, though aurally perceptible, is often invisible, fleeting, and difficult to explain. Collecting evidence to guide them toward the beginning concept of sound energy as a product of vibration is not always a straight path.

Unlike the act of observing a source of light, the eye does not always help the brain to clearly pinpoint the source of a sound. The sense of touch is only useful in the investigation if the sound-producing agent is within reach and safely accessible. Because of this, the science behind sound production and reception is not easily explained at an elementary level, and encouraging them to begin with an understanding of vibration as a source is an accessible starting point.

Research Questions

1. As they look for observable evidence in their explorations and experiences with sound, can students build a scientific habit of mind that will help them in other experiments?
2. By staging investigations that might seem to have "invisible" evidence, what explanations, prior knowledge, and experiences will the students use to produce reasonable explanations for the sounds they are hearing?
3. When faced with tangible evidence that helps them to understand the relationship of vibration to sound, will the students incorporate it into their understanding or chose to ignore it because their understanding is already rooted in invented explanations?

Curriculum Topic Study (CTS)

Background Research, "Sound" (p.224) (Keeley, 2005)

Clarification of the content from *Science for All Americans* (SFAA) and *Science Matters* (SM)

- The essence of science is validation by observation. Sooner or later, the validity of scientific claims is settled by referring to observations of phenomena. Hence, scientists concentrate on getting accurate data. To make their observations, scientists use their own senses and instruments that enhance those senses. (*SFAA*)
- Education should prepare people to read or listen to assertions critically, deciding what evidence to pay attention to and what to dismiss, and distinguishing careful arguments from shoddy ones. (*SFAA*)
- Students should learn to notice and be put on guard against a weak argument in which the conclusions do not follow logically from the evidence given. (*SFAA*)
- Some complicated motions can best be described by referring to the pattern of the motion such as sounds and waves. (*SFAA*)
- Vibration involves parts of a system moving back and forth in much the same place, so the motion can be summarized by how frequently it is repeated. (*SFAA*)
- Vibrations may set up a traveling disturbance that spreads away from its source. Sound is an example of this disturbance. It shows some behavior similar to surface waves on water. (*SFAA*)
- Sound is a special kind of kinetic energy caused by the regular patterns of atomic movement. We hear sounds because our eardrums vibrate in response to moving air particles. (*SM*)

Student learning goals from *Benchmarks for Science Literacy (BSL)* and *National Science Education Standards (NSES)*

- People can often learn about things around them by just observing those things carefully, but sometimes they can learn more by doing something to the things and noting what happens. (*BSL* Grades K-2)
- Describing things as accurately as possible is important in science because it enables people to compare their observations with those of others. (*BSL* Grades K-2)
- Describe and compare things in terms of number, shape, texture, size, weight, color, and motion. (*BSL* Grades K-2)
- Ask "How do you know?" in appropriate situations and attempt reasonable answers when others ask them the same question. (*BSL* Grades K-2)
- Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge). Good explanations are based on evidence from investigations. (*NSES* Grades K-4)
- Things move in many different ways, such as straight, zigzag, round and round, back and forth, and fast and slow. (*BSL* Grades K-2)

- Things that make sound vibrate. (*BSL* Grades K-2)
- Sound is produced by vibrating objects. The pitch of the sound can be varied by changing the rate of vibration. (*NSES* Grades K-4)

Student learning goals from *Maine Learning Results, 2007*
Grades Pre-K-2

- Ask questions and make observations about objects, organisms, and events in the environment.
- Know what constitutes evidence used for constructing a reasonable explanation.
- Give examples of things that make sounds by vibrating.

Teaching considerations from *Benchmarks for Science Literacy (BSL)*, *National Science Education Standards (NSES)*, and *Making Sense of Secondary Science* (*MSSS*)

- Children's investigations should be fun and exciting and provide them with an opportunity to tell others what they see, think, and wonder about. They should have lots of time to compare their observations with those of others. (*BLS*)
- Children at this level should not be expected to come up with scientifically accurate explanations for their observations. (*BLS*)
- Students will achieve understanding in different ways and at different depths as they answer questions about the natural world. (*NSES*)
- Children's experiences will provide an opportunity to be introduced to vibrations as a phenomenon rather than a theory. (*BSL*)
- Children can feel the vibrations on instruments as they hear the sounds. (*BSL*)
- Because children do not have a generalized theory of sound production transferable across contexts, teachers should plan to give students experiences of sound production in less obvious contexts where the vibrations are more clear. (*MSSS*)
- It may be useful to experiment with applying vibration ideas developed in obvious contexts to less obvious contexts with a view to developing a generalized theory. (*MSSS*)

Cognitive research from *Benchmarks for Science Literacy* (*BSL*) and *Making Sense of Secondary Science* (*MSSS*)

- Interviews have revealed that students usually have ideas about how the world works even before instruction. (*BSL*)
- Some learning difficulties students have may not be modifiable at all until brain maturation allows them to use higher levels of abstract thinking, whereas some current learning difficulties might be readily ameliorated by improved resources. (*BSL*)
- The relationship between evidence and theory is not only an important facet of the nature of science, it is also a critical issue in children's learning of science. (*MSSS*)
- When children look at phenomena, the sense that is made will be influenced by their pre-existing ideas. Children's ideas about natural phenomena play an organizational role in their construction of new knowledge and their interpretation of new information. (*MSSS*)
- Many children's explanations of how sounds are produced are in terms of the physical properties of the materials producing the sound. (*MSSS*)
- Pupils often commented upon the action used to generate the sound and attempted to suggest a mechanism for sound production, those proposed for a rubber band being very different from those proposed for the drum. However there were three main groups of explanations:

1. Those which involved the physical attributes of the object (for example the tautness of a drum);
2. Those referring to the force needed to produce the sound (for example the human action of beating the drum); and
3. Those which involved vibration. (*MSSS*)

- Movement or vibration of the sound source becomes more common with increasing age. (*MSSS*)

Classroom Research

Classroom Context

This research was conducted with a first-grade population in an urban school in central Maine. This is a Title I school. Roughly 70 percent of my first-grade classroom of 12 boys and six girls receive free or reduced lunch. Although the class totals 18 students, only 14 were present for the formally administered probe. These children have had the benefit of weekly instruction from our music specialist and have recently attended a school assembly featuring African drumming.

Methodology and Data Collection

Earlier in the year, my class engaged in a variety of sound explorations designed to help them begin building the vocabulary necessary to describe sound phenomena. Some of our explorations included the following activities:

1. Using rhythm instruments to accompany our singing.
2. Exploring rhythm instruments on their own without any specific instructions.
3. Working with a partner to compare mystery sounds made by materials hidden in covered cups and attempting to match up pairs of like sounds.
4. With an assortment of musical instruments and rhythm makers accessible for exploration, brainstorming how the sound was generated and reached their ears. (I did not mention or reinforce the concept of vibration but simply encouraged conversation about all aspects of the sounds they were making and hearing.)

An initial probe was given that asked the children to explore sound as it was conducted through various materials. Two dice were dropped on four materials: a carpet square, folded towel, cookie sheet, and tabletop. The purpose of this activity was to generate more discussion and discover what sort of "sound" vocabulary they used as they sought to identify the loudest and softest mediums for the conduction of sound. Throughout these preliminary experiences, I did not engage in any instruction about sound or its production or transference. Children were asked to compare, discuss, speculate, and test.

Then students were introduced to a variety of sound producers through a "sound bingo" game that used a recording of assorted familiar sounds, each illustrated by a picture. They included nature sounds (seashore, waterfall), animal sounds (cows, pigs, lion, frogs, dolphins, and elephants), human sounds (children clapping, laughing, and playing), musical sounds (violin, gong, tin whistle, drums, and band), and man-made sounds (traffic, train, fire engine, eating chips, and sawing wood).

After listening to the sounds and discussing them, children played sound bingo, connecting the sounds to the colored pictures. When it seemed that they were all familiar with the sounds and time had been given to discuss their own experiences with some of these sounds, individuals were invited to sort the colored picture cards into groups. This was an adaptation of the probe "Making Sounds" (Keeley et.al., 2005), which directed children to check the names on a list of sound-producing agents if they contained a vibration. I felt this would be too difficult for first graders, so I began with a card sort format. The first three students were given the following instructions:

"Can you put these cards into groups according to the sound they make? If you think their sounds are made the same or similar ways, group them together. You can have as many groups as you need."

The children were energetically sorting both randomly (it seemed) and according to sound similarities. One student placed water sounds together, placed animal sounds together, and decided that a train sound was similar to crunching chips. (See Appendix A.) The next two seemed to approach the task very randomly, changing the groups repeatedly. One of these students labeled a distinct group as "fun" sounds (laughing, clapping, ball game, sounds of playing). When it became obvious that the children did not perceive whether the sounds had vibrating parts or not, I decided to guide them more, using the specific language of the directions on the probe while still using a card sort format in lieu of a checklist.

When the next two students were given more direction and asked to sort the pictures into two groups, sounds made by a vibration and sounds made another way, they very laboriously examined each picture and had trouble making up their minds, only sorting a few pictures of each. Time did not allow them to finish sorting. (They had spent 15 minutes.)

In order to gather more data in a timely manner and because the children seemed to be struggling with the task, I returned to the original probe format of a checklist. To accommodate the difficulty that first graders would have in reading the list of sound-producing agents accurately and writing comments to explain their thinking, I adapted the probe. Using sounds from the bingo game they were now familiar with, I created a two-page checklist using 18 of the pictures. I played the recorded sounds for them, and they were asked to place an *X* beside the pictures showing sounds that were being made by a vibration. Then I interviewed individuals and asked them to explain some of their choices. (See Appendix B and C.)

Organization of Data and Findings

Figure 1 shows the responses of 14 first graders to the sound checklist. This data also is incorporated into Table 1, which organizes the students' responses during brainstorming sessions, interviews, and group discussions into the categories of understanding suggested by the research of Watt and Russell in *Making Sense of Secondary Science*. The responses to the checklist probe are listed under Tier I. Tier II includes the explanations that students gave for checking the sound pictures as having a vibration.

Students chose the sound that they believed to be produced by some sort of vibration

Figure 1: Sounds from Vibration

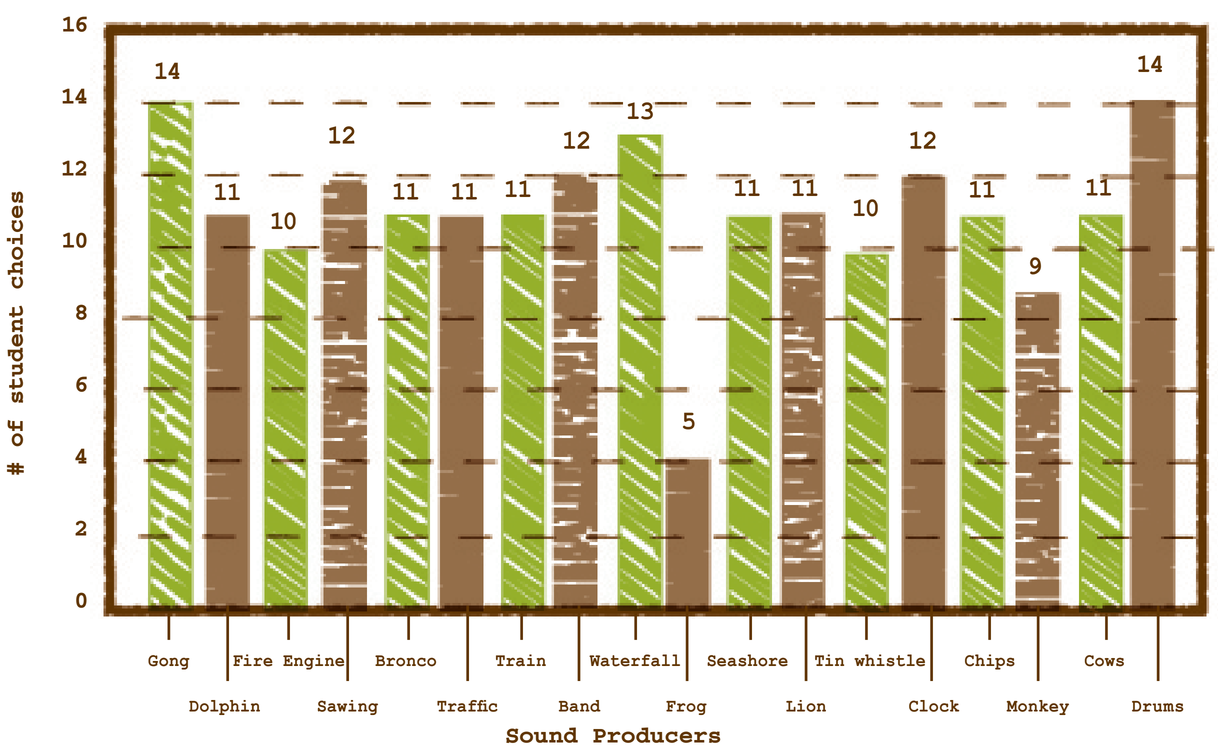

Table 1:

Table 1 also includes comments made by students when I extended my questions to include sound-producing objects that they handled in their explorations or were able to observe at that very moment. The sound agent that the student is referring to is in parentheses.

Students' preconceptions about the sources of sound Their responses to the question "What makes the sound?"				
	Physical Attributes	**Force**	**Vibration**	**Unexplained**
Preliminary Discussions	(tapping on table) It's hollow in there and it makes the sound go around inside	(table, drum) You bang it because you hit it medium	(tapping) Sound waves (guitar) I can see it moving and it keeps on getting smaller (the vibration on the string decreasing) until it stops.	(rhythm instruments) Sound effects (soft sound tapping) Because my hand is bumpy
Preliminary Group Probe Dropped Dice	(dice on table) Table is hard There's hard stuff under this Table is soft (dice on towel) Towel is soft and has holes in it Soft because the towel doesn't have a hard inside Sounds softer because the dice don't weigh as much		(dice on table, carpet) Table doesn't move much Carpet moves (dice on cookie sheet) It vibrates more than the table or carpet	(dice on cookie sheet) Makes your ears feel funny
Tier I Probe "Making Sound"			(students checked the sounds that they felt were made by a vibration See Figure 1) Note: All students checked the gong and the drum	The following items were indicated as "not vibrating" by the number of students noted frog – 9 students monkey – 5 students fire engine, tin whistle – 4 students dolphin, bronco, traffic, train, seashore, lion, eating chips, cows – 3 students sawing wood, clock – 2 students waterfall – 1 student

Table 2:

Students' preconceptions about the sources of sound Their responses to the question "What makes the sound?"				
	Physical Attributes	**Force**	**Vibration**	**Unexplained**
Tier II Interviews	(horse) It's running fast (baseball) When you hit the ball really hard (tin whistle) I think there's a little ball in there It's closed and there's holes in it and you blow in it You've got to blow into something and it has these little holes if you want it to make a sound It would be blowing out from the back that releases the sound (drums) It's coming out from the bottom (saw) The points that are on it and the wood touching the points	(gong) When people hit it The kid hit the gong (lion) The sound is really loud, so loud half of the woods can hear it (table) If they were vibrating against a table, then you would hear it (bat) You hit it really hard	(horse hoof beats) The legs are shaking (gong) It vibrates (violin) When you use a stick on it, the strings move (rooster, pig, dolphin) His mouth moves His mouth is vibrating (popcorn) The kernels bang around in there. (lion) his neck is vibrating (fire engine) The whole thing is shaking because of the engine. (train whistle) It's vibrating because someone is pulling it. (dolphin) The throat might be vibrating a little (seashore) All of the water is going up and down, it's kind of vibrating. When you walk in the water it kind of vibrates. (drum) The top would be vibrating and it sends it down to the bottom to let it go. (bat) If you hit the ball too hard, sometimes the bat shakes a little.	(traffic) sound and smoke (frog, train, ocean) student makes the sound as an explanation of its source (fire engine) You press the button and the siren goes on. The water goes "SHHush" (train) Well, it's the track as the train goes over it…or the train. (tin whistle) Because it's only this far from your mouth, it comes back and goes into your ear. (pig) It's like when you talk, and your voice comes out.

Data Analysis

- When interacting with sound-producing objects, students spent a lot of time talking about the kinds of sounds that were made and their volume, pitch, and appeal. They used comparative language such as "It sounds like a bell" and "It's loud" (louder, soft, softer, high, and kind of low).
- Some students' responses included the awareness of a vibrating object, especially when they had a memory or close-at-hand model of a vibrating part that they could view.
- Some students used technical language like "sound effects" and "sound waves" but could not elaborate further.
- Their descriptions of sound fell generally into the three categories of understanding as noted by Watt and Russell in *Making Sense of Secondary Science*: those which involved the physical attributes of the object (for example, the hollowness of a table), those referring to the force needed to produce the sound (for example, the human action of beating the drum), and those which involved vibration. A fourth category, unexplained phenomena, was noted. These explanations did not seem to be grounded in scientific thinking.

- When students were asked to describe what was making a particular sound, they often simply imitated the sound or could not put a thought into words.
- When given the checklist probe, every student responded that the gong and the drum produced a sound by vibration. Most of the other sounds were checked by at least 11 students, except for the frog, which was checked by only five students.
- When questioned about an object with a less obvious source of sound (the tin whistle or recorder), students described moving air as being a component that produced the sound but could not connect this to the idea of vibration. Their attention was drawn to the physical attributes of the whistle (recorder): its holes, the trapped air, and the idea of air being "released."
- Although students checked many of the sound options, they were sometimes unclear about what constituted the vibrating part of the sound-producing agent.

Throughout the sound investigations, probe, and discussions with students, I noticed that most of the students were aware of the phenomenon of vibration in a general sense, even though they did not always use that word. To them, sound was a moving entity, it started somewhere because something happened, and then "traveled" or "was released," finally reaching their ears. They readily identified certain moving things that produced a sound such as a gong, drums, and a violin string, but their descriptions of a vibrating source understandably became vaguer as the source was less observable. This corresponded to research which noted that young children require more experience with vibrating objects in obvious contexts before they can generalize this concept to less obvious contexts. As noted in my research, children of this age cannot be expected to produce scientifically accurate descriptions of phenomena. I found this to be true but also found that children searched for an explanation and often provided one, even when evidence was unobservable. Some of them seemed to expect evidence to appear, because at other times it was available to their senses. In the probe checklist, children seemed to choose many of the sounds more from their own generalization of "it must be so" than any hard evidence. In the interviews, when questioning revealed that a description of observable evidence was only available to them for some of the sound producers, they sometimes seemed willing to accept a non-scientific, simplistic, or incorrect idea rather than search for a physical explanation. In other words, they seemed comfortable with allowing conflicting ideas to coexist. Even after much discussion and guiding questions that pointed them toward a contradiction in their thinking, many of my students maintained the stance that some sounds were produced by vibration and some were released or simply occurred in another way.

Significance

Returning to my original questions, I found that, when faced with observable evidence (gong, drum, vibrating string), children were able to make a solid connection between sound and vibration. Many already understood this explanation and had prior experience to support their thinking. As they reflected upon the sound-producing agents with less obvious vibrations, they reverted to a generalization and assumed that the sound was produced in the same way, but they just couldn't see it. They hinted at some "point of contact" (saw in wood, train wheels on a track) or "force" (lion's roar) that created the sound, even though they couldn't see anything vibrating.

In the individual interviews, when I challenged an explanation that they gave and pointed out that I could move my hand back and forth or blow air from my nose without making a sound, it did not seem to disturb their thinking. They intuitively added something else that I should do, which in fact would then have increased the vibration enough to cause an audible sound. For example, instead of just waving my hands in the air, I should hit the table (force and point of contact). Blowing air softly from my nose wouldn't work, I needed a long nose like the elephant (vibrating column of air). They were intuitively adding an action that they knew from experience would in fact produce a sound. When I specifically asked why certain less obvious sound producers made a sound, many students simply said, "I don't know" and did not pose any questions in response. At this age level, it did not seem to bother them that some sounds were understandable and others weren't. This corresponded to the research by Asoko (Driver, 1994) which found that "reference to movement or vibration of the sound source became more common with increasing age."

In order to address some of the preconceptions that I observed and push children to ground their thinking in a more scientific examination of evidence, it will be necessary to structure experiences that provide students with a variety of direct experiences with sound-producing objects. Activities involving many mediums, sound conductors, and ways to manipulate sound will provide more tangible evidence to support students' thinking. As children are able to start and stop sound on their own and modulate and manipulate it, "these ideas may lead to the scientific view of sounds as vibrations traveling through air and other materials" (Driver, 1994).

Reflection

This project underlined for me that the science of sound is an extremely motivating area of investigation for first graders and a perfect arena for independent exploration. However, because of the fleeting nature of sound observations and the tendency among this age group to allow conflicting ideas to coexist in their thinking, it is necessary to provide real-world investigation. Although they were intrigued with recordings of a variety of sounds and were able to connect some of these sounds to prior knowledge, the activities surrounding recorded sounds only served to reveal the limits of their understanding. Confining my investigation of sound in the classroom to an activity such as sound bingo would deprive students of the opportunity to stretch their thinking into the areas of sound production, transmission, volume, and pitch. My classroom research showed me that students were eager to discuss, explore, and search for evidence in the world of sound, and it was difficult to hold them back. The free exploration periods quickly became overwhelming! However, they soon reached the limit of their sound vocabulary to describe what they understood.

Although the introductory sound activities were very motivating and the children were eager to produce sounds, they did not pose any questions unless materials were in their hands. Listening to sounds and reflecting on them revealed the limits of their understanding but did not push them to change any of their ideas. I was struck by the contrast between the Tier I and Tier II information I gathered from the probe. Had I not interviewed the students after administering the checklist probe, I might have assumed they knew a sufficient amount about sound. They all seemed to know that sound was made by vibration. But after interviewing them, I determined that, in fact, this was an impression that some of them generalized from the limited visual evidence they had gathered. They needed to have more evidence to extend their thinking.

In order to use this topic effectively in my classroom, it will be necessary for me to provide developmentally appropriate challenges that are structured but allow the students time for independent exploration. Because of the fleeting nature of the evidence they will be collecting and the difficulty of writing and drawing sound observations, I may supplement their use of science notebooks with a recording of what they are actually doing. Let the vibrating begin!

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Appendix A

Matt is sorting 18 pictures that show sound producing things. He has heard these sounds played in a sound bingo game and through other listening activities. He was asked to think about how these sounds were made and then sort the pictures into piles. (T = teacher and M = Matt)

M: (Looking at the gong.) That one is vibrating a lot, the gong, vibrating a lot
Sometimes drums…This is a ship.
These are all from farms. (Looking at the pictures of animals [sheep, cows].)

T: How do they make those farm sounds, the animals, how do they make those sounds?

M: I don't know. This is the instruments, the instrument pile.

T: How does that sound get made, can you imagine?

M: I don't know. I'm going to change this to the animal pile. This is the water pile, so the ship would be connected to that, too. I'll change the ship to that pile. This is the vibrating thing, I'll put this here. The motorcycle. This is music. That's a big saw.

T: How does that make a sound?

M: I don't know.

T: Is he doing something with it that makes a sound?

M: Pushing it against the wood. Clock kind of vibrates.

T: Is he doing something to make that sound?

M: I don't know. (He places sawing wood and the ship in the same pile.)

T: So the ship and the saw kind of sound the same?

M: (No response, he keeps sorting. Teacher points to a pile of cards he has put together.)

T: Do the sounds sound alike?

M: Well no, this is food and that's food. Food, so I'll put that together.

T: Is the sound the same?

M: This is the noise group. Drums, music, and having fun. (More sorting.)

T: OK, Matt, go through these groups and tell me what you call each of them.

M: (He points to four groups.) Noise and water… Animals … This is eating… Musical instruments.

Appendix B

Cameron and I reviewed his checklist and discussed the items that he marked as making a sound from a vibrating. (T = teacher and C = Cameron)

T: Is that (interview sheet) yours? OK, it looks like you checked a lot of these boxes here.

C: I checked every one!

T: Yes, you checked every single one. So, when I asked kids to put an X next to pictures of things that vibrate when they make a sound, you were thinking that all of these things have something in them that is vibrating?

C: Something.

T: So let's talk about some of them, what about…well, you pick one and tell me what you think is vibrating, shaking.

C: Well, like the trains.

T: Yes, what's happening there when a train makes a sound?

C: Well, it's either the track when the train is going over it, that makes it go K-K-K-K-K like that, or it's the train.

T: Well, how about the fire engine?

C: The fire engine! Well, the whole thing is shaking because of the engine.

T: OK.

C: So you hear that…so…um.

T: Well, what about when you hear that whistle?

C: The tin whistle. (That was another sound producer pictured.)

T: No, the whistle on the train.

C: Oh it's vibrating, how because someone is pulling it like this, that's what I mean by the train whistle vibrating.

T: How about the traffic, what do you think is vibrating there?

C: I don't know. (Long pause.)

T: You're not sure but you think something may be vibrating there?

C: Yes.

T: How about this dolphin?

C: I told you, I think his throat might be vibrating a little to make the sound.

T: How about the seashore?

C: The seashore! All of the water is going up and down, so it's vibrating, you know, like your computer when it's going like this, that's what I mean when it's vibrating. (He grabs the screen of the laptop and starts waving it back and forth.)

T: OK, so if I take my hands like this and they go up and down, are they vibrating?

C: Yes.

T: Do they make a sound?

C: No.

T: I wonder why?

C: Because if they were vibrating, like down like this. (He pats them against the table.)

T: You mean against the table?

(student transcript continued)

C: Yeah, something like this. (He bangs the table.) Then they'd make a sound.

(student transcript continued)

T: Well how about the frog?

C: The frog…throat, something in the throat.

T: OK. How about the drums?

C: Oh, the drums! It's coming out from the bottom and . . . the top is vibrating a little so when you hit it, like can I show you an example? (He reaches into the instrument box and takes out a tambourine with a drum head.) If this was the drum and this was the stick, can you hold this please, and I went to hit it, then pretty much the top would be vibrating and it sends it down to the bottom to let it go.

T: And what does it send?

C: A sound wave.

T: Try this recorder, does it make a sound?

C: Yes!

T: How come?

C: Because once you do it, once you blow into it. (Toot.) OK, like, if I blow into it and try to make a sound like this, then it would be blowing out from the back that releases the sound.

T: It releases the sound.

T: What is shaking?

C: Do you see that little hole in the back?

T: Yes, I do.

C: (Pause, he's thinking.)

T: So, Cameron, what is shaking if you play this recorder or the man plays the tin whistle? What is the vibrating part?

C: I don't know.

T: But you heard a sound, right?

C: Yeah.

T: But how did it get up to your ear?

C: Well, because you keep on, if you're going like this, wait I got to get it. (He plays.) You can hear it right. Well, because it's only this far from your mouth and it just comes back and goes right into your ear.

T: What is going into your ear?

C: The sound wave.

T: I wonder where it came from?

C: This. (He shows me the hole in the recorder again.)

T: I wonder—you didn't hit it or shake it?

C: No, I went like that. (He blows.) Then it would make a sound wave either from these (the holes) or it would either come from this or the back.

T: Let's look at this tone bell. (I ring it with a stick.) What is vibrating on this?

C: Well, this is actually vibrating on the top. The whole thing when you hit it.

T: Let's hit it again. What do you notice?

C: I hit it like this and it goes down. (He keeps banging.) I noticed that this piece of metal keeps, it keeps, it goes like…(He shakes his hand.) And once you touch it softly you can stop the shaking. You can actually feel it vibrating but just a little cause it stops.

Appendix C

After class responded to the sound checklist probe, I seated them in a circle and passed back their checklists. We discussed the choices they had made. (T = teacher and S = students' responses)

T: OK, Cassandra, which picture would you like to talk about?
S: The horse.
T: You put an X on the picture of the Bronco, what is it shaking on the horse that makes the sound?
S: Because it's running fast, when it is running fast.
T: And what part of it is shaking to make the sound?
S: His legs.
T: Who else wants to pick a picture and tell me about it? Jaryn?
S: The baseball game.
T: Did you put on X on baseball game?
S: Yes.
T: What is vibrating that makes all of that sound at the baseball game?
S: The bat.
T: Did you hear the bat do something? What did it do?
S: It hit the ball, and sometimes if you hit it too hard, the bat shakes a little.
T: And is that what makes the sound?
S: Yes.
S: (Madison) The dolphin.
T: OK, tell me about the dolphin when it makes a sound.
S: When it does its sound its throat is vibrating.
T: Oh, when it does its sound its throat is vibrating.
S: Yes!
T: Alexander, what picture do you want to tell me about?
S: The gong.
T: So tell me about the gong.
S: When people hit it, it vibrates.
T: So the gong vibrates. It shakes?
S: Yes.
T: So how does that gong sound get up to your ears?
S: You bang it with something else, and it shakes.
T: And then how does the sound get up to your ears? How do you hear it?
S: Well, then the vibration gets up to your ears.
T: OK, great. These are great ideas. OK, Jayde, what picture would you like to talk about?
S: The dolphin,
T: OK, tell me about the dolphin's sound.
S: (Pause) It vibrates and shakes.
T: Who can tell me about a picture, that when you look at it you would know something is shaking to make the sound? Sebastian. OK, you say that when you look at the violin you can see something shaking to make the sound. What part?
S: When you use a stick on it, the strings move.
T: OK, Domanic, what's your choice?

(student transcript continued)

S: The baseball game.

T: OK, what do you hear in a baseball game?

S: When you hit the ball, and when he hits the ball really hard it goes out of the field.

T: OK, he hits the ball really hard.

S: (Jayde) The man sawing, 'cause when he saws it kind of vibrates.

T: What part of that is vibrating?

S: The points that are on it and the wood that is sawing with the . . . (Long pause.)

T: So, when the points and the wood get together, you're telling me that makes a sound.

S: (Pause.)

T: And it's vibrating a little bit?

S: Yes, the points are.

T: OK, who else has been thinking?

S: (Gabriel) When the kid hit the gong.

T: And what was vibrating?

S: The whole gong.

T: OK, I'm going to pick a picture this time, and I want you to tell me about the sound. How about the fire engine?

S: (Matthew) It goes whhhoo whoooooo. (Imitates sound.)

T: Matthew did you put an X next to the fire engine?

S: Yes.

T: What do you think is shaking when you hear a fire engine?

S: When there's a fire, they come really quickly and they put out the fire, and they move the water and they do this . . . (Now he makes the water sound.)

T: OK, what makes the sound? On the fire engine . . .

S: (He makes another water shushing sound)

T: OK, the water makes a sound. But what about that fire engine coming down the street? What makes a sound? (The example did not use a water sound, just the fire engine siren.)

S: Well, you turn the wheel, and it moves.

T: It does, the fire engine moves, and does it make a sound?

S: Yeah.

T: How come?

S: Well when they push a button, it starts to go rrraaarrraa. (Makes a siren noise.)

T: So they push a button and the siren comes on?

S: (Matt A.) And then you have to move to the side.

T: OK. Let's pick another sound. How about the rooster? Tell me what's vibrating on a rooster? Matt S.

S: Um, its body. (He makes the rooster sound . . . then everyone makes it.)

S: (Jaryn) So his mouth is vibrating.

T: OK, let's pick one that no one has picked yet. Ben.

S: Well the pig, like when it talks . . . it like . . . wow . . . (Big pause.)

T: You take your time, think about it.

S: Well, it's like when your voice comes out, and his mouth moves.

T: OK, his mouth is moving, but what is shaking when he's making his sound?

S: His mouth. (He seems a little unsatisfied with his final idea.)

(student transcript continued)

T: You think his mouth is shaking? OK, who can tell me about the popcorn popping? If you put an X next to the popcorn popping, raise your hand. Would you tell me why you put an X there? What is shaking when you hear the popcorn pop?

S: (Alexander) Well, the popcorn goes like this (He waves his hands.)

T: OK, it moves around and it makes noise. All right, now if I move my hands around like this, do you hear them?

S: No.

T: Well, how come the popcorn is a sound we can hear?

S: Well, 'cause the kernels bang around, they're popping against the top.

T: So those kernels are banging around. OK, one that was a little mysterious to me was that frog. About ten people did not check the frog. Who can tell me why they did not put an X by the frog?

S: (Kaelee) Because I couldn't hear it breathing. And you said, "Don't check it," if there wasn't something moving in it and it probably wasn't moving.

S: (Sebastian) What about the lion?

T: What is vibrating?

S: His neck.

T: OK what part of his neck is vibrating?

S: The middle.

T: OK, so when his neck vibrates, how do you get to hear his voice?

S: Because it goes up to his mouth.

T: OK, but how does it get over to me? I don't want to get close to a lion's mouth. That would be dangerous. How does that sound get to me? Can someone help Sebastian? How does that sound get all the way over to me?

S: (Lucas) Well, it's really loud, so loud that half of the woods can hear it. So because it's loud, half of the woods can hear it.

T: Well how does he make it so loud?

S: Cause when his voice vibrates it gets louder and louder.

T: One more question. A lot of you marked the man blowing the tin whistle. When the man is blowing the tin whistle, what do you think is vibrating? (No response.) When the tin whistle is making a sound . . .

S: (Matt S.) Well, when you whistle like this (he whistles) it's pretty much the same sound as when you use the tin whistle.

T: OK. I have something like a tin whistle here. (I take out a recorder). Let's listen.

S: (Matt) I know there's a little ball in it.

T: OK, you think there is a ball in it. I know some whistles do have a ball. (Matt looks at the recorder.)

S: This one doesn't have a ball. (Pause.) No, you have to blow it,

T: What is shaking?

S: Well, your breath, cause it's closed, and there's holes in it and that's how it does it.

T: OK, Matt has a good idea. Does anyone else have an idea? Jacob.

S: Well, when the elephant makes his sound when he blows his whistle.

T: Does the elephant have a whistle?

S: No, well it's their nose . . . it probably vibrates, well when he blows out of nose.

T: (I try making a sound blowing out of my nose. Everyone laughs.)

S: No, Ms. V you have to have a big nose like an elephant.

Electrical Circuits: How do students learn best?

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Purpose of the Study

While framing the context of the action research project, our facilitator showed us an Annenberg video in which a student describes his own preconceptions about light and vision. In deciding on a topic of study for this school year, I reflected upon electrical circuits as a topic in which students seem to have a similar style of explaining how they worked. Students seem to have varied pieces of information regarding the workings of electrical circuits and, when faced with the holes in their information, fill them in with a variety of solutions that often take on magical qualities. Students use electricity all the time, but struggle to understand how it functions. When faced with new information about electricity, it often seems as outlandish as the ideas they have created, making acquiring and retaining the new knowledge more difficult. The action research I undertook had the goal of creating a format in which students could face their own preconceived notions of electrical circuits, be aware of how their ideas don't jibe, and could correct their understandings.

Research Questions

1. What do the standards and research say about teaching students about current electricity?
2. What do my students have as background knowledge or preconceived ideas about current electricity?
3. What are the experiences that students have that contribute to their preconceived ideas about current electricity?
4. How can we design instruction that best meets the needs of these students based on the answers derived from the questions above?

Curriculum Topic Study (CTS)

Background Research, "Electrical Charge and Energy" (p.208) (Keeley, 2005)

Clarification of content from *Science for All Americans* (SFAA) and *Science Matters* (SM)

- Current can travel through wires where the wire is a good conductor and the covering of the wire is a good insulator. Currents produce magnetic fields, as in the earth's core and electric motors. (*SFAA*)
- Electrical current is measured using the amp or ampere. This is the amount of charge passing by a certain point. Voltage measures the power or pressure of the electricity or the electron potential. Higher potential, for devices that require a lot of power, are rated for higher voltage. (*SM*)

Student learning goals from *Benchmarks for Science Literacy* (BSL), *National Science Education Standards* (NSES) and *Atlas of Science Literacy, Vol. 2* (ASL, 2)

- Electric currents and magnets can exert a force on each other. (*BSL* Grades 6-8)
- Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced. (*NSES* Grades 5-8)
- Electrical circuits require a complete loop through which an electrical current can pass. (*ASL, 2* Grades 6-8)
- A charged object can be charged in one of two ways, which we call either positively charged or negatively charged. Two objects that are charged in the same manner exert a force of repulsion on each other, while oppositely charged objects exert a force of attraction on each other. (*ASL, 2* Grades 6-8)

Student learning goals from *Maine Learning Results, 2007*

Grades 5-8

- Explain that electric currents and magnets can exert force on each other.

Student learning goals from *School Union #29 Science Curriculum*

Grade 8

- Circular systems (circuits)
- Simple electrical investigations

Teaching considerations from *Benchmarks for Science Literacy* (BSL), *National Science Education Standards* (NSES), and *Atlas of Science Literacy, Vol. 2* (ASL,2)

- Students should make devices to observe the magnetic effects of current and the electric effects of moving magnets. At first, the devices can be simple electromagnets; later, more complex devices, such as motor kits, can be introduced. (*BSL*)

- Electric and magnetic forces and the relationship between them ought to be treated qualitatively. Fields can be introduced, but only intuitively. Most important is that students get a sense of electric and magnetic fields and of some simple relationships between magnets and electric currents. Direction rules have little importance for general literacy. The priority should be on what conditions induce an electric current. Diagrams of field lines often produce misconceptions, such as the lines are the only places where force exists. (*BSL*)
- The understanding of energy in grades 5-8 will build on the K-4 experiences with light, heat, sound, electricity, magnetism, and the motion of objects. In grades 5-8, students begin to see the connections among those phenomena and to become familiar with the idea that energy is an important property of substances and that most changes involve energy transfer. (*NSES*)
- In middle school, the focus is on the effect of forces on objects. (*ASL, 2*)
- Students are to understand the concept of "charge" as the property acquired by the interacting objects and to recognize that there are two ways in which an object can be charged. It should be noted that the phrase "a charged object can be charged in one of two ways" refers to the final state of the object, not the method used to get it to that state. (*ASL, 2*)

Cognitive research from *Making Sense of Secondary Science* (MSSS) and *Atlas of Science Literacy, Vol. 2* (ASL, 2)

- Students, ages 8-12, when faced with lighting a bulb with a wire and battery, have a source-consumer model in which the battery gives something to the bulb. (*MSSS*)
- These concepts of electricity are difficult to change—students often hold on to them through college level engineering and physics courses. (*MSSS*)
- Students often think that only one of the poles of the battery has to be connected to the bulb—"The Unipolar Model." (*MSSS*)
- Students may think that current travels out of both poles of the battery and clashes in the bulb—"The Clashing Currents Model." (*MSSS*)
- Students may think that less electricity passes out of a bulb than into the bulb—"The Current Consumed Model." (*MSSS*)
- Students see a battery as "delivering a constant current in a closed circuit rather than maintaining a constant voltage or potential difference." (*MSSS*)
- Often times, analogies and drawings belie a lack of understanding. Students can explain the analogy or draw the circuit, but cannot translate either to the practical setting. (*MSSS*)
- Electricity, current, and energy are often times used interchangeably by students. (*MSSS*)
- Students do not generally have an awareness of the magnetic effect of an electric current. (*MSSS*)
- Before instruction, many elementary and middle school students are not aware of the bipolarity of batteries and light bulbs, do not recognize the need for a complete circuit to make a bulb light, and do not succeed in making a lamp light when given a battery and a number of connecting wires. This suggests that they also do not understand or cannot apply the concept of a complete circuit. Teaching sequences that take account of students' ideas can help middle-school students make progress in this area. (*ASL, 2*)
- Students of all ages have difficulty reasoning that all parts of a circuit are interrelated and influence each other. Instead, they think of circuits in terms of electric current traveling around the circuit meeting each component in turn. They think of a change in the circuit affecting only those components that come after the change. This "sequential" reasoning underlies many problems that students have in understanding electric circuits and is highly resistant to change. (*ASL, 2*)
- Little is known about students' reasoning about the microscopic mechanisms that underlie electric current and their interpretation in terms of electrostatic entities. Students may think of the battery as the only source of electrons which move in the circuit, i.e., the battery releases electrons into the wires which play no active role. They also may think of electrons moving through a circuit as single unconnected particles moving around. (*ASL, 2*)

- Students tend to start instruction with one concept for electricity in electric circuits which has the properties of movement, storability, and consumability that students label “current,” “energy,” or “electricity.” Even after instruction, many students of all ages do not differentiate between electric current and electric energy. They also tend to think that the battery is the source of the current and that the circuit is initially empty of the stuff that flows through the wires. Many students after instruction believe that a battery releases the same amount of current regardless of the circuit to which it is attached and that the fixed current flows out of the battery and diminishes every time it goes through a circuit element that uses up the current so that there is less current at the end of the circuit. These beliefs are highly resistant to change. Identifying energy as the quantity that is dissipated can help students reconcile their intuitive belief that something is used in circuits with the formal knowledge that electric current is conserved. (*ASL, 2*)

Classroom Research

Classroom Context

The students in this study are eighth graders in Poland, Maine, a rural town in Androscoggin County, which is in the western part of the state. Bruce M. Whittier Middle School is attached to the regional high school, which is the first new high school built in Maine in 50 years. We are part of a school union, which includes Minot and Mechanic Falls. Poland has a highly transient population—there are a large number of rental trailer parks—with students bouncing between the three towns and the neighboring sister cities of Lewiston and Auburn. More than 50 percent of our student body qualifies for free and reduced lunch. The size of the middle school is 136 students this year, with 63 in the eighth grade.

Methodology and Data Collection

I designed a probe, which I administered to all students. (See Appendix A.) Five students are in a pull-out science class and 52 of the 58 who take regular education science were in attendance on the days that I administered the probe. I also administered the probe in the form of an interview with eight students, adding the element of providing the materials (batteries, bulbs, and wires) mentioned in the probe and videotaping the interview. I used “Prediction Sheet 1: Will the bulb light?” and “Prediction Sheet 2: Will the bulb(s) light?” with my students. (Stepans, 2003) (Appendix B and C)

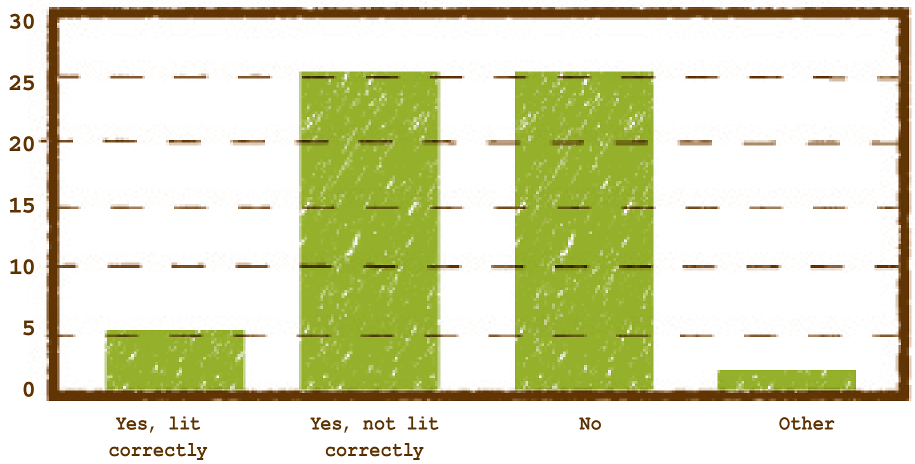
Data Organization and Findings

Based on informal student interviews, observations during activities, and classroom discussion, I knew that significant misconceptions remained about what happened to the electric current as it passed to and through the filament in a light bulb. Using the Prediction Sheet 1 (Stepans, 2003), I was able to determine the gaps in understanding that remained after the initial round of labs and activities. After the students moved to the lab benches to test their predictions and determine whether they had been right or wrong, most returned a few minutes later, puzzled as to why some had worked and others had not. Students could not explain the path of the current through the bulb from the posts on either side of the housing unit that we were using. Students could not figure out how to light a bulb without the housing unit. After I pointed out the connections on the housing from the posts to the bulb and asked them what this might mean, ultimately, through a variety of individuals sharing ideas, students were able to come up with the bulb being wired so that current passed from the base, up to the filament, and then through the other side to the threading on the side of the bulb. After lighting a bulb for them in this manner and during the subsequent discussions, when students had an idea about how it might work, I would try to light a bulb that way to discover if it might work. When it would not, students continued to reason how the electricity might pass from one side of the filament to the other. After ten to 15 minutes of processing in this manner, students had an understanding of what had been missing when they had made their previous predictions and what they could do to fix them.

When we approached the subject of parallel and series circuits, we followed a similar process, this time using Prediction Sheet 2 (Stepans, 2003). Although students had read and answered questions about the two types of circuits, it was not until they had tried a variety of scenarios, making predictions, making mistakes, and then seeing why they had made those mistakes that they understood the difference between the two types and could predict accurately how they would work.

Figure 1:

Student response to: If you were given a lightbulb, a wire and a battery, could you light the bulb? If so, how? Draw an illustration of how this might work.



Students were asked "If you were given a light bulb, a wire and a battery, could you light the bulb? If so, how? Draw an illustration of how this might work." Their responses to the questions (Figure 1) fell mostly into the categories of Yes (they thought it could be done, but did not know how to do wire it correctly) or No (they did not think it was possible). Five students had a prior conception of this that would successfully wire a light bulb and a battery.

Most students who answered this question with the response that it was possible did not draw a complete circuit, but rather a wire connected to the bulb and one side of the battery. Additional information gleaned from this question included:

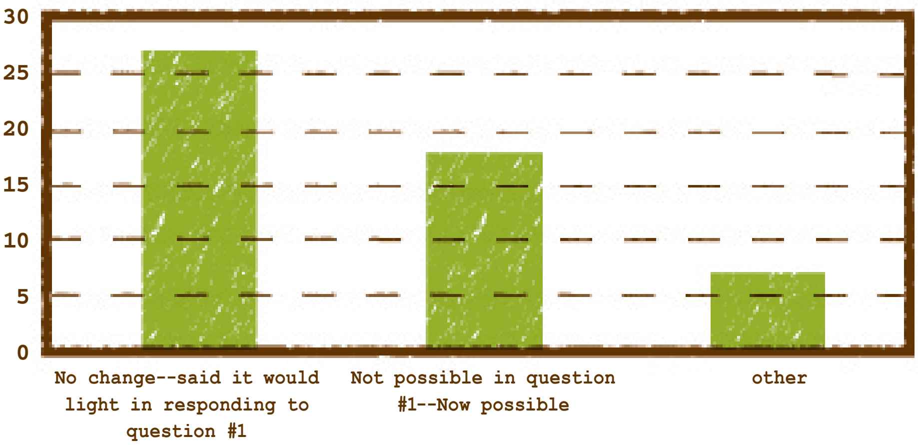
- Some responses that explained that it would not work, because you needed electricity to light a bulb, which could only come from an outlet;
- Two students who said it was not possible, but when interviewed and had the materials, surprised themselves and were able to light the bulb; and
- Two students who thought it was possible, but could not light the bulb in the interview.

Students were asked "What would be possible if you were to add a second wire that is different from the first attempt to light the light bulb?" Their responses (Figure 2) were mostly centered around a belief that it would either not change because it worked with one wire or that it would now work because you now had a way for the electricity to go out and back.

Of the 17 students who responded that it was not possible to light the bulb with one wire, but would be with two, ten students drew this correctly, while seven did not. Of the 27 who said it would light before, 13 did not draw the new configuration, ten drew it incorrectly, and only four drew it correctly. Four of the 27 also believed the bulb would become brighter due to the extra wire, while one believed it would be dimmer. Seven of the eight students interviewed were able to light the bulb correctly.

Figure 2:

Student response to: What would be possible if you were to add a second wire that is different from the first attempt to light the bulb?



The questions "What would happen if you were to add a second battery? A third? A fourth?" elicited a wide array of responses (Figure 3). While more than half believed that adding batteries would add power and make the bulb brighter, many students also believed that more than two batteries would be too much power or that this would not work, cause no change, or last longer.

In interviewing students, some reacted with genuine surprise when the bulb burned more brightly with the additional batteries and a few were nervous about the bulb "blowing" if we added three or four batteries. The concept of language implications in regards to electricity and previously held beliefs came up frequently in interviews, both formal and informal. These previously held beliefs included light bulbs exploding with too much power "like in the *Green Mile*" and batteries being living, because "If you can have a dead battery, then they must be alive when they work." Despite 20 percent of the students believing that three or four batteries might be too much power, more than half of the students did grasp the concept that adding batteries would make the bulbs burn more brightly prior to our in-class instruction.

Figure 3:

Student response to: What would happen if you were to add a second battery? A third? A fourth?

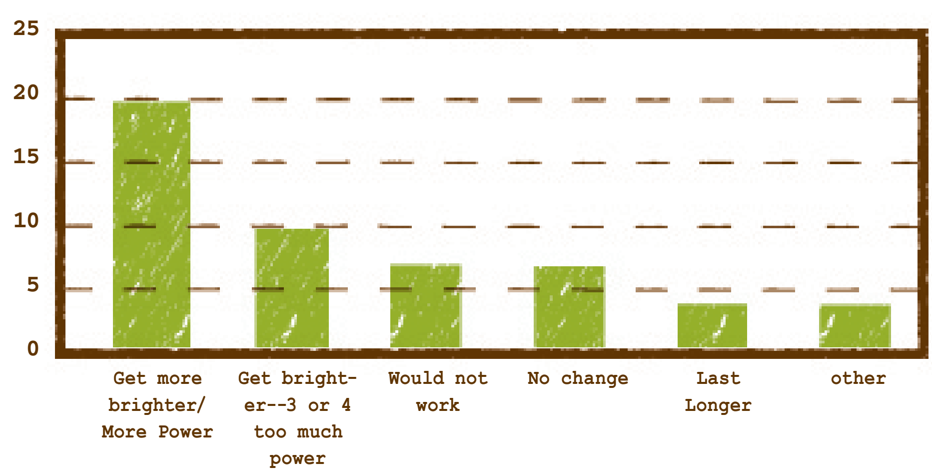
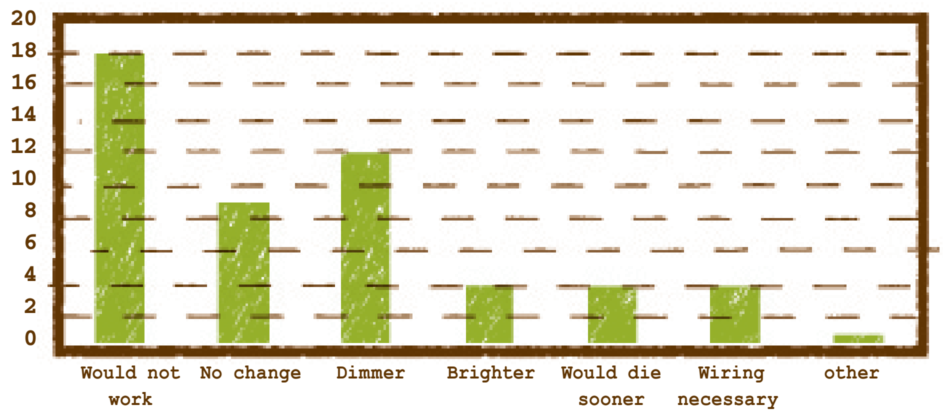


Figure 4:

Student response to: What would happen if you were to add a second light bulb? A third? A fourth?



By the time students were asked "What would happen if you were to add a second light bulb? A third? A fourth?" it appeared in both interviews and written responses (Figure 4) that there was a lot of guessing going on. More students believed it would not work at all than believed it would be come dimmer. Almost as many predicted no change and four believed it would become brighter. One thought that in future years, I should ask students to rate their confidence in their responses, that is, to identify if they are just giving their best guess or if they have a reason for their response.

Drawings of the wiring in response to this question were difficult to interpret. Based on the interviews, only two students were able to connect multiple light bulbs, either in series or in parallel, without assistance from the interviewer. Most seemed to be guessing at what might be happening by the time they reached this question

Responses to "What is physically happening when you light the light bulb?" (Figure 5) showed only three students mentioning electricity traveling back to the battery despite mention of the circuit concept in earlier responses.

Of the 29 respondents who mentioned that electricity travels from the battery to the bulb, only eight mentioned that it traveled through the wire, although others may have presumed this was too obvious to mention. Misconceptions identified in the responses include that electricity can travel in a direction and without a circuit, that it converts to heat to travel through the wires, and that the positive and negative poles of the battery each send out a particle that then creates light in the bulb when they collide in the middle.

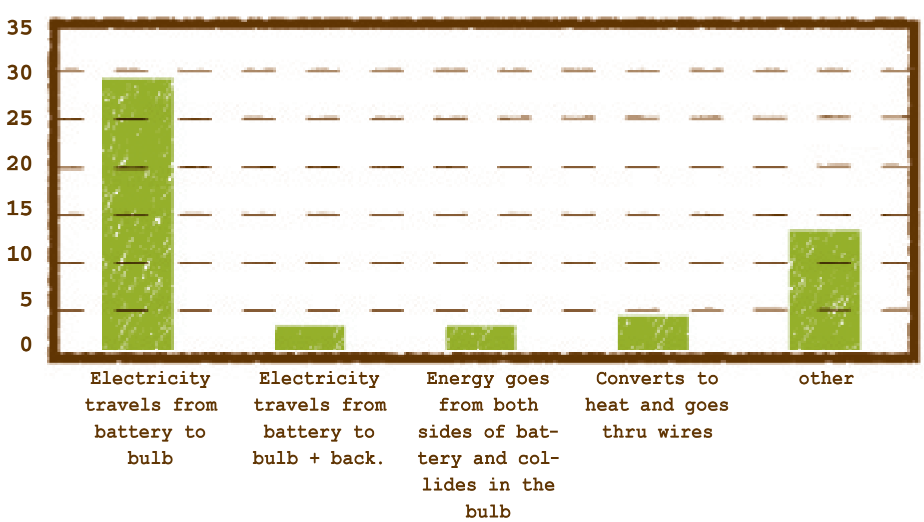
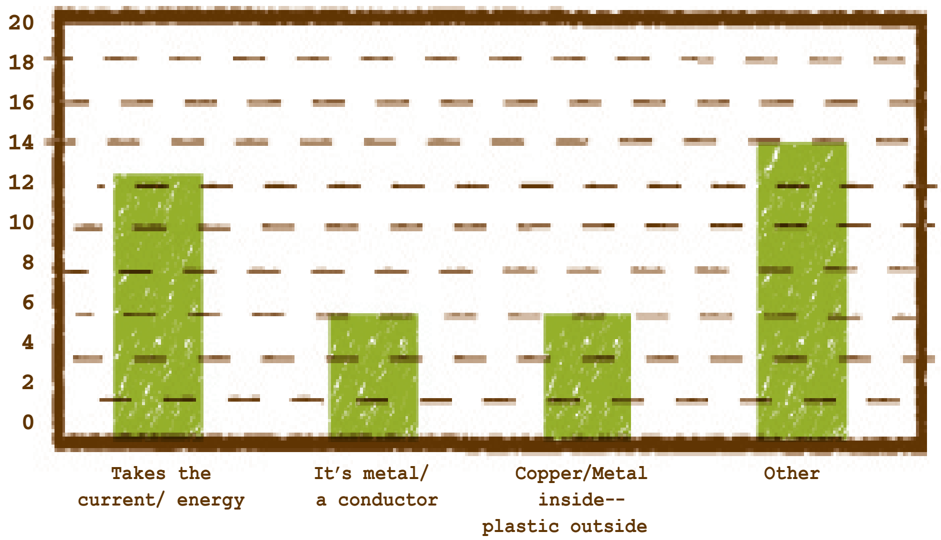


Figure 5:

Student response to: What is physically happening when you light the lightbulb?

Figure 6:

Student response to: What is important about the qualities of the wire that make it important in lighting the bulb?

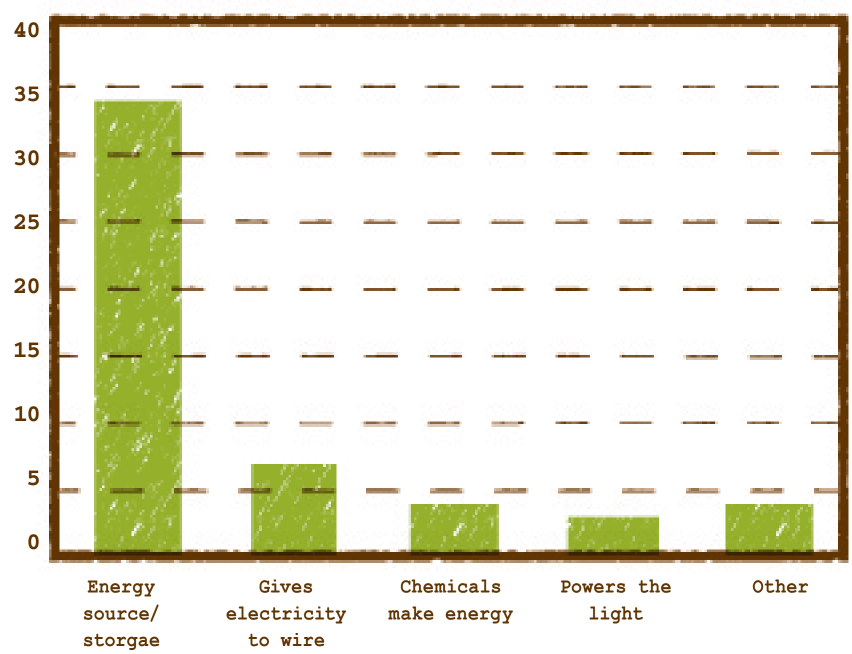


"What is important about the qualities of the wire that make it important in lighting the bulb?" yielded a wide range of responses, from the wire takes the current or energy (stated by 17 students) to the wire is a conductor (stated by eight students) to the conducting wire paired with the insulating casing is of value (stated by eight students).

When asked "What is the role of the battery? How does it do what it does?" student responses (Figure 7) were certainly the most consistent. Even the responses that were categorized differently had a lot of overlap. Students knew the role of the battery was to supply the electricity, although they said it in some different ways. Many times the battery also was described as making electricity. Note that there is a second part to this question, which is unanswered in the written responses. In the interviews, most students stated that they "really had no idea how the battery worked," although some mentioned that they knew of the importance of some of the materials, such as metals and acid.

Figure 7:

Student response to: What is the role of the battery? How does it do what it does?



Data Analysis

Student responses to the first question (Figure 1) showed that student preconceptions pair with those found in *Atlas of Science Literacy, Vol. 2*, particularly those regarding the lack of understanding of the necessity of a circuit in order for electrons to move.

Student responses to the second question (Figure 2) indicate that although many students do not understand the movement of electrons or the importance of the circuit, students can figure out through trial and error how to light a bulb.

Student responses to the third question (Figure 3) illustrate that while some students may have an idea of how part of the electrical circuit works, those same students and others have disparate thoughts about how the rest of the system works.

I was interested in student responses to the fourth question Figure 4) due to the commonly held belief stated in *Atlas of Science Literacy, Vol. 2*: "Many students after instruction believe that a battery releases the same amount of current regardless of the circuit to which it is attached, that the fixed current flows out of the battery and diminishes every time it goes through a circuit element that uses up the current, so that there is less current at the end of the circuit." Student responses corroborate the statement, as student responses are widely distributed and indicate no apparent grasp of the concept of the relationship between batteries and the devices that use that energy.

Responses to the fifth question (Figure 5) point out again the source-consumer model of electricity as a misconception common to middle-level learners. Although when you bring up the idea of electricity, traveling in a circuit is always mentioned, few grasp what that really means. This is the question that, in retrospect, seemed the most in need of repair. In the future, I would replace it with the Stephans probe.

With more responses to the sixth question (Figure 6) in "Other" than in any of the other categories, the value of this question needs to be examined. I was hoping to grasp a sense of students' understanding of conductors and insulators. In formal and informal interviews, I realized that this was an area of extremely limited exposure, which also may account for what appears to be a lack of understanding of the question. In either case, I knew that I needed to start from square one with this topic, and I began by having students make predictions about which materials were good conductors and which were not, as outlined in *Targeting Students' Science Misconceptions*.

Student responses to the seventh question (Figure 7) were certainly the most consistent. Even the responses that were categorized differently had a lot of overlap.

Significance

Using shorter chunks of targeted activities was the major change in my instructional practices. In analyzing students' responses to the questions above, as a teacher, I initially focused on the details of what they did and did not know ahead of time. In the past I have taught a number of labs accessing the information around this subject that have been comprehensive in nature. Making a comprehensive lab to tackle each of the chunks of electrically related learning and a means to process each of these pieces seemed daunting and impractical. In reflecting on the pieces of information that students would be learning and the likelihood that they would be confused, I felt that waiting until the lab was completed to process was too long a time. Students' previously held beliefs as indicated by the responses to the questions in the probe and in the research cited in *Atlas for Science Literacy, Vol. 2* were widely varied and highly resistant to change.

As I searched for a solution to best approach this unit of instruction based on the results of the survey, I reviewed *Targeting Students' Science Misconceptions* and it occurred to me that teaching in shorter sections using quick activities and then corrections and clarification would lead to greater conceptual understanding. Although it was a bit of a hunch, it seemed to make sense to shorten the "accessing prior knowledge to inquiry-based activities to correcting and clarifying" loop. As it has been my experience to try and create comprehensive stand-alone labs and activities, this is a shift in my thinking. This creates more time for discussion around what students are thinking as we go through the activities which, with middle-school students, is an important element to their retention of information. The short turn around time also minimizes students leaving class without clarifying points of confusion.

Reflection

Taking the time to analyze a section of the curriculum that I teach allows me to better understand the material from that unit and how best to teach it. It also provides some lessons that apply to other units within the curriculum. I've discussed the idea that occurred to me through reflection on the results of students answering questions about circuits based on their prior knowledge. The question that remains is "Was this effective?" Anecdotally, I felt that students were both more engaged and more accurately grasping the concepts in our discussions as we went through the activities. I also felt that students were generally more enthusiastic about having these discussions, perhaps because they felt that they were learning and were excited about their new discoveries. An example of this occurred when students were reasoning the path of electricity through a light bulb. I paused to notice that, without exception, in all sections of my classes, I had no behavioral, nurse, locker, pencil sharpener, or restroom needs for the 15 minutes that we processed. This is a most unusual experience for a teacher of middle-level students.

In terms of student retention of this material, I had a lab practical portion of the cumulative assessment that we did near the end of the electricity unit. In the practical, I asked students to use the wires, batteries, and bulbs to do all of the steps that were included as part of the survey. No student scored lower than a 3 (out of 5). The class average was a 4.48 (out of 5).

As I consider other units I teach, I will certainly apply the pieces of this structure including the probes/surveys of prior knowledge and the piece about tackling each of the chunks of misconceptions in smaller and tighter activities. Creating the time in the planning process for science talk to occur immediately after the discovery period is essential. Waiting until the next class is to be avoided if at all possible. Best practice in teaching science continues to be based on the analysis of what we do, reflection upon our data, and adjustments based on the needs of our students.

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Appendix A *The probe*

1.) If you were given a light bulb, a wire and a battery, could you light the bulb? If so, how? Draw an illustration of how this might work.

2.) What would be possible if you were to add a second wire that is different from the first attempt to light the light bulb?

3.) What would happen if you were to add a second battery? A third? A fourth?

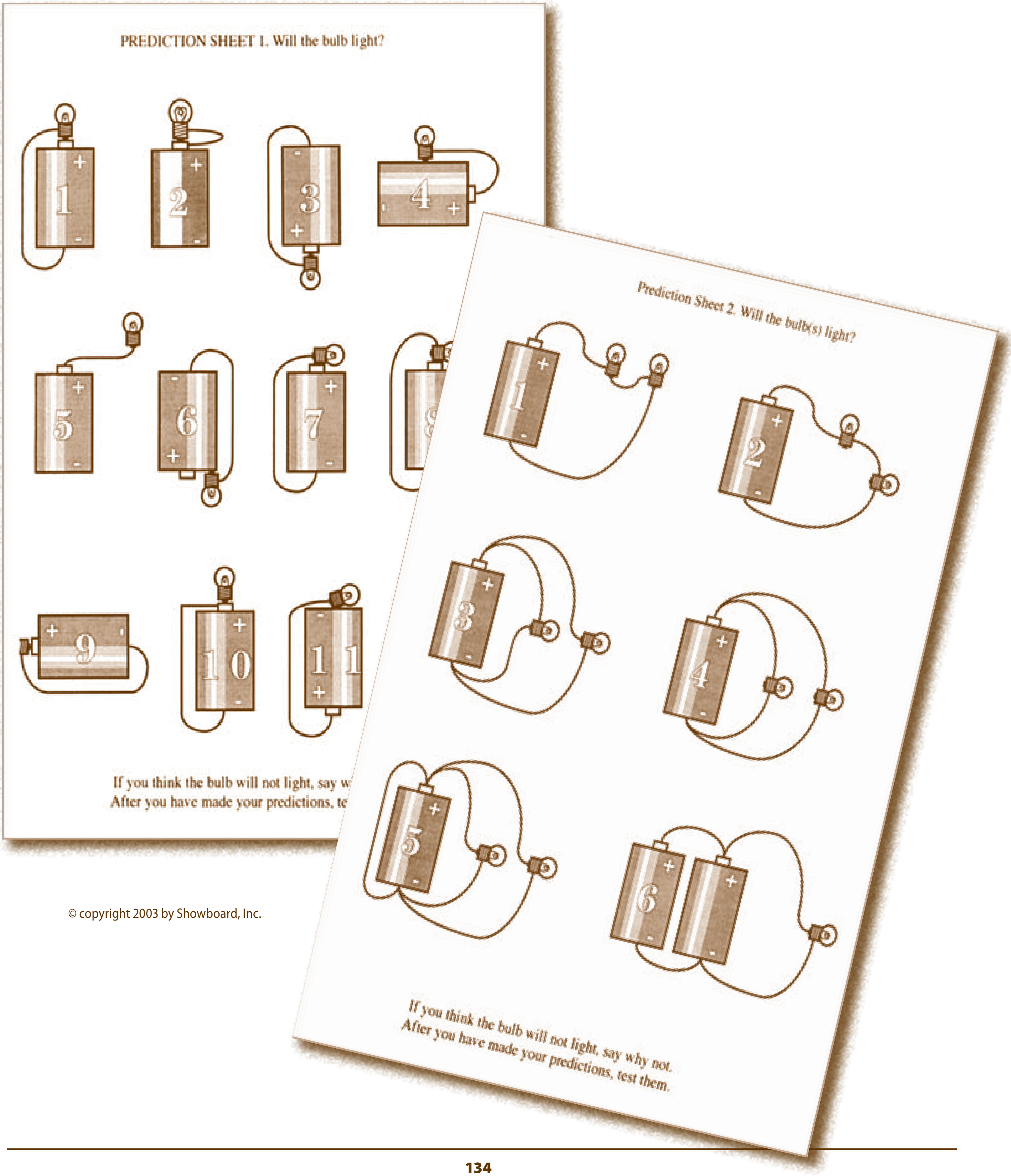
4.) What would happen if you were to add a second light bulb? A third? A fourth?

5.) What is physically happening when you light the light bulb? What is lighting the bulb? How is that happening? How does that work?

6.) What is important about the qualities of the wire that make it important in lighting the bulb?

7.) What is the role of the battery? How does it do what it does?

Appendix B


PREDICTION SHEET 1. Will the bulb light?
1
2
3
4
5
6
7
9
10
11
If you think the bulb will not light, say w
After you have made your predictions, te
Prediction Sheet 2. Will the bulb(s) light?
1
2
3
4
5
6
If you think the bulb will not light, say why not.
After you have made your predictions, test them.

SC4 Project

Science Content,

Conceptual Change and Collaboration

A Math Science Partnership (MSP)

project that includes:

Maine MATHEMATICS and SCIENCE Alliance

University of NEW ENGLAND

and four Maine school districts.

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