Title: Teaching and Learning Big Ideas in Science

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Abstract

Fifth grade students' general knowledge of the concept of energy relates almost entirely to the ideas of activity or electricity. Specific investigations can help them integrate the idea that energy must have a source and that it can be transferred. Even so, students struggling with abstract concepts most frequently state this integration in concrete terms.

Introduction

Among the 'big ideas' in science is the concept of energy. The intangibility of the concept of energy means that many naïve conceptions exist regarding its nature. However, the fact that it is a 'big idea' means that it is relevant to more than one discipline of science, and that grasping the concept of energy can have far-reaching implications for students. Learning about energy in relation to water will give students a basis for comparison and contrast when they are exploring energy in other disciplines, such as motion or photosynthesis. The students in Michelle Campos' fifth grade class are studying the hydrosphere, which provides an excellent opportunity for the study of the transformations of energy involving water. Jacqueline Grennon- and Martin Brooks refer to the study of big ideas as the quest for essence (1993), and suggest that students learn better when moving from the whole (i.e., the concept of the transferability of energy) to the part (i.e., its transferability in its interaction with water). They use the whole as a way to make sense of the parts. Each student breaks the whole into parts he or she can understand, based on individual style or temperament.

It is common practice to use a K-W-L chart (What I Know, What I Want to Know, What I Learned) in the service of reading comprehension (Ogle 1986). This tool is also nicely adaptable to conceptual change lessons in science. In both situations, it is desirable to activate prior knowledge in students. In science, this is a way to help uncover naïve conceptions on a topic. Contradictions that may emerge in the "What I Know" column can provide clues to teachers and learners as to where to go next--what should be in the "What I Want to Know" column. Maintaining the chart throughout a particular unit gives students a chance to refer to their original conceptions and self-assess conceptual change. I have adapted this chart to an "Initial Ideas" chart with only one list comparable to the "What I Know" column.

In his study of naïve conceptions of energy, Ricardo Trumper analyzed student misconceptions among pre-service elementary teachers (1990) using a list of alternative frameworks created by Watts (1983) and Gilbert and Pope (1986). The most prevalent of these alternative frameworks regarding energy are:

- Anthropocentric: energy is associated with human beings;
- Depository: some objects have energy and expend it;
- Ingredient: energy is a dormant ingredient in some objects, released by a trigger;
- Activity: energy is an obvious activity;

- Product: energy is a by-product of a situation;
- Functional: energy is seen as a very general kind of fuel associated with making life comfortable;
- Flow Transfer: energy is seen as a type of fluid transferred in certain processes (Trumper 1990).

These alternative frameworks are similar to the general knowledge to which Solomon refers in her work with students (1992). Their consistency with accepted scientific evidence is secondary to the fact that in Solomon's words, "(T)hey contain meanings rather more than facts." They are expressed in imprecise language that is not meant to stand up to scientific scrutiny. Students assume (as does anyone else in possession of general knowledge) that everyone "knows" the same things they "know." Fifth graders studying water and energy are likely to have a functioning vocabulary on the topic, although probably more in the area of general than scientific knowledge. Because of the nature of water, I expected to hear ideas similar to the depository, ingredient and flow-transfer of energy.

Trumper (1990) used a questionnaire with free association, pictures involving the energy concept, and predictions based on pictured situations to evaluate pre-service teachers. All of these tools, with age-appropriate adaptations, were used in this action research project as well.

In this project, students explored two major questions:

- What is the energy source in certain water-related situations?
- When and how is that energy transferred elsewhere?

They examined these questions through comparison, contrast and investigation. As a final assessment, students were asked to view a set of pictures and answer these questions about the concept of energy.

Demographic Data

Novi Meadows School is a building housing the fifth and sixth grade classrooms for the entire Novi Community School District in southeastern Michigan. There are nearly one thousand students at Novi Meadows. Novi is an affluent community, and only 2.6% of the students are eligible for free or reduced price lunch (most recent data - 1999). State standardized assessment scores are above the state average. Science assessments are done later in the fifth grade, so the available test data is for a previous group of students.

This group of fifty students consists of 31 boys and 19 girls. There are two Asian students, two African-American students, and two Indian students. The remaining 44 students are Caucasian. There are fourteen special education students included in the group.

Since this project was conducted early in the school year, the only unit previously completed in science was one on measurement. As we began our project together, the students were just entering a unit on the hydrosphere.

Procedures

Before I met with the students, their regular classroom teacher, Michelle Campos, assisted me by administering a pre-assessment. The students were given a short period of time

(5-10 minutes) to write down their first thoughts about energy. What I hoped to accomplish with the limited time period is to access only the students' general knowledge, and not let them delve too deeply into what they think I want to hear. I was interested in first impressions for this exercise.

My first visit to the school began with making an "Initial Ideas" chart, similar to the "K" column of a K-W-L chart. Students were asked for their ideas about whether water has energy. The question was deliberately non-specific because it was not a right-and-wrong exercise. Accessing naive conceptions is, at this point, akin to asking students what is in their pockets. Only they can tell me what is there and I did not want to evaluate it at this point. At the end of every subsequent visit, we examined this chart as a group to decide whether any students would like to change or restate any of the ideas on the chart. This activity was designed to help students reflect on what they learned in every lesson, and to give them a visual cue in recognizing their own misconceptions.

My second visit focused on the concept of energy as it relates to water. We discussed whether water has energy intrinsically, and how energy can be transferred to water. We explored the idea of observing the energy in heated water and concentrated on where the energy came from, and how we could observe where it goes. As they worked in groups, students were asked to complete a lab sheet. Although I planned to supervise students and listen in on student discussions, I wanted a more comprehensive way to analyze their thoughts about the investigation. The lab sheet questions asked students to predict what would happen when heat energy was applied to water, and though it concentrated on *observable* phenomena, I also asked students to make inferences about the transfers of energy based on what they saw. Before the end of the session, we revisited the "Initial Ideas" chart, as well.

My third visit started with questions about how water can do work. We began with the example of the Colorado River and the enormous amount of work it did to cut the Grand Canyon through erosion. Our exploration was meant to illustrate the effect of different land gradients or slopes on newly cut rivers. Again, the lab sheet focused on the energy source in the investigation and the subsequent transfers of energy based on observable phenomena. We revisited the "Initial Ideas" chart.

My last visit to the school was for the purpose of post-assessment. The assessment consisted of two parts. For the first part, the students participated in a class discussion of the sources and transfers of energy we had witnessed in the conducted investigations. For the second part of the assessment, I gave the students a set of pictures and asked them to write about how the picture relates to energy. This exercise is somewhat similar to Trumper's (1990), but is more specifically related to water by the pictures I used. We also made our final review of the "Initial Ideas" chart.

Because we have worked together in the past, Michelle was content to let me handle the lessons for the most part, and I am grateful for the experience. On one occasion she interjected to connect some questions of mine with some learning she wanted to include, and at the end of the river slope lesson, she did a masterful job of tying all the pieces together much more coherently than I felt I was doing. Working with Michelle's guidance was extremely valuable for me as an inexperienced teacher.

Data Analysis

Pre-Assessment

Students answered my pre-assessment question in a wide variety of ways and with many different ideas. "When I think of energy I think of..." is what the students were asked, and they were given no constraints on what form their answers should take. About half of the students chose to think of this as a word-association exercise and came up with lists of terms. The rest of them chose to write in sentence form, but there were commonalities in all of the answers. Only two students had answers that were ambiguous, and that was mostly a question of interpreting invented spelling that was beyond me. Using Trumper's framework, student replies fell mostly into four categories: anthropocentric (related to humans), functional (mostly related to modern electric conveniences), ingredient (contained in a substance and released by a trigger) and energy as an obvious activity. Here are some of the terms that were commonly used by the students and which inspired me to classify the ideas the way I did:

Anthropocentric:

"athletic" "aggressive" "active" "strength" "breathing"

"healthy" "powerful" "strong" "energetic" "alive"

"life" "hyper" (as in hyperactive) "thought energy"

Functional:

"light bulb" "power source" "electricity" "batteries" "TV"

"outlets" "plugs" "computer" "microwaves"

"cable" (as in cable TV) "wires"

Ingredient:

"sugar" "vitamins" "food" "water"

"Mountain Dew"

Activity:

"running" "walking" "skipping" "swimming" "hockey"

"football" "playing" "baseball" "soccer" "swinging"

"jumping on a trampoline"

The students Trumper worked with in his project were significantly older than the students I worked with. The answers I obtained from fifth graders were totally consistent with the life-experience of ten-year-old children. There were two things that seemed significant regarding students' answers. One was that there were a number of students who, through the use of "science words" seemed to be associating energy with a scientific concept. Some of the terms students used were electrons, volts, light sources, gravity and molecule. The other thing that seemed prominent to me was the fact that of over fifty students, only four wrote anything that could be construed as recognition that energy must come from a source, and that it can be transferred:

"You have a lot of sugar and are ready to run all over the place"

"a flow of electricity"

"You have to have energy like volts to have a light bulb light up"

and somewhat ambiguously:

"it makes me think of the sun and the world."

The main question I decided to explore with the students is this idea that energy is transferred--that it must come from somewhere and that it can be redistributed.

The other piece of pre-assessment I used was the Initial Ideas chart. I broke this into two pieces for students, 1) Where does water "get" energy? and 2) How can water transfer its energy? Some of the ideas students put forth showed that students had some conception that energy had something to do with motion, such as "Water gets energy from moving boats...from moving fish and people." The functional idea from Trumper's framework stayed with students, who though that "Water gets energy from something electrical." The ideas we would end up exploring included, "Water gets energy from gravity/falling" and "Water gets energy by absorbing it from the sun (warming up)."

When asked, "How does water transfer energy?" the replies all had to do with motion: "Water makes other water turn/move...makes a waterwheel turn...in the form of steam can move things (steamboat, steam train)." In some form, we would explore all of these ideas about energy transfer.

Investigation One: Thermal Energy and Water

The first exploration I set up for the students involved using a hot plate to heat a small beaker of water with a small quantity of pencil shavings in it. They were asked to name the energy source in the experiment, and to use their observations to decide where energy was being transferred to. Students were asked to predict what would happen before heating the jar and to sketch and record what actually happened after they heated the beaker. Nearly 80% of the students made a prediction that did not agree with their result. The most common answer was some variation on "The pencil shavings will rise to the top." When questioned about how the shavings would get to the top of the water, most students related one of two ideas. Either, "The water evaporates at the top, so the shavings will go up there, too," or "The shavings will get hot, and heat rises." From this I surmise that, though their initial ideas of energy transfer all had to do with motion, students were not applying this idea to the investigation. The actual result is that the pencil shavings will begin to rise and fall in easily visible convection currents, showing that the pencil shavings and, thus, the water molecules are increasing their motion.

Students were easily ably to identify the energy source in this experiment as the hot plate. When asked about the energy transfer, students were also required to list the observed evidence that supported their conclusion. There was a fairly even distribution between students suggesting that the energy was transferred to the beaker (25%), the water (36%), and the pencil shavings (26%), with the remainder being ambiguous or blank answers.

Class discussion was useful to clarify these ideas when it was time to explain what had been observed. Everyone agreed that the hot plate had been the energy source in the investigation. The disagreement between students regarding the energy transfer was helpful when it started to become clear to them that, through a chain of events, the energy had been transferred to the beaker, the water, and the shavings. We added this to the Initial Ideas chart, and modified "Water gets energy by absorbing it from the sun (warming up)." to include "or by absorbing heat from a hot plate."

Investigation Two: Gravitational Potential Energy and Water

The next investigation explored the idea that the gravitational potential energy of water increases proportionally to its height above the ground. Using sand and long stream tables, students created two different rivers; one with the stream table flat, relying only on the slope of the sand, and the other with one end of the stream table lifted to create an artificially steeper slope. As in the previous investigation, students were asked to identify the energy source and to point out evidence that shows to where the energy is being transferred.

The energy source in this experiment, the fact that the water is being acted upon by gravity, was a much more difficult thing for students to grasp. I tried a bit of scaffolding by first asking, "What makes the water flow downhill?" and then asking about the energy source. The answer to the two questions should have been the same or related in an overt way. 24% of students were able to do this on their own. The most common answer for the energy source was "water," and I believe the setup of the experiment was such that this was an understandable mistake.

The energy transfer candidates for this investigation were sand (44%), water (10%), or "the bottom of the hill (28%)." Interestingly, some students (10%) were able to put their answer in the form of a chain, similar to what we used in the first investigation, though I had not specifically requested it. Class discussion showed that students agreed the chains had some similarities. We added the new chain to the Initial Ideas chart.

Post-Assessment

For the final assessment, I gave students a set of four questions related to two pictures. The first picture was a representation of water evaporating on a sunny day and featured questions about the energy source and energy transfer. The second picture was of a waterfall and featured a question about the energy source and the following: "How could this waterfall do work? How could it transfer its energy?" 100% of students were able to correctly identify the sun as the energy source in the first picture, and 70% were able to correctly identify gravity/steep slope as the water's energy source in the second picture. This last was a significant increase over the success rates in the lab sheet, and I attribute it to the sharing of ideas in the whole-class discussion.

53% of students were able to state that energy was being transferred to the water in the pond in the first picture and 57% were able to suggest a reasonable form of work for the moving water to do (e.g., turn a waterwheel, turn a turbine, erosion, cut a canyon, dig a deeper pond). I believe the success rate was greater for the more difficult question of work because the time elapsed between the lesson and the assessment was only one week. The thermal energy investigation had been done three weeks earlier.

Conclusions

As I suspected, students began our exploration with a working vocabulary regarding energy. Because they are children, the vocabulary was limited to their personal experiences like sports, electronic devices, hyperactivity, and caffeinated soft drinks. The idea of transferring energy from one form to another was outside their frame of reference. What I tried to do with these explorations is to make them familiar with the idea that energy can be transferred--the example I frequently referred to had to do with a bowling ball--that it must "go" somewhere and doesn't just disappear.

The combination of investigation and discussion is key to student understanding. Students with somewhat unfocused ideas during the investigations did a better job that I expected on the final assessment. I believe this is primarily because of the whole-class discussions we engaged in after the investigations. That discussion would not have been possible without first engaging students in the investigations, so the two are tied together.

I believe that what I accomplished with the students would be a good basis for further investigation. Their understanding of the concept of energy is only beginning to emerge at this point. The picture I have helped them form of the "whole" (Brooks 1993); the concept of the transferability of energy, stems from their understanding of the "part;" looking at energy sources and transfers related to the hydrosphere. By examining other "parts" of the concept in other disciplines such as physical science or life science, their understanding of the "whole" will grow.

Discussion

I found this project to be a valuable experience. The only difficulties I encountered had primarily to do with scheduling problems. Michelle was extremely accommodating to me in this regard and went out of her way to allow me access to her students.

The time limitations were a source of frustration in two ways. The first is that fifty minutes seems entirely too short a time for engaging fifth grade students and asking them to perform an investigation and to still have time for class discussion afterward. All of these elements are critical for understanding. The second is that I would have liked to have gone on with students further into the concept, and four visits was less time than I would like to have spent with them.

I now know how long it can take to address one small facet of the concept of energy. I also feel more confident addressing "big ideas" in science. These are the two ways I feel this project will most impact my future teaching. I had no trouble at all adapting the study of energy to a unit on the hydrosphere and feel confident I could do the same with any similar concept with nearly any science unit. As a new teacher, I feel this will be especially important. I feel I can guide my students in the study of these "big ideas," even if they are not explicitly explored in the text assigned to us.

If I were to explore this topic further, I'd like to use University of Michigan-Dearborn' unique facilities to explore questions about how water is used to do work. The Rouge River has a small fall in it on Henry Ford's Fair Lane Estate that was built higher in order to give the water greater gravitational potential energy and allow it to do more work. Besides seeing a historic site and appreciating the ingenuity of the engineers involved, I think students would expand their understanding of the concepts involved.

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