MainePSP Student Energy Survey, Pre-Iinstruction Data, Fall 2014

Alex Axthelm, Michael C. Wittmann

November 12, 2014

1 MainePSP Energy Survey: Design and Implementation

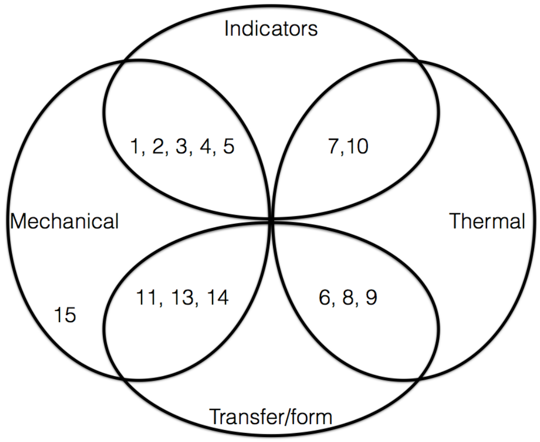
Teachers and researchers in the Maine Physical Sciences Partnership have multiple points of interest in knowing how students are learning essential ideas about energy, a core idea in the NGSS and other learning standards. As part of our PBIS instruction, Energy is a central component of teaching physical science. For the 2014-2015 academic year, we asked students a survey with 17 questions about energy. Questions can be grouped according to the kind or forms of energy they are asking about (mechanical or thermal) and the topics they are getting at (indicators of energy or questions about transfer and transformation). Some questions implicitly use conservation of energy, and only one really makes use of it. Also, there are a few open-ended questions that we're not analyzing in this report. The breakdown of questions can be seen on the cloverleaf picture down below.

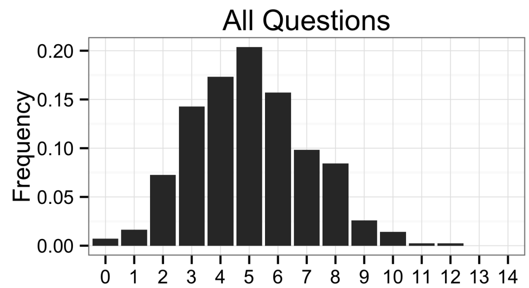
We'd like to give you a brief summary of results from the energy survey. We looked at trends across the different "groups" of questions - mechanical or thermal, indicators or transfer/tranformation - as well as at each individual question.

2 Overall results: Lots for us to build on in the classroom

Students on average answer about 5±2 of the 14 questions correct. We found that about 90% of students scored 7 or lower on the overall survey. That's not so bad, for pre-instruction data, and gives us plenty of room for students to improve during the course of the year.

We looked at performance for each question and found an interesting result. For 8 of the questions (out of 14), the most commonly selected answer (or the one tied for most commonly selected) was the correct answer. If it wasn't the most commonly chosen answer, the correct answer was the second-most chosen answer for all but one question. But, very few students got 8 questions right. This indicates that the students who selected the correct answers for some questions did not do so consistently on all questions. It tells us that students strengths lie in many areas. As teachers, we have to pay attention to all the ideas that are on the survey in order to help all our students. But, we also have the chance to *use* all these good student ideas in our teaching.



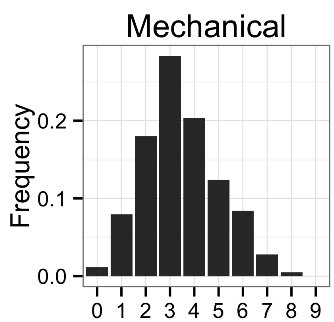


3 Organizing by Forms of Energy

We grouped questions in terms of mechanical energy (potential, kinetic, and elastic) and thermal energy.

3.1 Mechanical energy

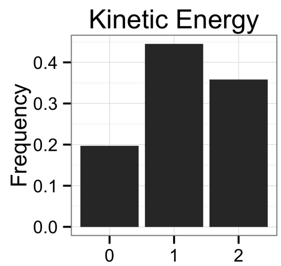
Questions: 1, 2, 3, 4, 5, 11, 13, 14, 15

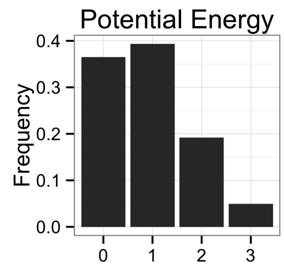


(Horizontal axes are "number of questions answered," frequency is "ratio answered correctly")

Some of the questions on the survey are about mechanical energy, which we thought of as kinetic, potential, and elastic energy.

Students were readily able to identify kinetic energy, but had more difficulty recognizing potential energy.





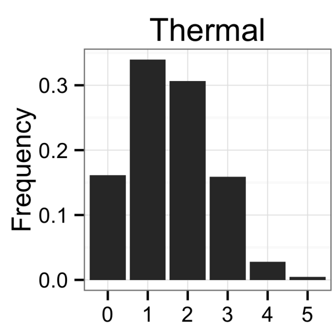
On the kinetic energy questions (1 and 2), 80% of the students got at least one correct, and about 1/3 of students got both.

On the 3 potential energy questions (3, 4, and 5), about 75% of the students got 0 or 1 question right. That should not be a surprise, because they haven't really learned about potential energy yet. What's more interesting is if you look at questions 3, 4, and 5 individually (which you can do later in the document): each is answered correctly about 30% of the time. What this tells us is that there's nearly NO overlap between students getting one question right and getting other questions right. Again, that's not a surprise, because the questions are asking about different things. One (Q3) is straight up about indicators, one (Q4) is about the relationship between work and potential energy when climbing a mountain, and one (Q5) is about the confusion between force and time compared to vertical location as an indicator of potential energy.

In general, we think students understand kinetic energy more than potential energy, and we expect to see lots of improvement over the school year given the topics discussed in the Energy unit of PBIS.

3.2 Thermal Energy

Questions: 6, 7, 8, 9, 10



Some of the questions on the survey are about thermal energy, meaning ideas about temperature and heat. We also asked a few question about thermal energy flow, including the idea that "coldness" flows, not just "heat."

There were 5 questions explicitly about thermal energy. (The questions in which there's a transfer to thermal energy, like Q14, the pendulum question, aren't counted here.) About 80% of students got fewer than 3 correct. That tells us there's a lot of room for improvement here.

We believe that student errors often come from perception in common world, where the most obvious indicator of thermal energy is temperature. Here are three examples:

1. One issue with "thermal" energy is that most everyday speech involving the word "thermal" concerns temperature, rather than any of the other properties related to thermal energy. So, asking about mass, or kind of material, or speed of molecules, won't really make sense to a student thinking about just temperature (though it's related to some of those properties).

2. As expected, students often indicated that cold is a property (or possibly a type of energy) that can be transferred. After all, don't we say "don't let the cold in" when someone leaves the door open? It's really hard to think about heat flow, almost like heat is going the opposite direction from what we feel most of the year.

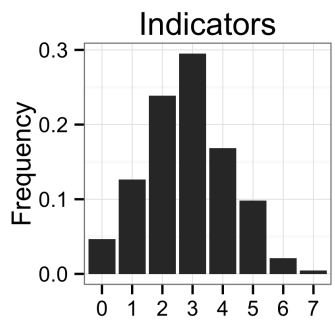
3. Also, when you touch different objects, like wood or metal, you're feeling not the temperature of the object but how quickly energy is flowing from your hand to the object. The wood feels warmer but isn't - and that's really hard to understand.

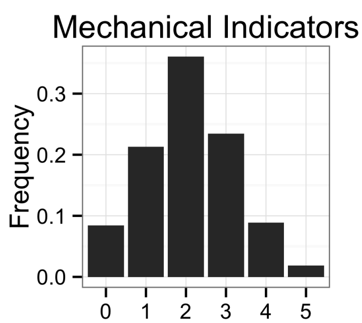
4 Organizing by Topics

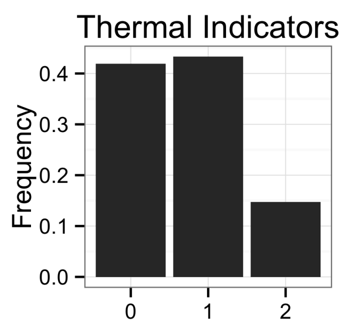
Topics on this survey were the indicators of energy and energy flow, transfer, and transformation.

4.1 Indicators of Energy

Questions: (mechanical: 1, 2, 3, 4, 5) and (thermal: 7, 10)







Some of our questions were about indicators: do you know what variables determine the thermal, kinetic, or potential energy of an object? Indicators for kinetic energy are mass and speed; indicators for gravitational potential energy are mass and height above the ground; and indicators for elastic potential energy are the stretchiness of a spring or rubber band and how far it is stretched. Indicators for thermal energy can be thought of both in terms of bulk properties (what kind of material, how much of it, and its temperature) and microscopic properties (what kinds of molecules, and how fast they are moving).

A common theme in the indicator questions was that speed is an indicator of energy.

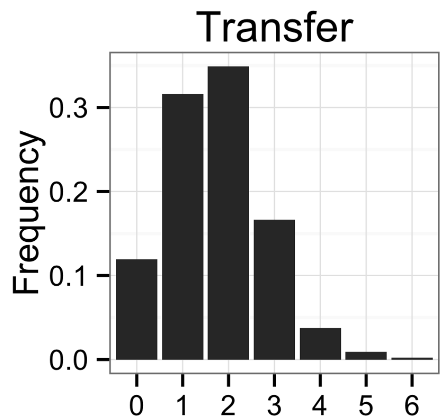
Even on questions where speed is unrelated to the amount of energy (potential), students believed that speed determines energy. This thinking can be seen in the answers to questions that are not explicitly about indicators of energy, such as question 11, the cart with spring, and question 14, the pendulum swinging.

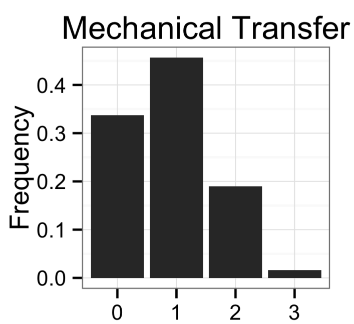
We found other evidence to suggest that students didn't know how to connect speed and energy very well. For some students, it was like a binary statement: a moving object had kinetic energy and a motionless object did not. But, the actual speed (how fast you were going) did not correlate with the amount of energy (how much energy you have).

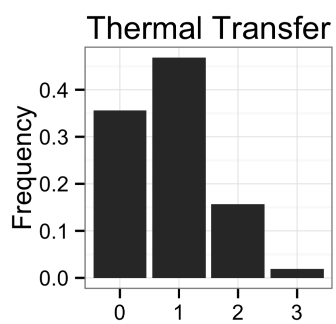
The only exception to the idea that "speed means energy" was in thermal energy, where students were likely considering the bulk velocity, rather than the speed of each molecule.

4.2 Transfer, Transformation, and Flow of Energy

Questions: (thermal only: 6, 8, 9) and (mechanical and thermal: 11, 13, 14)







Some of our questions were about transfer and transformation - do you know where energy flows in a system? These questions were mostly about energy transformation, like from kinetic to thermal energy, and about transfer, like thermal energy leaving an object and going into another object or into the air, or thermal energy traveling from one location to another.

An underlying theme to the students answers in questions about transfer is that they do not recognize conservation of energy. This is evident in both mechanical (question 11) and thermal (question 9) systems.

Students also had difficulty identifying the recipients of energy. This can be seen in Question 14, with the pendulum stopping, as most students did not identify the air as receiving the energy. That's an interesting contrast to question 13, with the box stopping, where most students DID identify the ground as receiving the energy.

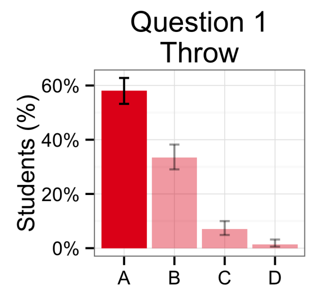
5 Looking at the Data Question by Question

5.1 Kinetic energy questions

Question 1 - Throw

This question was concerned with identification of mechanical energy, specifically motion energy (kinetic energy). Most students answered correctly (A).

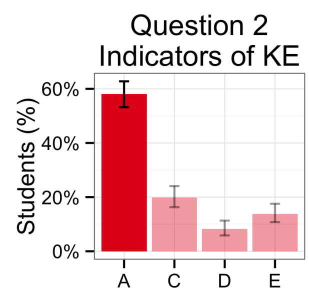
The most common incorrect answer, B, suggests that students do not understand the relationship between movement and kinetic energy. A possible student misconception that would lead to this answer is that there is a transfer of energy from the person to the thrown ball, while the falling ball has no obvious source of energy. This isn't the only place we see the idea that objects only have energy if it comes from a visible source - the hand is an obvious source of energy, but falling might not be connected to a "source" in the same way.



Question 2 - Indicators of KE

Most students correctly identified that the kinetic energy depends on both the mass and the speed of the object.

A nearly equal number of students answered B and D (about 30% of the total). Both of these answers indicate that the speed of the object is not relevant to the amount of motion energy. It is possible that students answering in this way might believe that *any* moving object will have the same amount of motion energy, as long as it's moving. In other words, the amount of motion energy that an object has is determined by whether or not it is moving, not by the nature of its motion.



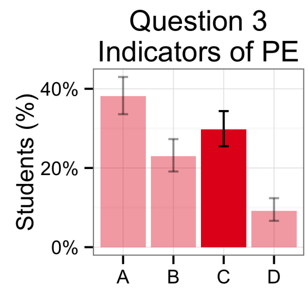
5.2 Potential energy questions

Question 3 - Indicators of PE

A correct answer is that an object's gravitational potential energy depends on its position above the Earth.

The most common answer was that an object's gravitational potential energy depends on both its position *and* its speed. This corresponds to the idea that students believe that energy is related to speed. This is more evident in the students who gave the second most common incorrect answer, that the gravitational potential energy is *only* dependent on speed. In total, over half the students though potential energy depends on speed.

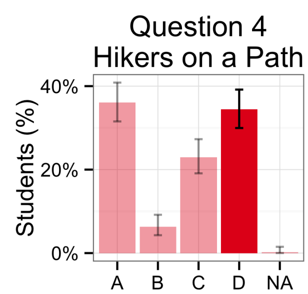
This reasoning is interesting to us because we often "measure" an object's potential energy in terms of the kinetic energy it later attained. Since energy is conserved, that means potential energy is related to kinetic energy. But, that's not what this question is asking, even if it's what some students might be thinking.



Question 4 - Hikers on a Path

A correct answer is that all the hikers have the same potential energy, and it doesn't matter how they got there.

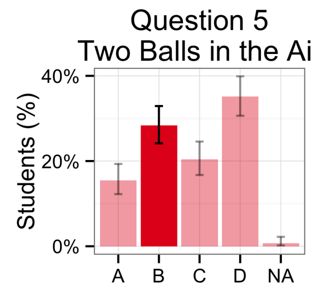
The most common response was that the hiker who took the most direct path would have the greatest gravitational potential energy. This indicates that the students were not considering that height is (the only) indicator of GPE in this case, not the path taken. Instead, they might have thought of the effort involved in climbing the mountain (leading to the highest potential after the steepest path), or they could have thought of the path that used up the least energy to get to the top (so you have more left over), or they could have thought of the shortest path, or the steepest path, or the one you walk the fastest being the one that leads to the highest potential energy. This is a really rich question to have conversations about in class, we think.



Question 5 - Two Balls in the Air

A correct answer is that the gravitational potential energy is only determined by the height above the ground.

Most of the students replied that that for the two balls to have the same GPE at the same point in time, they must have been thrown with the same force. This is only going to be true if they are also thrown at the same time, which wasn't part of the question and isn't always true. The question helps us see that some students were thinking about a cause of energy (the force), rather than the indicator of energy (height) - it's like in question 1, where the source of the energy is important, not the indicators of energy.

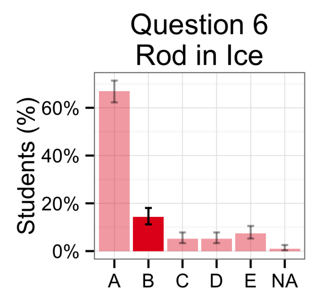


5.3 Thermal energy questions

Question 6 - Rod in Ice

This question is one of two in which the idea of "cold" as a kind of energy comes up. Few students answer correctly.

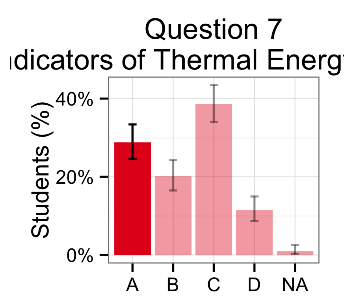
Students overwhelmingly answered that cold had transferred for the lower end of the rod to the upper end. This suggests that the students thought of cold as a property of its own, rather than being the absence of thermal energy. This answer *does* indicate that students understand that metals are thermal conductors, even if they are not thinking of thermal energy the way we would like.



Question 7 - Indicators of Thermal Energy, part I

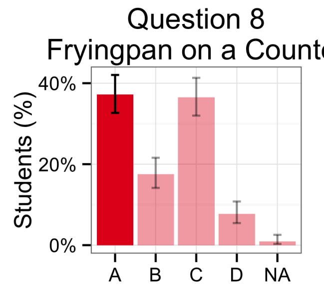
A correct answer is that thermal energy depends on both the type and speed of molecules.

The most common answer was that the type of molecules that make up an object affect the thermal energy of that object, but not the speed of those molecules. We believe that the students might have been thinking of speed on a macroscopic scale. This also suggests that the students were considering only solid objects, rather than liquids or gasses. That the students replied that the type of molecules determine thermal energy suggests that they think of different materials having different properties. For example, metals and concrete feel colder than wood or plastic when touched at room temperature



Question 8 - Frying Pan on a Counter

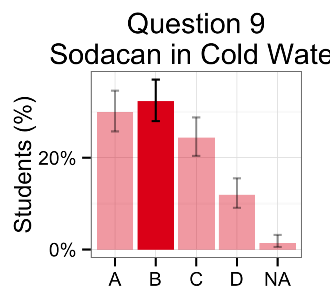
Most of the students answered this question correctly. The most common incorrect answer is nearly the same as the correct answer but also includes coldness being transferred from the counter and the air to the pan. This indicates that the students believe that not only does thermal energy ("warmth") move, but coldness can too. It is possible that the students believe that coldness is a separate (although linked) property from warmth.



It is worth noting that every option for this question includes energy transfer to or from the air. This means that we cannot determine if these students were thinking about the air as an object that can give or receive energy (something that comes up in question 14).

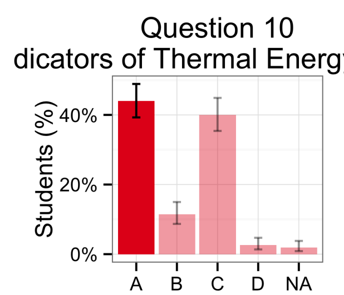
Question 9 - Sodacan in Cold Water

The student responses for this question were spread over several answers, with nearly the same proportion of students answering A and B. Both of these answers include the idea that the thermal energy from the can is transferred into the water. Answer A, however has the water staying at the same temperature, rather than changing, as it does in answer B. This indicates that the students that answered A were not considering conservation of energy. This mistake is understandable, as the change in temperature of the water from the added energy of a single soda can would be small, but non-zero.



Question 10 - Indicators of Thermal Energy, part II

Most students replied with the correct answer, that the thermal energy of an object depends on both the mass and the temperature of the object. However, the most common incorrect answer was that the thermal energy depends on the temperature, but not the mass. Almost nobody replied that the thermal energy does not depend on temperature.



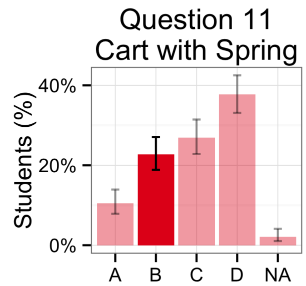
A possible reason for students to think that thermal energy does not depend on mass is because they correlate thermal energy with temperature, which is independent of mass. A student might recognize that two objects of different sizes can be the same temperature, and then conclude they have the same thermal energy.

5.4 Energy Flow Questions (transfer of energy)

Question 11 - Cart with Spring

A correct answer has all the spring energy transferred to the kinetic energy of the cart.

The most common answer was that the cart increases in motion energy, but that the spring still has the same amount of energy. This suggests a student model in which springs have energy regardless of being stretched or compressed - they have the potential to be stretched or compressed, after all. The increased motion energy has to be present, since the cart is moving.



Notably, many students answered that both the spring and the cart would have more energy at the end (answer C). These students might be thinking that the spring gains energy as it extends, either because the spring is moving (motion), or because it is moving toward a state with more energy (evidenced by the car moving). Honestly, we're not sure what to make of this answer...

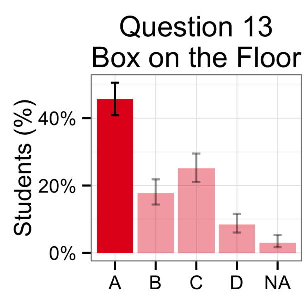
Question 12 - Box on a Ramp

This was a free response question, and we haven't analyzed it for this report...

Question 13 - Box on the Floor

Most students correctly stated that the the kinetic energy is converted into thermal energy.

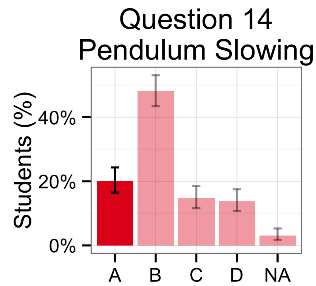
The most common incorrect answer is that the kinetic energy stays the same, and new thermal energy is made. A possible student model for this is that the kinetic energy of an object is the same, so long as it is moving. Since the kinetic energy is the same, the thermal energy must be created, as the box gets warmer.



Question 14 - Pendulum Slowing

A correct answer has the kinetic energy of the pendulum transform to thermal energy which is released into the air.

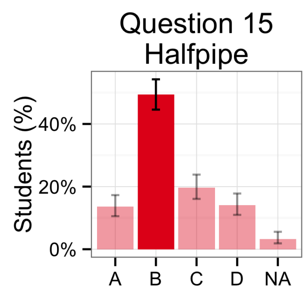
Most students replied that the ball stops swinging because the kinetic energy is used up a little bit each time the ball swings. A student responding this way likely recognizes that there is no more motion energy in the ball, but does not think that the energy was transferred into the air. This student might not recognize that the air is an object that can have energy - thinking of air as an object is hard for a lot of kids.



Question 15 - Halfpipe

Most students provided the correct answer, which is based on thinking about conservation of energy.

The most common incorrect answer was that the ball goes higher than it started. A student answering in this manner might be thinking about a skateboard or snowboard half-pipe, where a skater can add energy by pumping at the right moment, and thus end up higher than when she started. The number of students who said that the ball goes beyond the top of the ramp suggests that some might be thinking of skate parks or half-pipes.



Question 16 - Book on a Table

This was a free response question, and we haven't analyzed it for this report...

Question 17 - Pushing a Spring

This was a free response question, and we haven't analyzed it for this report...