A Grade 3-5 Learning Progression for Energy

Under the NSF-funded exploratory research grant, *Rethinking How to Teach Energy: Laying the Foundation in Elementary School*, our team developed a preliminary learning progression that articulates how specific learning experiences can promote the progressive transformation and integration of students' ideas about energy from Grade 3 to Grade 5. We have identified foundational ideas and practices that are central to a scientific understanding of energy, essential for an informed citizen, and can progressively and meaningfully evolve during the primary grades. And we developed and tested, through exploratory interviews and classroom investigations, a series of key learning experiences that promote such progressive development (Lacy and Crissman, 2012; Wiser, 2012a and 2012b; Lacy et al., 2012).

Based on existing literature and our own research, we have identified ideas that children bring into Grade 3 (Lower Anchor) and the understandings about energy that students could reach by the end of Grade 5 (5th grade Stepping Stone*)*. By Grade 3, students typically believe that people, a car, or a battery-operated appliance have energy, but they do not necessarily believe that a moving ball has energy. They do not believe that energy is transferred, or that it is a quantity. They focus strongly on causal relationships (Goswami, 2008). These preexisting ideas can be roadblocks to understanding if curricula do not account for them, but they can also be important resources for learning if curricula are designed to exploit or address them.

The 5th grade Stepping Stone is the form of the foundational ideas and practices that students could understand by the end of 5th grade, and the contexts in which they could apply them. The goal is not a fully scientific view of energy at the end of 5th grade. Rather it is to give students a sound experiential and conceptual foundation on which to build a more complete understanding through well-designed instruction in middle and high school. To define the Stepping Stone we considered the *Framework* (NRC, 2012a), draft Science Standards (Achieve, 2011) and current research on teaching energy in middle school (Jin & Anderson 2012; Mohan et al., 2009; Nordine et al., 2010). We reviewed existing curricula, consulted a group of elementary school teachers and gathered empirical evidence on how students' ideas can progress when they engage in key learning experiences.

What is the Network of Foundational Ideas?

The principle of conservation is at the heart of the concept of energy in science (Duit, 1981; Elkana, 1974; Goldring & Osborne, 1994; Millar, 2005). Like any conservation principle, it constrains the possible behaviors of a system, telling us, across a vast range of natural phenomena, what *cannot* happen (no matter what it's made out of, a dropped ball will not bounce higher than its starting point). Yet if the principle is taught without experience in why it is useful, how to reason with it, and what kinds of questions it can and cannot address, it is just empty words, and indeed is unlikely to be believed.

The Energy Lens and the Energy Quartet

We propose that energy education focus on how scientists use what we call the "Energy Lens." Energy will be taught not as a discrete topic but as an analytical tool (Jin & Anderson, 2012) or intellectual stance that can be productively used to explore many topics in science and society. Looking through the Energy Lens means observing changes in a system (such as changes in speed and temperature), and knowing that those changes can be understood as indicators of energy changes; knowing that energy loss by an object corresponds to energy gain by one or more other objects or systems; and thinking of those corresponding energy changes as energy transfer. Using the Energy Lens entails asking a set of questions about virtually any phenomenon in the physical world:

- What is the system of interest?
- What physical changes or other interesting behaviors are taking place?

- Where in the system are energy changes occurring?
- Where does the energy come from?
- Where does the energy go?
- What is the evidence for our answers?

Through repeated exposure to these questions in various forms and contexts, students will acquire the habit of mind of asking them – and tentatively answering them – about phenomena they encounter in their daily lives and throughout their science and engineering education. In addition, the Energy Lens provides teachers with an understanding of energy as a crosscutting concept and a common language that can be brought to bear on other science curriculum units.

The specific phenomena and experiences that students encounter are aimed at developing their understanding of four key aspects or strands of the energy concept, the "Energy Quartet":[1]

1. The nature and manifestations ("forms") of energy;
2. Transfers and transformations of energy;
3. Dissipation and degradation of energy;
4. Conservation of energy.

From a scientific perspective the strands do not have equal status. Understanding conservation is the overarching goal, and so stands apart from and above the others. Dissipation and degradation could logically be subsumed under transfers and transformations, but our experience with students and teachers has persuaded us that they deserve their own category. Most importantly, the strands are interconnected, interdependent and concurrent, and they must be interwoven and developed in parallel (Duit & Haeussler, 2004). The idea that the energy stored in a stretched rubber band is the same "stuff" as the energy of a rolling ball makes sense only because one can be transferred to the other. Dissipation makes sense only if "heat" has already been recognized as a form of energy and it has been shown that other forms of energy can be converted into thermal energy (Lacy et al., 2012).

The Energy Learning Progression Map (below) outlines how the four strands will develop across the three grades, including typical activities and connections to the *Inquiry Project* matter curriculum. This outline provides a starting point, and will be revised in an iterative process during future research and development. We sketch here the development of the *Transfers and Transformations* strand from Grade 3 to Grade 5.

In Grade 3 students learn to apply the Energy Lens to easily observed mechanical phenomena. In order to use the Energy Lens, students must adopt a model of energy as something that is transferred between objects or systems, and that manifests itself in different forms (Millar, 2005; Scherr et al., 2012; Swackhamer, 2005). They begin with examples of transfer from one object to another, for example in collisions, or when a battery or twisted rubber band makes a propeller spin. Our interviews show that children can easily link decreases in one object's energy with increases in another's (e.g. a moving marble striking a stationary one) but do not readily conclude that energy is *transferred* from one to the other. Students will observe, describe, and represent coordinated gains and losses in diverse systems of growing complexity. Familiar words like "give" and "share" will be introduced to convey the idea that something is transferred from one object to the other.

In Grade 4 transfer and transformation become a central focus, with many examples of increasing complexity including energy transformations within a single object or system (e.g. a falling ball), and situations involving multiple objects and/or forms, as when an electrical circuit drives a fan and a light bulb. Students begin to observe, and use representations to show, that gains and losses are correlated in magnitude (e.g. a capacitor charged to higher voltage can make a bulb burn brighter and longer). By the

[1] We recognize that some of these terms are controversial, particularly "forms" and "transformations". For a full discussion see Lacy et al., 2012.

Energy Learning Progression Map

Aspect	3rd Grade: Energy and Motion	4th Grade: Energy in Everyday Devices	5th Grade: Food, Fuel and Heat
Nature/ Manifestations ("Forms") of Energy	Energy of motion and stored energy in batteries, springs and elastics. Batteries, springs, elastics have energy because they can cause motion. Indicators (e.g. speed, deformation) as rough measures of amount.	Stored gravitational energy is a property of object/earth system, not just object. Light and sound as carriers of energy. Energy is not matter – energy can transfer even when matter does not.	Thermal energy is a form of energy. No such thing as "cold energy". Food and fuels release stored energy when they combine with oxygen. Sunlight as energy source for organisms, weather, food, etc.
Transfers and Transforma-tions	Energy gains/losses in combination. Gains and losses described as "giving to" or "sharing with." In some transfers form also changes. Introduce "system" for group of interacting objects.	Gains/losses correlated in amount (less/more – not quantitative). More than one form of energy, change of form within single object/system. Choice of system can depend on context.	Thermal energy flows from hotter to cooler objects. Other forms transform into thermal. Thermal energy can transform into other forms, but not completely. Applications to real-world phenomena.
Dissipation/ Degradation	Students speculate about "Where does the energy go?" when the phenomenon stops.	Sound, light, heat can remove energy from the system. "Lost" energy cannot be fully recovered.	Large system may absorb thermal energy without becoming noticeably hotter. Apparently "lost" energy could be thermal energy in the environment. Closed vs. open systems.
Conservation	Must have energy to give energy. Students learn to ask "Where does the energy come from?"	Trace energy flow in simple devices, using pencil & paper and concrete representations. Amount of available energy limits what device can do.	Trace energy flow in diverse real-world systems, including chemical & biological, with environment. Draw inferences, make predictions using energy arguments.
Prototypical Activities	Collisions. Balls, springs, elastics. Propeller (battery, rubber band) All phenomena in horizontal plane.	Simple circuits, capacitor, solar cell. Balls, carts & ramps, pendulum. Magnets Phenomena including height changes.	Hot object in cold water. Chemical hand warmers. Smashing steel spheres burn paper. Fan in insulated box – temp. increase.
Connections to Matter Curriculum	Practices: Asking questions; Carrying out investigations; Developing and using models; Arguing from evidence; Obtaining evaluating, communicating information.	Similarities/differences between energy and matter. Divisibility – energy can be "divided up" like matter, but it doesn't go away. Concept of a system.	Closed vs. open systems. Flow, transfer, transformation. Thermal energy as random kinetic energy – particulate model. Energy in gas expansion, evaporation.

end of Grade 4 students should have the expectation that energy gains and losses occur in combination, and the habit of looking for the loss corresponding to an observed gain, and begin to think of those gains and losses as a transfer – that is, that the energy gained is the same "stuff" as the energy lost.

In Grade 5 the emphasis shifts to thermal energy and includes food and fuels as energy resources. Purely thermal phenomena, e.g., a hot object placed in cool water, provide clear examples of energy transfer. Students will also experience the transformation of other forms of energy into heat and of heat into other forms, helping them accept "heat" as energy. Through activities in which small temperature changes are measured, students will observe the dissipation of energy in the environment, will recognize thermal energy as a ubiquitous byproduct of all phenomena, and include it in tracing energy transfers.

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