The role of language in the teaching of energy: The case of 'heat energy'

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Abstract
This article describes the different terms that scientists, science standards, and science curricula use when describing basic ideas related to thermodynamics. An intermediate proposal is offered to bridge the language discrepancies until the scientific community reaches consensus.

Energy instruction—lots of hot spots, a lot of work ahead
One of the crosscutting concepts in science is that of energy. Energy plays an indispensable role in scientific work. Energy also plays a defining role in geopolitical affairs and economic issues. Recognition of the multiple roles energy plays animates our expectations that our students will 1) learn to represent the detailed story of energy flows in foundational contexts, 2) be able to optimize systems to maximize "useful" energy transfers and minimize "unwanted" transfers, and 3) innovate to meet present and future energy-related problems of unprecedented magnitude in human history.

And yet, energy instruction comes with special challenges. Energy is a very abstract concept, one that cannot be operationally defined (independently of its specific forms). It is also a concept that all scientific and engineering disciplines claim as their own and think about *in different, discipline-specific ways.* Physicists, for instance, rarely care about accounting for energy changes in the environment when they track the energy inputs and outputs of well-defined systems. Chemists often concern themselves more with concepts such as enthalpy and free energy than with energy itself. Many biologists and physicists use different conceptual frameworks for thinking about systems. And the list goes on…

Because of the abstract nature of energy, the role of metaphors becomes indispensable in energy instruction. However, because metaphors are funded by conceptual structures in the mind of the beholder of the metaphor, the choice of words used to communicate thoughts about energy becomes crucial.

Them is fightin' words
Here are three specific examples of well-meaning words that are vacuous at best, and utterly confusing at worst.

"Energy is the ability to do work." How can a physical concept be "an ability?" The following question illustrates—albeit tongue-in-cheek—this conundrum. Is energy the *ability* of the to *do* the multiplication associated with the concept of *work* in physics? And how about the situations when there *is* energy transfer but without macroscopic force or displacement of objects, as in the cooling of a hot cup of espresso? Or the uneasy relationship between this statement and the second law of thermodynamics?

"*Energy is what causes things to happen."* How can energy, whose total value in a closed system (such as the universe) remains the same forever, be the *cause* of changes in said system? How does energy cause hot objects to become colder and cold objects to become hotter? How does energy cause a car to speed up after the light turns green on Monday when the road is dry but not on Tuesday when there is an oil slick at the intersection? How does energy, which remains constant for an orbiting object in a circular orbit, cause the object to change its position?

"Thermal energy is the motion of molecules or atoms in an object." How can a form of energy be motion? And what is motion exactly? Is it the qualitative sense of something being here now and there later? Does a cup of espresso acquire more thermal energy after the car in the drive thru has started to move away from the roadside coffee hut?

Thinking more about this last context is the purpose of this paper.

The instructional dilemma

The words that we use and the way in which we use them are important for learning. Without a common understanding of words we use to convey old and new ideas, meaning is not shared, and new understanding is challenging. So what happens when a teacher is asked to teach about the ideas broadly classified as "thermodynamics"? In other words (irony noted), the theories and explanations that help us make sense of the observations that objects have a property measured by a thermometer, called temperature, and that when two objects with different temperatures are touching or mixed, after a while, they will reach the same temperature. Two of the concepts that are often given specific names when studying thermodynamic phenomena are:

1) The energy associated with an object that is dependent on the object's temperature, and
2) The process by which this energy is transferred from one object to another when objects at different temperatures are in contact.

As the teacher prepares to introduce these ideas to her students, she might turn to college textbooks. Given the diversity of the background of science teachers in this country, it is not surprising that the language a specific teacher might recall will be dependent on the particular science course she remembers the most or the most handy textbook.

For example, if you walked into a university geology course, you might hear the professor describing these ideas like the following:

> *"There is thermal energy within this system. And when you heat the system, there is an increase in thermal energy of the system."*

A lecture in a physics course would likely use the same phrasing. However, in a chemistry class, the professor might say,

> *"When heat flows into an object, the kinetic part of the internal energy might increase."*

And different still would be the description you might hear in a biology course.

> *"When heat is transferred, there is often a corresponding change in the kinetic energy of the molecular motion."*

A limited review of college science textbooks reveals the following language for these four disciplines of science. (See Table 1)

Table 1: Typical Language from College Textbooks.

College Textbooks	**1) the energy contained by an object that is dependent on its temperature**	**2) the process by which this energy is transferred from one object to another when objects at different temperatures are in contact.**
Physics (Halliday, Resnick, & Krane, 1992; Walker, 2009)	Thermal energy	Heat, Heating
Biology (Freeman, 2010)	Thermal energy, Kinetic energy of molecular motion	Heat is transferred
Chemistry (Timberlake, 2009)	Kinetic part of the thermal energy, Heat	Heat flows
Geology (Chernicoff & Whitney, 2006)	Thermal energy	Heat, Heating

The next step in preparation the teacher would take is to review the curriculum and teacher resource materials to see how these ideas developed through the lessons. Again, this review would yield different results depending on the curriculum the teacher uses. (See Table 2)

Table 2: Language used by common pre-college science curriculum

Common Middle and High School Curriculum	**1) the energy contained by an object that is dependent on its temperature**	**2) the process by which this energy is transferred from one object to another when objects at different temperatures are in contact.**
Modeling Instruction (Wells, Hestenes, & Swackhammer, 1995)	Thermal energy, Translational part of the kinetic energy of the molecules	Heat, Heating
PET, Interactions (F. Goldberg, Robinson, Otero, & Thompson, 2007; Fred Goldberg, Bendall, Heller, & Poel, 2006)	Thermal Energy	Heat energy transfer

Living by Chemistry (Stacy, 2006)	Average kinetic energy of particles	Heat
Conceptual Physics (Hewitt, 2001)	Thermal energy Kinetic part of the internal energy	Heat is transferred
IQWST	Thermal energy Total kinetic energy of all the particles	Heat, Heated, Heating Thermal energy is added/removed
Properties of Matter –STC (National Science Resources Center, 2000)	Heat, Heat energy	Heat

If the teacher noticed a conflict in language, the next place she might turn would be her state's science standards documents. These documents are often used by a teacher to decide what common language she would encourage in her classroom as students grasp for words to name the ideas they are exploring and testing in class. As in previous searches, the exact words used would depend on the state the teacher is teaching. But even more concerning would be that many states use a wide variety of words to describe these concepts. (Table 3 below shows the wide range of terms used by the state science standards and Figure 1 illustrates the number of terms used by each state for each of the concepts.)

Table 3: Language used in the state science standards documents

	1) the energy contained by an object that is dependent on its temperature	**2) the process by which this energy is transferred from one object to another when objects at different temperatures are in contact.**
State Standard Language (See Appendix A)	Heat, Heat energy, Thermal energy, Kinetic energy Internal energy	Heat, Heat (energy) transfer Heat flow, Heating/heated Thermal energy transfer Absorb/release/gain/lose/dissipate/move heat

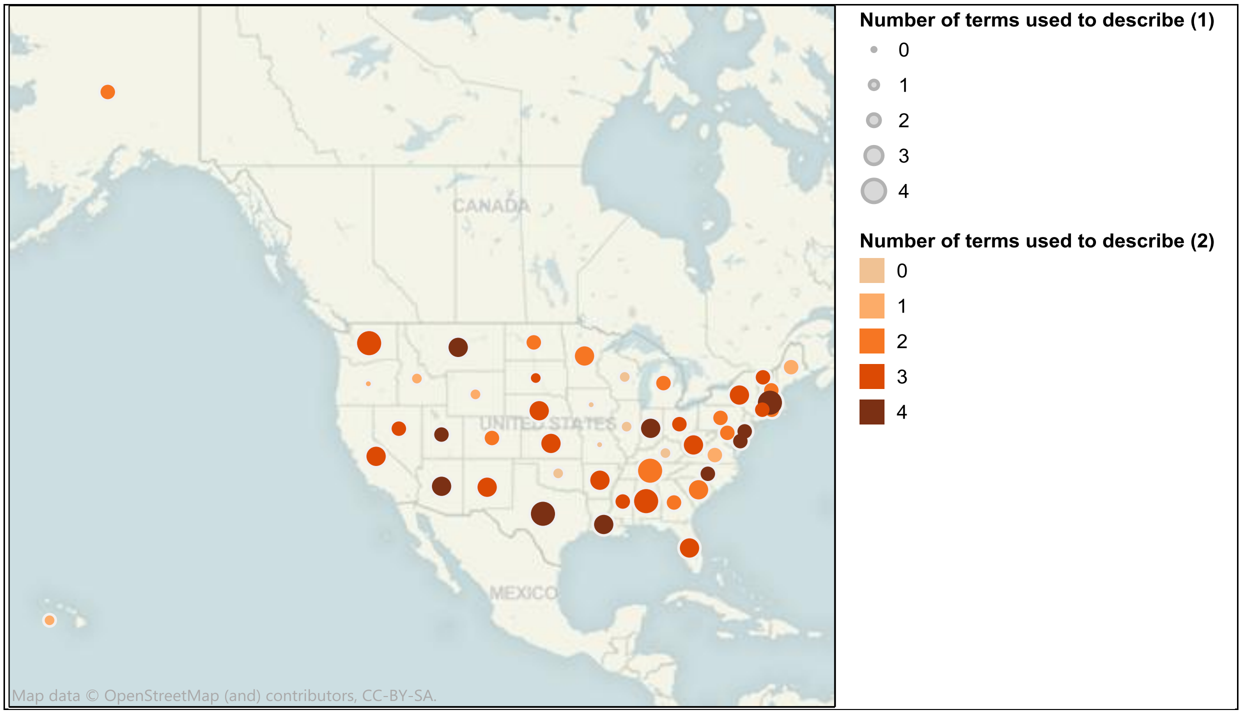

Figure 1: Number of different terms used to describe (1) the energy of an object and (2) the process of transferring the energy due to the temperature of an object.

The teacher who might be both confused and frustrated at this point might finally turn to the national standards, benchmarks, and frameworks that have been produced over the years. However, as was the case in all previous searches, these documents would only reinforce the confusing landscape for the teacher. (See Table 4)

Table 4: Language used in the national science documents

National Documents	1) the energy contained by an object that is dependent on its temperature	2) the process by which this energy is transferred from one object to another when objects at different temperatures are in contact.
National Science Education Standards (National Research Council, 1996)	Heat	Heating Heat can move
Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993)	Heat, Heat energy,	Transfer of heat
Benchmarks for Science Literacy (American Association for the Advancement of Science, 2010)	Thermal energy	Thermal energy is transferred Heating Heat flow Heat is transferred
Science Framework for the 2011 National Assessment of Educational Progress (National Assessment Governing Board, 2010)	Heat, Thermal energy	Heating

Further complicating the dilemma for the teacher is the laypersons' (i.e., students') use of the word "heat." In everyday conversation, "heat" is commonly used to describe both a process (to heat something) and a property of objects that are hot compared with their surroundings (it has a lot of heat). This latter use often leads to the confusion between heat energy and temperature.

Intermediate Recommendations

One of the goals of science is, through consensus, to arrive at agreed upon theories that explain natural phenomenon. In the service of this goal, scientists spend a great deal of time agreeing upon the language that describes the ideas. Rarely is there a well-established theory or phenomenon for which there is no consensus on the language we use to describe it. However, with the topic of energy, we find that we do not have consensus. Part of the reason for this is that energy is a concept that is cross-disciplinary, but science is often still siloed into its traditional domains.

Language used in science should eventually have shared meaning for students. When the scientists, standards, and curriculum are all conflicting, what is a teacher to do?

Since there is no scientific consensus yet, teachers clearly will need to continue to make their own professional decisions informed by the material that have to teach about these topics. This will remain the case until we, as a nation, write and adopt common core science standards, following the lead of the math and language arts educators. (Council of Chief State School Officers & National Governors Association Center for Best Practices, 2010)

We do have two intermediate recommendations for educators. First, we suggest teachers qualify with the word "energy" whatever terms they choose to use, as in "the object contains heat **energy**" or "there is heat **energy** transferred from the warmer object to the cooler object."

While this recommendation may seem trivial, the emphasis on "energy" as a model used to describe the phenomenon involving temperature differences will go a long way for the student's future studies in any science discipline. In addition, whatever words students encounter in their next science class to describe these concepts will fit into an existing framework of energy.

The second recommendation is one informed by research on student learning in science that may already be a part of the teacher's repertoire of instructional practice. While introducing these ideas, begin first with the phenomena and observations, for which you want to build a scientific description. Next, as students begin to use new and different language to try to explain their observations, ask students to qualify exactly what they are describing.

For example, a classroom dialog after an investigation in which two samples of water at different temperatures are mixed might look like the following.

> *S: I think that heat is shared by the hot and cold water when they are mixed.*
>
> *T: Can you tell me what you mean by "heat"?*
>
> *S: It is related to the temperature of the water. The hotter water has more heat, so it gives some to the colder water until the heat evens out.*
>
> *T: Hmm, did the cold water change its temperature the same amount as the hot water?*
>
> *S: No, the hot water changed a lot more, but that is because there was less hot water compared with the cold water.*
>
> *T: So it looks like the cold water increased its temperature by 5 degrees, while the hot water decreased its temperature by 15 degrees. So the temperature changes were different, but you started by telling me that they water shared the "heat". If that were true, then the "heat" must not be temperature exactly. Is "heat" a form of energy?*

S: Yes, heat is energy that moves from the hot water into the cold water. The heat energy keeps moving until the hot and cold water reach the same temperature. Since there is three times as much cold water as hot water, the cold water did not change its temperature as much as the hot water did.

T: So it sounds like you are saying that "heat energy" is the energy that moved from the hotter object to the cooler object.

S: Right.

T: This seems to fit the data. Do we know anything about the energy in the hot and cold water to start with or just about the amount of energy that the hot water gave to the cold water?

S: I think there is more heat energy in hotter objects, but it also seems like there might be more heat energy if more massive objects. So I am not sure.

T: OK. For now then, let's focus on the heat energy that is moving from a hotter object to a cooler object until the objects reach the same temperatures.

While many class discussions would look different, the essential aspects of this conversation are common. Quite often students are confusing temperature with energy and confusing the energy that is moving from hot to cold with the energy contained within an object. While this short dialog might not have changed the student's understanding of these ideas, it probably has gotten him to start thinking about temperature and heat energy as distinct ideas. Also, the student might now be aware that from this investigation we can compare the energy that is moving from the hot to the cold object but not the energy contained within the objects. The emphasis on communicating a deep understanding should serve students well in any course they will encounter in their future studies.

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http://www.spu.edu/depts/physics/tcp/examples.asp.

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Appendix: State Science Standards

	Link to Science Standards (or a download page)
AL	http://alex.state.al.us/browseSC.php
AK	http://www.eed.state.ak.us/standards/pdf/standards.pdf
AZ	http://www.ade.state.az.us/standards/science/downloads/ScienceStandard.pdf
AR	http://arkansased.org/educators/pdf/science_k-8_011006.pdf
CA	http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf
CO	http://www.cde.state.co.us/scripts/allstandards/COStandards.asp?stid=7&stid2=0&glid2=0
CT	http://www.sde.ct.gov/sde/lib/sde/pdf/curriculum/science/PK8_sciencecurriculumstand

	ards2009.pdf
DE	http://www.doe.k12.de.us/infosuites/staff/ci/content_areas/files/science/dapa_Science Standards.pdf
FL	http://www.floridastandards.org/Downloads.aspx
GA	https://www.georgiastandards.org/Standards/Pages/BrowseStandards/ScienceStandards.aspx
HI	http://www.hcps.k12.hi.us/PUBLIC/contst1.nsf/2be12f699cdba2840a2567830069239d/fbc32f9bf7fcc6bd0a2567e000146fc7/$FILE/Science%20Booklet.pdf
ID	http://www.sde.idaho.gov/site/content_standards/science_standards.htm
IL	http://www.isbe.state.il.us/ILS/science/standards.htm
IN	http://dc.doe.in.gov/Standards/AcademicStandards/PrintLibrary/docs-core/2008-06-09-corestandards-science.pdf
IA	http://www.iowa.gov/educate/index.php?option=com_content&view=article&id=1350&Itemid=2287
KS	http://www.ksde.org/Default.aspx?tabid=144
KY	http://www.education.ky.gov/NR/rdonlyres/6C5BD824-B2E3-4D10-B219-7878176323DC/0/SPLDScience.pdf
LA	http://www.doe.state.la.us/lde/saa/1842.html
ME	http://www.maine.gov/education/lres/scitech/documents/sci_tech102207.pdf
MD	http://mdk12.org/assessments/vsc/index.html
MA	http://www.doe.mass.edu/frameworks/scitech/1006.pdf
MI	http://www.michigan.gov/documents/mde/Complete_Science_GLCE_12-12-07_218314_7.pdf
MN	http://education.state.mn.us/mdeprod/groups/Standards/documents/Publication/013906.pdf
MS	http://www.mde.k12.ms.us/acad/id/curriculum/Science/Webpage%20links%207%2031%2008.htm
MO	http://dese.mo.gov/standards/science.html
MT	http://www.opi.mt.gov/pdf/standards/09ScienceELE.pdf
NE	http://www.education.ne.gov/science/Documents/2010ArticulatedScienceStandards.pdf
NV	http://nde.doe.nv.gov/Standards_Science.html
NH	http://www.education.nh.gov/instruction/curriculum/science/documents/framework.pdf
NJ	http://www.state.nj.us/education/aps/cccs/science/frameworks/2009progressions.pdf
NM	http://www.ped.state.nm.us/MathScience/dl08/Standards/ScienceStandardsV2.pdf
NY	http://www.p12.nysed.gov/ciai/cores.html#MST
NC	http://www.ncpublicschools.org/docs/curriculum/science/scos/2004/science.pdf
ND	http://www.dpi.state.nd.us/standard/content/science/science.pdf
OH	http://www.ode.state.oh.us/GD/Templates/Pages/ODE/ODEDetail.aspx?page=3&TopicRelationID=1705&ContentID=834&Content=88581
OK	http://sde.state.ok.us/Curriculum/PASS/Subject/science.pdf
OR	http://www.ode.state.or.us/teachlearn/real/standards/sbd.aspx
PA	http://www.portal.state.pa.us/portal/server.pt/community/state_academic_standards/

	19721
RI	http://www.ride.ri.gov/Instruction/gle.aspx#science
SC	http://ed.sc.gov/agency/Standards-and-Learning/Academic-Standards/old/cso/standards/science/index.html
SD	http://doe.sd.gov/ContentStandards/index.asp
TN	http://www.tn.gov/education/ci/sci/index.shtml
TX	http://ritter.tea.state.tx.us/rules/tac/chapter112/index.html
UT	http://www.uen.org/core/science/index.shtml
VT	http://education.vermont.gov/new/pdfdoc/pubs/grade_expectations/science.pdf
VA	http://www.doe.virginia.gov/testing/sol/standards_docs/science/2010/complete/stds_all_science.pdf
WA	http://www.k12.wa.us/Science/pubdocs/WAScienceStandards.pdf
WV	http://wveis.k12.wv.us/Teach21/public/cso/cso.cfm
WI	http://dpi.state.wi.us/standards/sciintro.html
WY	http://www.k12.wy.us/SA/standards/Standards%202008%20Science.pdf