International Journal of Environmental & Science Education
(2013), 8, 521-534

Exploring high school students' perceptions of solar energy and solar cells

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Received 11 July 2012; Accepted 26 April 2013

Doi: 10.12973/ijese.2013.216a

Although studies examining student understanding of key concepts are common throughout the science education literature, few have examined science concepts linked to conservation or environmental issues such as global warming and alternative energy. How students make sense of these complex concepts has the potential to influence their role as future decision-makers; it therefore becomes important to explore this baseline knowledge, especially when such concepts receive limited discussion in typical school curricula. In this study, a questionnaire incorporating both multiple choice and open-ended responses was administered to high school sophomores to better understand their conceptions of solar energy and photovoltaic cells. Analysis revealed that while students reported familiarity with photovoltaic cells, there was confusion as to how they actually worked. An underlying misconception involved the roles of light or heat from the sun in the function of these solar cells. Implications for instruction and future research are suggested.

Keywords: energy misconceptions, environmental science, photovoltaic cell, solar energy

Exploring High School Students' Perceptions of Solar Energy and Solar Cells

If we wish to develop new advocates for the environment, who look critically at current issues such as global warming and carbon emissions impacts, we might consider targeting high school students on the threshold of becoming drivers (and thereby extensive fuel consumers.) Unfortunately such environment- and conservation-related topics receive limited explicit attention in K-12 state and national science standards. The National Science Education Standards do mention several energy-related topics, such as energy transfer, energy as a fuel that can be stored, used and exhausted, global climate and chemical reactions that result in urban smog (NRC, 1996), yet environmental science is still not considered an important subject on par with biology and chemistry (Coyle, 2005). In the Science Content Standards for California Public Schools, solar energy is mentioned through the discussion of food webs as it is transformed to other forms of energy (grades 4 and 6), but little is mentioned about its utilities as an alternative source of energy (CDE, 1998). In California, the Education and Environment Initiative (EEI) has led to the development of standards and the design of curriculum components that examine the interaction and interdependence of human societies and natural systems (California Environmental Protection Agency, 2007). The emergence of such initiatives, in California and other states, suggests that environmental education may soon become a mandatory component of public education, but the extent to which such efforts make their way into an already crowded curriculum remains to be seen.

Nevertheless, as society begins to consider more seriously the alternatives to fossil fuels and the growth of 'green' industry, understanding of the science and technology related to energy becomes more and more important. Not only does this include awareness of the impacts of using such energy sources, but also understanding just how these different alternatives actually work. In their investigation of museum visitor's conception of environmental radiation and the effectiveness of a related exhibition, Henriksen and Jorde (2001) questioned whether providing a stronger scientific basis for decision-making related to concepts such as ionizing radiation and global warming (via an exhibition), could change or strengthen positions on relevant environmental issues. Their study indicated that the exhibition did indeed help to influence visitor understanding and subsequently led to a decrease in 'opinion-based' reasoning for environmental stance. For the same reason, we would suggest that students who understand the basic principles behind photovoltaic cells and other alternate energy sources (such as wind turbines) would be more likely to be better informed in their decision-making (at both personal and public levels.) In addition, we feel that such perspectives would help students to be better informed regarding *their* potential to become part of a new workforce surrounding these 'green' technologies.

The Challenge of Conceptual Change

Because students already have ideas about how the natural world works, high school science teachers often face a daunting question: "What do students know and how can I use that information to support instruction?". Indeed, a constructivist perspective on learning suggests that humans generally construct an understanding of the world based on observations and experiences inside and out of school. This understanding is subsequently used to organize ideas, make predictions, and provide explanations that may or may not be consistent with established scientific knowledge. Consequently, upon entering the science classroom, students often interpret scientific (and environment-related) phenomenon in ways that are radically different from the teacher's or the scientist's perspective (Driver, Squires, Rushworth, & Wood-Robinson, 1994). Changing students' minds and helping them more deeply understand a phenomenon that is inconsistent with their current knowledge structure requires conceptual change. Such changes can be as simple as helping students re-organize concepts (e.g. humans are not different from mammals, but rather are a *kind* of mammal) to more complicated restructuring of longstanding networks that are generally resistant to change (NRC, 2007). Such efforts first require a better picture of what conceptual structures currently exist; this then allows us to better strategize how best to build on or revise current knowledge in ways that lead to more effective predictions and explanations of the natural world.

Prior Knowledge about Energy Alternatives

Research on student understanding of renewable or alternate energy sources is almost non-existent (see for instance Solomon, 1985), although several studies have examined public attitudes related to alternative energy (see for instance Bang et al., 2000; Kinsey, Haines & Peterson, 2003; Krohn & Damborg, 1999). In 2002, the National Environmental Education and Training Foundation (NEETF) published its tenth annual national report card on energy knowledge, attitudes and behavior. The report, based on randomly selected telephone interviews with 1,503 adults (over age 18), suggested that a majority of Americans (75%) rated themselves as having a lot of knowledge about energy issues and problems. In addition, approximately 90% of the respondents in the NEETF survey indicated that energy conservation should be taught in our schools. Yet when asked to complete a short 'energy awareness' quiz, only 12% were able to pass the quiz. For instance, only 36% of adult participants were able to identify 'burning oil, coal or wood' as the primary source of energy in the United States. The report suggests that while Americans generally respond positively to the importance of energy alternatives and conservation, they overestimate their understanding of these concepts.

The National Energy Education Development (NEED) project provides educational materials and a weeklong training for teachers participating in special grant-funded workshops. A variety of hands-on educational kits and information about other resources and suppliers is made available to every teacher. In order to assess the effectiveness of the program, NEED has conducted pre- and post-program surveys for participating students (NEED, 2003). The polls are designed for different grade levels (primary, elementary, intermediate, secondary) and test student understanding of basic concepts related energy and resource use. Although the NEED survey was originally designed as a pre/post-test to examine the effectiveness of a particular curriculum, examination of the pre-test findings do provide a useful baseline of student understanding. As with the adults, students were generally unable to correctly identify which energy source produced most of our electricity (25% of elementary/middle school students, 50% of high school students). Although the NEED survey does provide some information regarding student understanding of these concepts, it is important to recognize that it consists of multiple choice questions with specific answers provided. The NEED assessment does not allow for student explanations, nor does the report indicate which incorrect answers were common— both pieces of information that would help identify student misconceptions. Furthermore, although some of the NEED programming involves discussion of solar energy and solar (photovoltaic) cells, none of the poll questions specifically addressed the student knowledge of solar cells, nor how this technology actually works.

Misconceptions Related to Energy

Understanding how energy alternatives work is further complicated by the abstract nature of energy itself, as well as the everyday use of the term. For instance, although a scientific definition of energy might be 'the ability to do work' or 'the ability of matter to cause changes' (Stepans, 2003), the term is used more liberally in common language, sometimes described in terms of fuel, activity level or even a person's mood. Understanding these scientific definitions is difficult since energy is intangible — we can sense changes caused by energy, but not really the energy itself. Several researchers have identified challenges to student understanding of energy concepts (Driver et. al, 1994; Trumper, 1990; Watts, 1983), including perceptions of energy as force, fuel or fluid, as well as something that is 'used up.'

Several studies have looked at conception of energy with respect to the complex concepts of the greenhouse effect and global warming. In their study of elementary students' understanding of the greenhouse effect, Koulaidis and Christidou (1999) noted that students were more likely to refer to the sun as a source of thermal energy, than a source of light energy (or radiation). They also noticed that in many cases, students did not distinguish between the different forms of energy yielded by the sun, resulting in terms such as ultraviolet rays, sun rays, and heat rays essentially being used interchangeably. Several other studies of environmental issues and the greenhouse effect suggest similar confusion between thermal and light energy when considering the role of the sun (Choi, Niyogi, Shepardson, and Charusombat, 2010; Henriksen and Jorde, 2001).

While there is some evidence to demonstrate student misconceptions regarding 'sun's energy', there is a dearth of published studies documenting students' (or the general public's) conceptions of energy transformation (e.g. from electricity to heat or light) or more specifically how people make sense of technology related to energy production (e.g. wind turbines, photovoltaic technology) (Kisiel, 2008).

The purpose of this exploratory investigation was to add to this limited knowledge on student understanding of alternative energy sources — specifically solar energy and photovoltaic cells. Such knowledge should provide a useful baseline as we consider how best to promote public understanding of science and environmental issues.

Methodology

Research Questions

This exploratory investigation sought to identify high school students' underlying conceptions of solar energy and photovoltaic technology. Two questions guided the inquiry: 1) To what extent do students understand how solar (photovoltaic) cells work? and 2) To what extent do students recognize the role of light energy in the production of electricity from solar cells?

Sample

A sample of 327 high school students from ten different sophomore Biology classes (student ages 14-15), and two different teachers, were invited to participate in the study, which was conducted within a single Southern California high school. The student demographics in this school of 2,300, are similar to those of other schools in the region and represent a multi-ethnic community comprising primarily of students of Latino (49%), white (35%), Asian (8%) and other (8%) ethnicities (Filipino, African American, American Indian and Pacific Islanders), (CDE, 2010). The targeted population for this study reflected boys (47%) and girls (53%) enrolled in both advanced (46%) and general biology (54%) classes. The high school, located in southeast Los Angeles County, serves a local middle class community, not unlike other communities throughout Southern California. A small number of students are bussed to school, and about 11% students are on the free/reduced price meal program suggesting that students come from neighboring communities and belong to varied economic strata. This school might be considered as a representation of the local community and a survey among these students likely reflects the general thinking patterns consistent with many high school students in California.

The research project was introduced to students, and the necessary parental consent forms and individual assent forms were provided, as per University Internal Review Board (IRB) requirements. The necessary forms were collected over a few weeks, resulting in a final sample of 196 students used for the study. Those students without parental consent were asked to participate, as their responses would be useful for informing the co-author's science instruction- however, their comments were not incorporated into the data set used for the research project.

Energy as a topic is obvious in all content areas (earth, life and physical science) of the science standards as mandated by the California Environmental Protection Agency (2007). Life science standards (including biology) emphasize the role of sunlight as the energy source for the formation of energy pyramids, food webs and ecosystems, as well as its role of sunlight in photosynthesis. The co-author of the investigation, one of the two participating teachers, has also recently coupled discussion of solar energy and photovoltaics with her discussion of photosynthesis in her high school biology. The choice of this teen population sprung from this innovative curriculum choice and the desire to understand how students made sense of a topic not explicitly expressed as part of the curriculum (up to that point.) It is important to note, however, that data used for this study was collected several months *prior* to the instructional unit in the biology class that includes discussion of photosynthesis. As such, the students surveyed would not have been exposed to high school science curricula that promote understanding of solar energy or energy transfer.

Data Collection

A combination of multiple choice and open-ended questions were used to assess student knowledge and understanding about solar energy and solar cell technology. A seven-item survey, including both multiple choice and open-ended questions, was administered to all students in all participating students on the same day (See appendix for full survey.) During the survey, students were directed to look at small solar cells (photovoltaic panels) that were placed at clearly visible locations in both classrooms, to serve as a reference for the survey questions. An image of a solar panel was also included on the questionnaire itself for further clarification. Several questions were used to target expected misunderstandings, based in part on findings from an earlier study of public understanding of solar energy (Kisiel, 2008) as well as related literature (Coyle, 2005; Henriques, 2002; Solomon, 1985). Keeley, Eberle and Farrin (2005) used multiple-choice format for their formative assessment probes for classroom teachers, with known or expected misconceptions as possible explanation choices. A similar pattern was used in this study to address known misconceptions from earlier studies and classroom observations. Open-ended responses were also used to help to clarify the sources of misconceptions, as well as allow for the exposure of other possible areas of confusion few studies in this area of inquiry, such as those implemented as part of the NEED project, have allowed for such student elaboration. This triangulation of qualitative and quantitative data ultimately allows for greater validity and an interpretation of findings more indicative of student understanding (Patton, 1990). A pilot survey was tested using older students (11^{th} and 12^{th} graders) on the campus who had already taken Biology. Responses from these volunteers were used to clarify both multiple-choice and open-response questions and ultimately improve the validity of the survey.

Analysis

Analysis of student responses included both quantitative and qualitative approaches. Data generated from multiple-choice questions resulted in descriptive statistics that included frequencies and cross-tabulations (including chi-square analyses) that allowed for comparisons between subgroups (e.g. students with accurate vs. inaccurate conceptions). Responses for open-ended questions were examined via an iterative process to identify recurring patterns resulting in categorization of student ideas (Patton, 1990). Some categories were similar to those used in previous studies (Kisiel, 2008) although new categories surfaced from the data. Repeated evaluation of designated categories, reorganization of categories and collaborative discussions between co-authors, helped to validate the data. Qualitative data were initially coded by the lead author; these designations were then checked independently by the co-author, using the same category criteria. Disagreements were re-examined and discussed, resulting in further refined criteria and consistency across the data set.

Once the range of responses was identified for each question, response frequencies were calculated to provide a better understanding of common responses for this population. Because different students occasionally skipped different questions, the total number of useful responses varied slightly for each question. Rather than completely dismiss any questionnaire that was not completed in its entirety, which would result in a lower sample size overall, the researchers chose to look at the effective sample size for each question. This approach allowed for capture of *all relevant* responses for each question and resulted in percentage calculations that are more representative of those students responding to particular questions. The effective sample size has been reported for each question as part of the analysis.

Findings

Student Familiarity and Understanding of Photovoltaics

To ensure that students had a shared conception of 'solar panels,' a picture was provided to the students at the start of the survey, and a small version of an actual solar panel was placed on display in the classroom. Students were initially asked whether they had ever seen a solar panel, and if so, where they had seen it. Most students (94%) indicated that they had some familiarity with solar cells. They reported seeing solar panels outdoors (on streets, deserts and beaches-40%), on rooftops (38%), in previous classes (23%), in appliances such as garden lights and calculators (10%), and in the media (15%).

A simple open-ended question "How do you think the solar panel works?" provided the students an opportunity to describe in detail, what they know about solar panels. In many cases, students did not provide complete descriptions of the mechanism, but rather key components or steps. Several categories of responses were developed for this question, addressing a range of student ideas (see Table 1). A small number of respondents (3%) provided accurate and detailed explanations of the photovoltaic process light exciting the electrons to generate an electrical current consistent with a full scientific explanation. A larger number (17%) of student provided a more generalized, but essentially correct explanation, involving two key components: light (or sun's radiation) and the conversion of energy to electricity.

Most of the other responses suggested parts of the process, typically without a complete mechanism. Note that these additional categories are not mutually exclusive, as students often provided multiple ideas. For instance, numerous responses correctly identified one of the key components of the photovoltaic mechanism, either the light (without mentioning electricity) or the generation of electricity (without specifically mentioning light energy). Such responses, though correct in part, did not explain the entire process. Approximately one third of the students mentioned some kind of *energy transformation* ('converts energy from sun') while a similar proportion of respondents mentioned *energy absorption* ('takes in sun's energy') without referring to a specific source or the final product of electricity. A smaller group (8%) of students suggested that solar panels could be devices that *stored* energy and would run electrical appliances when there is no sunlight.

The variety of responses from this initial question, and the different perceptions of sun as an energy source led to a second categorization of student explanations. For this analysis, responses were coded to find out whether students understood that the photovoltaic panels relied specifically on *light energy* from the sun rather than *thermal* (heat) energy to generate electricity. Student responses ranged from mentioning light, heat, both heat and light or in most cases just 'sun energy' in general. All responses were categorized into mutually exclusive groups (see Table 2).

Table 1. *Student explanations of solar panels*

Explanation Category	Description	Sample responses	% (N = 178)*
Photovoltaics	Responses that specified electron flow of light energy to electricity.	Solar cells are made up of electrons and when the sun's rays hit them, some electrons come loose….The loose electrons … begin to move around and it generates energy. This energy is brought out of the panels through wires and they go through boxes where they are converted into usable electricity-A72	3%
Light transformed to electricity	Responses that mentioned sunlight as the source of energy that transformed to electricity.	Solar panels absorb sunlight and convert it to electricity-B24	17%
Light energy as an input	Responses that mentioned the light (*photo)* aspect.	It absorbs sunlight….-A57	16%
Electricity as an outcome	Responses that mentioned the electricity (*voltaics)* aspect.	It feeds off the sun's energy which gives off electricity-A55	13%
Energy transformati-on	Responses that mentioned heat or energy more generally as being transformed.	I think solar panels collect the sun's rays and is able to convert that heat into energy-B70	32%
Energy absorption	Responses that mentioned absorption of energy generally.	They absorb energy from the sun-A53	28%
Energy storage	Responses that mentioned solar panels as storage devices.	The panels would store the sun's rays and use it later on as energy-B34	8%
Incoherent or incomplete responses	Responses that did not address the question	Provides energy-A59	5%

Note: Sample size reported in this table (and subsequent tables in this study) is based on those students who effectively responded to the question. Blanks and illegible responses were not included in the sample size.

Responses that did not mention a source in their response or did not respond to the question were excluded from the total number for percentage calculations resulting in an effective sample size of 170. (This approach demonstrates the researcher choice to maximize available responses for each question, as described earlier.)

Table 2. *Student explanations categorized by energy type*

Energy Type Mentioned	Examples	% (N=170)
Light	It absorb[s] sunlight and convert[s] it into energy-A44	41%
Heat	It collects the suns heat rays and uses its heat as energy-A71	8%
Light and Heat	The solar cells on a solar panel absorb light and heat, and the light and heat cause chemical reactions in the cells like batteries. This produces electricity-B50	3%
Sun	Solar panels take in the sun's energy-B39	48%

For this alternate coding scheme, responses that mentioned sunlight, brightness or radiation were coded as indicating a *light* source. A large number of students (41%, n=170) referred to light as source, although it is important to note that not all of these students necessarily described the complete photovoltaic process. Responses that referred to heat, warmth, or temperature were categorized under the *heat* category (8%). Some of the responses (3%) specifically mentioned both thermal and light energy being absorbed by the solar panels and such responses were placed in the third category. Finally, explanations that mentioned 'sun's energy' in a general sense were placed under the 'sun' category. Nearly half (48%) of the responses used the general term 'sun's energy'; given the open-ended nature of the question, and the lack of additional probing for this paper-and-pencil survey, and it was difficult to say whether these students made the distinction between the two aspects of solar energy.

The Role of Light or Heat

Student understanding of the energy source for photovoltaic cells was further probed by directing student attention to practical applications and possible explanations. For instance, students were given the prompt "Solar panels work better when there are clear skies. Why do you think so?" with four possible responses: a) Because the solar panels absorb heat from the sun; b) Because the solar panels absorb light from the sun; c) Because the solar panels absorb both heat and light from the sun. d) Any other reason. About a third (36%) responded correctly indicating absorption of light as the reason; a smaller number of students (13%) suggested that absorbing heat led to better efficiency of solar panels during clear skies. However, more than half (58%) of the students responded that both light *and* heat improved panel effectiveness, again suggesting an underlying confusion or misconception of heat as a contributing factor in the function of photovoltaic panels. A crosstab comparison revealed that students who correctly identified the role of light in the initial open-ended question were *more likely* to answer this question correctly, understanding that clear skies allowed for more light, which allowed solar panels to be more productive [$\chi^2(1) =6.62$, p=0.01].

An additional question was developed to further understand misconceptions related to heat as a possible factor in the efficiency of photovoltaic cells. Students were given a scenario where hot air (via a hair dryer) was blown onto one solar panel, while cold air was blown on another. They were then asked to predict which panel would 'work better' under those conditions. They were also permitted to choose 'both would work the same' or 'not sure' as responses. Because thermal energy does not play a significant role in the efficiency of a photovoltaic cell, the most accurate response would be 'both would work the same.' Yet only 15% of the students selected that correct option. Nearly half (51%) responded that the PV cell with the hot air would work better; nearly one third indicated that they were not sure, and only a few students (3%) suggested that the 'cold air' cell would work better. Furthermore, unlike the question about clear skies, chi square analysis suggests that students who correctly identified the role of light for solar panel function (in the initial question) were NOT any more likely to recognize that the temperature of the air (i.e. heat) doesn't really affect solar cell performance [$\chi^2(1)=0.0671$, p=0.42].

The confusion of the role of heat and light was further demonstrated when students were asked what time of day solar panels worked best. The intent was to see whether students understood how the angle of incident light impacted the efficiency of photovoltaic panels. Although 72% of students (n=192) reported correctly that 'middle of the day' was best, several different rationales were provided. Analysis of these open-ended responses showed that nearly a quarter (24%) of those who identified mid-day as being the best time made reference to the proper angle of the sun, while another 24% simply reported light was brightest during that time. Again, however, a significant number of students (22%) indicated that the heat of the sun (or heat AND light) was greatest mid-day, thereby allowing the panels to work best then. And as with the initial question about how panels worked in the first place, a large group of students simply reported that the sun was strongest then (without explicit reference to angle, light, or heat). A second chi-square analysis was conducted comparing responses to the optimal time for solar cell function and responses to the initial question regarding the mechanism for solar cells. In this case, analysis showed that students who correctly used a photovoltaic explanation were more likely to identify mid-day as when solar cells work best. [$\chi^2(1)=4.52$, p=.033].

Discussion

Findings from this study revealed familiarity and some understanding of photovoltaics among high school students, although misconceptions and contradictions were apparent. While most students understood that solar panels, like the ones shown on the survey and displayed in class, allowed for the production of electricity, there seemed to be some confusion regarding the form of energy that these panels absorbed for conversion to electricity. Light was featured in many responses as the primary factor determining the efficiency of a photovoltaic cell, but many students mentioned heat as an equally important factor.

The picture in the survey and the model placed in full view of the students was clearly a photovoltaic cell; these we included to ensure that students were at least visually familiar with the technology being discussed in the survey. It is conceivable, however, that students' prior understanding of solar panels involved examples that worked through heat transfer. There are many examples of solar technology that feature thermal energy. Solar water heaters installed on rooftops work on the thermal capacity of the sun to warm up small quantities of water pumped through narrow tubes. Although these thermal 'solar panels' look quite different from the PV cell panels, it is quite possible that this older conception may have contributed to students' use of explanations involving thermal energy. There are other examples of thermal-based energy innovations. For instance, mirror-based thermal systems can generate electricity by using focused heat from the sun to converting water into steam, which then runs a turbine. Even more common is the simple solar oven, a favorite study tool among students, that uses mirrors to concentrate sunlight and provides enough heat to bake cookies. Students learn by extending patterns of understanding to include new information. Recognizing the sun as a source of heat and light is an everyday experience for students, but the idea of distinguishing light energy separate from the thermal energy from the sun may be a difficult concept in itself (Colburn, 2007.)

Student explanations of the working of the solar panel ranged from detailed explanations of electrons being excited and the production of electrical current, to simple conversions of the sun energy into usable energy. Analysis of these explanations with specific attention to the source of energy revealed more than half of the students referred to the general term of 'sun's energy' as being needed for solar panels to work, making it difficult to ascertain student understanding of the correct form of energy utilized by photovoltaic panels. This dual and somewhat abstract nature of solar energy makes it all the more difficult to clearly understand the technology of photovoltaics.

Comparison of responses across questions revealed some apparent contradictions in thought. While students who correctly provided photovoltaic explanations for solar cells initially were just as likely to use heat explanations when asked about the effect of warm air on solar cells (i.e the hair dryer scenario), these same students were *more* likely to recognize that mid-day is the optimal time for working solar cells. This connection between solar cell function and angle of sun, however, does not rule out a thermal explanation, since mid-day can also be seen as the time of day when temperature is highest. It seems likely, then, that some of the students who recognized the role of photovoltaics when asked about solar cells, created alternate explanations when confronted with an additional variable (heat) that could be incorporated into an explanation as well.

Even though students may recognize that light energy is needed for PV solar panels to work, the complexities of this technology were not entirely apparent to students. Solar panels were compared to storage batteries that could help people survive through cold and cloudy winter days. These students suggested that the panels absorb heat or light from the sun during the day and power electrical appliances through the night. One student even compared the panel to a solar-powered flashlight. While solar cells, whether singular or in a panel array, essentially function the same way, what happens to the electrical energy may vary depending on the application—the electricity may be used immediately as a point source of energy, it may be transferred to the power 'grid', where it becomes available to multiple consumers, or it may be used to charge a battery. Students' variety of experiences with solar cells and solar panels lead to a variety of conceptions as to how they work. Everyday explanations are developed to make sense of these experiences in the absence of explicit instructional efforts. In some cases these self-developed, common sense explanations are appropriate, in some cases they are not.

As described earlier, the conception of the sun as a source of different kinds of radiant energy (e.g. visible light, ultraviolet radiation, infrared radiation/heat) has implications for student understanding of several key undesirable environmental processes, including climate change and the greenhouse effect, as well as possible solutions to these problems (Choi et al., 2010; Henrikson and Jorde, 2001.) Yet changing the way students think about the 'sun's energy' or other areas of confusion related to solar energy may require them to think more deeply about the nature of energy, and different energy forms. For instance, it may be difficult for students, especially those who have grown up in southern California, to imagine sunlight without warmth. Adjusting the way they think about the sun's energy, while not automatic, will require students to elaborate on their existing conceptual structures related to solar energy (or energy more broadly) and possibly experience a conflict with their expectations (Driver et al., 1994; NRC, 2007). Such misconceptions have to be drawn out, discussed and clarified to bring a change in student "perceptions" whether that be a simple reorganization of concepts (e.g. 'solar energy' may include *both* visible light and thermal energy both of which are forms of radiant energy) or a more complex restructuring of their previously built knowledge framework (Henriques, 2002; Liu & Ruiz, 2008, NRC 2007). By conducting some of the thought experiments described in the survey (e.g. comparing the effects of hair dryers), students are may be able to expand their conception of solar energy, allowing them to more effectively assess the efficiency of different solar technologies under different conditions.

The investigation presented here is limited in its scope—additional studies are needed to obtain a clearer picture of students' conceptions of solar energy, and how solar panels work. More direct clinical interviews, which would allow for probing and clarification of student responses, might be able to reduce some of the ambiguity reported by students participating in this investigation. Furthermore, it is not clear to what extent these responses reflect a regional bias and whether students located in different climate regions, or even communities or nations that make greater use of solar technology, are likely to have significantly different responses. Nevertheless, the investigation does provide an additional view, if only a snapshot, of the public's familiarity with solar technologies and potential areas of misunderstanding.

Students accumulate numerous bits of information in the course of their studies and daily life experiences, but it is the overarching responsibility of the teachers to integrate such experiences and explanations into the school science curriculum. Current content standards in California, which drive science instruction, incorporate only limited discussion of renewable energy within the basic disciplines of physics, chemistry, earth science and life science (CDE, 1998). Yet students in high school, beginning their training as members of a future workforce, need the opportunity to understand how we use energy, and how we might curtail such use via alternatives. Studies such as the one presented here, remind us that 'going green' means making sure we clarify just what 'green' means, including an understanding of the science and technology that are presented as alternatives to our current actions. Finding creative ways to integrate such concepts into the classroom curriculum (e.g. discussion of photovoltaics in tandem with photosynthesis) becomes a key responsibility of science educators charged with improving our public's scientific literacy.

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Please cite as: Kishore, P., & Kisiel, J. (2013). Exploring high school students' perceptions of solar energy and solar cells. *International Journal of Environmental and Science Education,* 8, 521-534. doi: 10.12973/ijese.2013.216a

Appendix: Student Questionnaire

Energy Survey

This questionnaire is for research purposes only. The answers will not be graded and will not in any way affect your school grades. Anonymity will be maintained at all times. Answer the questions to the best of your knowledge and do not worry about grammar and spelling.

1. Solar panels are made of several photovoltaic (solar) cells as shown below.
[*image of solar panels was inserted here*]

Have you ever seen one?

A. Yes
B. No

2. If you HAVE seen a solar panel (other than these examples), where did you see it? (Try to describe the location and the purpose for which it might have been used. If you've seen them in more than one place, describe those as well.)

3. How do you think the solar panel works? (Try to explain it as you would to a friend)

4. Where did you learn about solar panels? (Check all that apply)

A. Magazines/books
B. School/classes
C. Internet
D. Visit to a solar-paneled building
E. Friends and family
F. Television
G. Other (Describe in the space below)

5. Solar panels work better when there are clear skies. Why do you think so?

A. Because the solar panels absorb heat from the sun
B. Because the solar panels absorb light from the sun
C. Because the solar panels absorb both heat and light from the sun
D. Any other reason (explain below):

6. a. When during the day do solar panels work best?

A. During sunrise and sunset
B. During the middle of the day
C. Solar panels work as well any time of the day

b. Why do you think so?

7. A hair dryer blows hot air on SOLAR CELL A; another hair dryer blows cold air on SOLAR CELL B. Which SOLAR CELL do you think would work better under these conditions?

A. Cell A
B. Cell B
C. Both would work about the same
D. Not sure