Identifying a Solar Cell Misconception Held by Middle School Students

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Abstract

The purpose of this study is to describe the effects of collaboration between a university and middle school that was designed to increase middle school students' knowledge of solar energy. Three undergraduates enrolled in a service-learning course that covered basic solar energy concepts and formative assessment instructional strategies. The focal point of the course was the implementation of several activities in a middle school classroom that addressed middle school students' misconceptions about solar energy, such as the amount of solar energy production at low temperatures or on a cloudy day. Data from this study include student performance on a written assessment, individual interviews, and student work. Findings suggest that although middle school students who participated in the activities increased their general knowledge of solar cells, many of the students' conceptions about how exactly solar cells work were fairly persistent. This paper provides useful information on K-12 outreach efforts that can help students acquire the dispositions and knowledge they need in order to participate in STEM fields.

Keywords: STEM, Engineering, K-12, K-12 Outreach

Introduction

One goal of K-12 engineering design tasks is to increase student motivation and persistence in engineering careers. However, without an understanding of student misconceptions around the science content embedded in engineering design tasks, these benefits will not be realized. This is a pressing issue given decreased enrollments and diminishing persistence in obtaining engineering higher education degrees (Ohland et al., 2008), and the immediate and projected need for engineers (see for example, National Science Board, 2011). Implementing engineering design tasks may increase short-term interest and motivation to pursue engineering, but a more long term, sustained interest requires adequately preparing students for this pursuit. This preparation includes ensuring that students accurately apply mathematics and science concepts to engineering design tasks because those who incorrectly apply these concepts further solidify inaccurate beliefs. This complicates efforts to change their conceptions at a later time and creates a general public who lack an understanding of STEM issues.

Science and mathematics educators acknowledge that students bring prior conceptions about how the world works to the classroom (see for example, Minstrell, 1982). These conceptions are often deeply-held beliefs based on prior experiences within and outside of the classroom setting. These conceptions may not necessarily be accurate or may not generalize across situations, but might fit within students' conceptions. These inaccurate conceptions are often referred to as misconceptions, alternative frameworks, naïve conceptions, or alternative conceptions. Educators are tasked with identifying these misconceptions, guiding students to realize the limitations of these misconceptions, and helping students recognize the universality of scientific conceptions (National Research Council, 2001).

Literature Review

Student misconceptions

Students' science misconceptions have been documented in terms of a variety of beliefs such as the shape of the earth (see for example, Vosniadou & Brewer, 1992), and weight and density (see for example, Yin, Tomita, & Shavelson, 2008). Recently, the American Association for the Advancement of Science (2011) created a website with information about common student misconceptions in earth, life, and physical science, and the nature of science.

Research suggests that addressing student misconceptions can be beneficial to teachers and students. Teachers who gather information about misconceptions are better able to structure and target instructional opportunities that specifically address student misconceptions. Such instructional opportunities help students to work toward more accurate conceptions, as well as increase achievement and motivation (see for example, Black & Wiliam, 1998). Thus, teachers who are better able to address student misconceptions about science and mathematics concepts that are relevant to engineering design tasks increase their students' opportunity to successfully engage in the tasks.

This study focuses on student misconceptions around solar energy, particularly the use of solar cells to generate energy. We focus on solar energy for several reasons. First, there are numerous solar energy design projects that K-12 students are engaged in, such as building a solar-powered car. For example, NASA sponsors a project that allows students to calculate the energy output in different areas of the country by analyzing incoming solar radiation graphs. Second, increasing student interest in this field will increase motivation to pursue careers in an area where there is a high projected need. Finally, even if students do not pursue careers in solar energy or engineering design, creating a more educated public about this form of renewable energy is highly desirable. In this study, we address the following research questions:

1. Can we identify student misconceptions about the use of solar cells to generate power?
2. How persistent are these misconceptions?
3. Can students be guided to recognize the limitations of these misconceptions?

The long-term goal of this research is to increase the knowledge and awareness of solar energy and inspire students to pursue STEM careers, particularly engineering. The short-term goal of this research is to identify student misconceptions around solar cells and provide instructional opportunities that will help to address these misconceptions.

Providing students with content knowledge on solar cells before they begin their engineering design tasks is one way to ensure that students have the requisite knowledge to be successful. Students need to know how the solar cell works so they are able to successfully design their project in a way that allows the solar cell to produce as much electricity as possible. If students do not know how a solar cell works, they might design their project in ways that minimize rather than maximize the amount of electricity produced. For example, suppose students engage in the common engineering design task of designing a solar powered car. If they do not know how a solar cell works, they might not realize that the amount of electricity generated by the solar cell is affected by the amount of sun being absorbed by the solar cell. They might believe that the amount of heat being absorbed by the solar cell is primarily responsible for the amount of energy created. This translates to a belief that their car is more effective on a hot night than on a cold, sunny day. Without some basic knowledge of how solar cells work, students will not be able to apply their mathematics and science knowledge to the engineering design project (Katehi, Pearson, & Feder, 2009).

Methodology

Sample

Four eighth grade teachers were recruited through the MESA Program at the University of California, Riverside. The MESA Program provides professional development opportunities for middle and high school teachers, and provides students the opportunity to participate in hands-on mathematic, engineering and science competitions. All teachers are from Mira Loma Middle School in California and have been involved with the MESA Program for the past two years. The middle school includes 910 seventh and eighth grade students of which approximately 80% are Hispanic, 35% are designated as English Language learners, and 76% are eligible for free or reduced priced meals (California Department of Education, 2010). The school has a 2009 academic performance index (API) score of 4. The API is a decile rank from one (lowest) to ten (highest) based on student performance on standardized achievement measures in Mathematics, English-Language Arts and Science (only grades five, eight, and nine through eleven), and History-Social Science (grades eight through eleven).

These teachers expressed interest in learning more about solar energy and wanted to start a solar design project with their students. All of the students included in this study elected to be in science and mathematics classrooms that focused on engineering design tasks. These students are highly motivated in that they applied to be in these classrooms and committed to spending time to participate in these design projects and learn grade-level specific standards on their own time. Participation in this study was voluntary. The middle school students and teachers did not receive any monetary compensation for their participation.

Measures

There are three measures included in this study: written assessment, individual interview, and student work (Table 1). Data from the written assessment was collected from a sample of eighth grade students (N = 136) across four classrooms, and the individual interviews and student work were collected from a single classroom (Classroom 4, N = 37).

Written assessment. The written assessment included ten multiple choice items and two short response items. The items were designed to measure three concepts: how solar cells work (six items), the effect of shade on the amount of energy solar cells produce (three items), and the effect of the angle on the amount of solar cells produce (three items).

Individual interview. The purpose of the individual interview was to better understand student misconceptions about the use of solar cells to produce energy. The semi-structured individual interview included six items. The interviews were conducted by two of the authors. Prior to the interviews, the interviewers discussed ways to probe student responses so that the responses would be comparable. The interviewers listened to the audio recordings of the interviews to ensure that they covered the structured portion of the interview and also probed student responses in similar ways.

Student work. Students in Classroom 4 worked in small groups on two solar cell activities. One activity focused on the angle of the solar cell and the other focused on heat. In this study, we report on the student work for the activity focused on heat. During this activity, students measured and recorded the current generated by the solar cell under six different conditions and responded to five short response questions on how temperature affects the amount of energy produced. The student work was completed individually and collected at the end of the class period.

TABLE 1: ITEMS FROM WRITTEN ASSESSMENT, INDIVIDUAL INTERVIEW, STUDENT WORK

Written assessment	1. Solar cells convert a. heat to electricity b. light to electricity c. light to heat d. energy to heat 2. Solar cells generate power by a. absorbing radiation b. transmitting radiation c. reflecting radiation d. creating radiation 3. When dust collects on a solar cell the power produced increases. 4. A solar cell generates power on a cloudy day. 5. A solar cell closer to the sun generates more power. 6. The power produced by a solar cell can be increased by aiming it directly at the sun. 7. Using a large lens to concentrate sunlight on a solar cell will increase the power generated. 8. It is too cold to use solar cells in some places. 9. More light will increase the amount of power produced by the solar cell. 10. At high noon the power generated by a solar cell on a sloped roof is greater than the power generated by a solar cell on a flat roof. 11. How does the angle of the light source relate to the amount of power generated by the solar cell? 12. How does shade relate to the amount of power generated by the solar cell?
Individual interview	You’ve seen pictures of solar cells in class. Have you noticed any solar cells in your neighborhood? Where? Would the amount of power generated by a solar cell depend on the amount of light hitting the solar cell? How? Would the angle at which the light hits the solar cell affect the amount of power generated? How? Would heat from the sun affect the amount of power generated by the solar cell? How? If you were going to use a solar cell as a power source what would you do to ensure you produce as much electricity as possible?
Student work	Measure and record the current generated by the solar cell under the following conditions: flashlight on, standard room temperature; flashlight off, standard room temperature; flash light off, hair dryer; flash light off, hand warmer; flashlight off, ice pack; flash light on, ice pack. Under which condition was the most current generated? Did the current increase, decrease, or stay the same when the solar cell was heated? Did the current increase, decrease, or stay the same when the solar cell was cooled? Does the current generated by the solar cell depend on the temperature of the solar cell? What evidence do you have to support your answer?

Note. The three response options for written assessment items 3-10 are: true, false, I don’t know.

Procedures

Undergraduate service learning course. Three undergraduate students (one junior engineer major, one senior biology major, and one senior mathematics major) were selected to participate in a ten-week, undergraduate service learning course. The course was led by an engineering professor and an education professor, and provided students with content knowledge on solar energy and formative assessment instructional strategies. The focal point of the course was the implementation of three visits to a single middle school classroom (N = 37). The first visit provided an overview of solar energy through a whole class discussion and activity. The next two visits (approximately one week apart) consisted of two different activities in small-groups that addressed the middle school students' misconceptions about solar cells, such as the amount of solar energy production at low temperatures or on a cloudy day. The activities were also designed to relate to several of the California Content Standards (Grade 8). By the end of the three visits, the middle school students were expected to know that solar cells are used as a power source, solar cells convert light to electricity, solar cells generate power by absorbing radiation, and the amount of light absorbed by the solar cell can be impacted by a variety of factors.

Prior to the three visits, eighth graders from the four classrooms completed the written assessment. In addition, a random sample of students (N = 20) from one of the classrooms (Classroom 4) were individually interviewed. Information about student misconceptions gathered from the written and individual interviews guided the creation of the two activities. Approximately two weeks after the three visits, all of the students in Classroom 4 completed the written assessment and those who were individually interviewed before the lessons were interviewed again. None of the students from the other three classrooms completed the written post-assessment.

Coding written assessment, individual interviews, and student work. The total number of points for the written pre-assessment and written post-assessment is 11. The ten items from the multiple choice portion of the written assessment was coded as correct or incorrect. The two short-response items were combined and coded in terms of whether the student demonstrated an understanding that the amount of energy generated by the solar cell was dependent on the amount of light being absorbed by the solar cell.

The coding scheme for the two short-response items and the five student work items was similar. A single, dichotomous score was created based on the two short-response items on the written assessment and the five student work items. A different coding scheme was created for the individual interviews. The scale for this score ranged from 0 to 2 because the interviewers were able to more carefully probe student responses and gather more evidence of the extent to which students understood the relationship between sunlight and the amount of energy generated by the solar cell (Table 2).

TABLE 2: EXAMPLE STUDENT RESPONSES

	Written Assessment, Student Work	Individual Interviews
Code	Does the current generated by the solar cell depend on the temperature of the solar cell? What evidence do you have to support your answer?	Would heat from the sun affect the amount of power generated by the solar cell? How?
0	Yes. Different temperatures make the power generated different. Yes. It doesn't depend on the heat but the cold because it makes it colder.	Yes. It all just depends on the heat. It would generate more power at night in Arizona (compared to Alaska) because there is more heat.
1	No. Just on the light. No. The light is what gave the cell it's electricity.	The more light it absorbs, the more energy it gets. I don't know whether the heat from the sun matters. It's mostly the light but some heat is needed.
2	N/A	Heat doesn't matter. On the experiment, I saw that if you put an ice pack or a hot towel, it doesn't make a difference for the solar cell. Temperature doesn't matter.

We investigated the dependability of the measures using generalizability theory (Brennan, 2002). Generalizability theory estimates the magnitude of multiple sources of error and provides a reliability coefficient for the proposed use of the measures. We investigated students as the object of measurement with one source of variation that contributed to errors in measurement: raters. Raters were provided with a rubric for scoring and were involved in the creation of the assessment and solar cell activities. All three raters scored all of the student work. The advantage of using generalizability theory is to interpret variance components, particularly, difference from one rater to another. Generalizability theory also allowed us to estimate the overall reliability of the measure with three raters and calculate how this reliability index varies when changing the number of raters.

TABLE 3: ANALYSIS OF VARIANCE FOR STUDENT WORK

Sources of Variation	*Sum of Squares*	*df*	*Mean Squares*	*Estimated Variance Components*	*Percentage of Total Variance*
Student	14.07	28	0.50	0.16	87.40
Rater	0.92	2	0.05	0.00	0.40
Residual	1.24	56	0.02	0.02	12.10
Total	15.40	86	0.18		

Findings from the generalizability theory model confirmed the lack of variability due to raters (Table 3). Less than 1% of the variability was due to differences between raters. Most of the variation (87%) was due to differences between students. Approximately 12% of the residual variation is due to the interaction between students and raters. The relative and absolute generalizability coefficients, which provide information about relative or comparative decisions and criterion-referenced interpretation, respectively, are similar and high (0.95). A decision study varying the number of raters indicates that the relative and absolute decisions are virtually the same with both indicating an acceptable level of reliability with just one rater's observations. Based on these results, we decided to have only one rater code the remaining student responses (short response on the written assessments, individual interviews).

Findings

Descriptive statistics for the different measures are provided in Table 4. The alpha coefficient for the eleven items on the written pre-assessment is low ($\alpha = 0.64$). The same eleven items have a higher alpha coefficient for the written post-assessment ($\alpha = 0.92$). Students in Classroom 4 who participated in the solar cell activities performed statistically higher on the written post-assessment ($M = 7.86$, $SD = 1.93$) than the written pre-assessment ($M = 5.07$, $SD = 2.37$), $t(36)=-6.21$, $p < .01$. Classroom 4 student responses to the individual interviews were also statistically higher on the post-interview ($M = 1.40$, $SD = 0.50$) than then pre-interview ($M = 0.40$, $SD = 0.50$), $t(19)=-6.89$, $p < .01$.

TABLE 4: DESCRIPTIVE STATISTICS FOR MEASURES

	N	*Mean*	*SD*	*Minimum*	*Maximum*
1. Written pre-assessment	38	4.76	2.21	0	9
2. Pre-interview	20	0.25	0.44	0	1
3. Student work	29	0.79	0.41	0	1
4. Written post-assessment	37	7.86	1.93	0	11
5. Post- interview	20	1.40	0.50	0	2

Although there were no statistically significant differences between the four classrooms, $F(3, 132) = 2.31$, $p = .08$, on the total number of items answered correctly on the written pre-assessment (Figure 1), there were significant and practical differences when looking at particular items. For example, almost half of the students in Classrooms 1 and 4 indicated that solar cells convert heat to electricity, while less than 20% of the students from the other two classrooms indicated this response. Over 60% of the students in Classroom 3 correctly indicated that solar cells convert light to electricity and 35% of the students responded accurately about the role of heat in generating energy. Half of the students in Classroom 2 indicated that solar cells convert light to electricity, but only 18% provided an accurate description of the role of heat in generating energy.

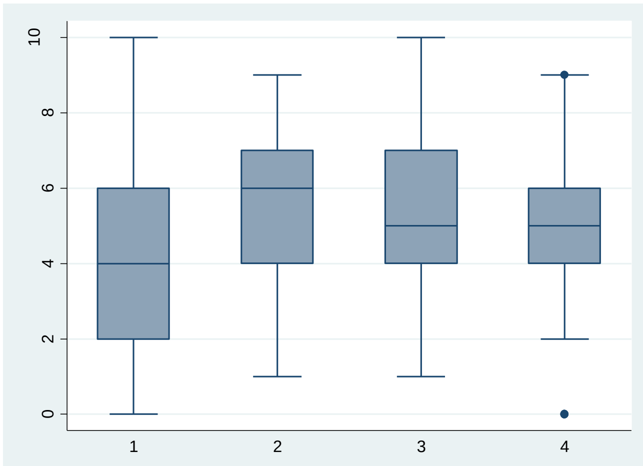

FIGURE 1: NUMBER CORRECT ON WRITTEN PRE-ASSESSMENT BY CLASSROOM.

The interviews provided a method for us to further probe student thinking about the relationship between heat, light and the amount of energy produced by the solar cell (Figure 2). On the pre-interview, of the 20 students interviewed, none of the students were able to verbalize an accurate relationship between heat, light and the amount of energy produced by the solar cell. Sixty percent of the students did not know whether light was related to the amount of energy produced by the solar cell (category 0). The other 40% indicated some understanding that the amount of energy produced was related to the amount of light, but also believed that heat was a factor in the amount of energy produced (category 1). On the post-interview, after completing the solar cell activities, 60% could verbalize that light affected the amount of energy produced, and the remainder of the students accurately identified the relationship between heat, light, and the amount of energy produced by the solar cell (category 2).

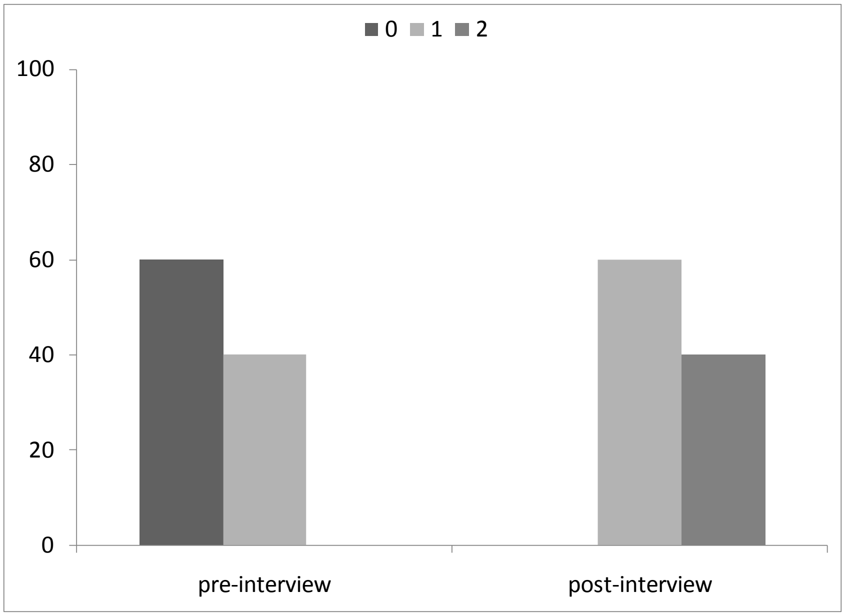

FIGURE 2: STUDENT RESPONSES, PRE-INTERVIEW AND POST-INTERVIEW ($N = 20$)

The correlations between the different measures indicate a significant, positive relationship between the two post-assessment measures but no significant relationships between the other measures (Table 5). This suggests that how well students performed on the written pre-assessment was not related to the quality of their student work or how well they performed on the written post-assessment or post-interview.

TABLE 5: CORRELATIONS BETWEEN DIFFERENT MEASURES FOR CLASSROOM 4 ($N = 37$)

	1	2	3	4	5
1. Written pre-assessment	- - -				
2. Pre-interview	0.21	- - -			
3. Student work	-0.37	-0.22	- - -		
4. Written post-assessment	-0.03	0.20	0.03	- - -	
5. Post- interview	-0.05	0.22	0.66**	0.42*	- - -

*$p < .05$. **$p < .01$.

Discussion

Data from four middle school classrooms suggest that we identified a student misconception around the use of solar cells to generate power. Many of these students did not have formal education experiences with solar cells but have informal experiences with solar cells and alternative explanations for how solar cells work. Through our initial interviews with a sample of students ($N = 20$), we found that 70% of the student had seen solar cells and 80% knew that solar cells generated energy. However, none of the students accurately verbalized the process of how solar cells generate energy. We provided information on how the solar cell generates energy through an introductory lecture. Simply telling students how a solar cell works did not change their conceptions. It was not until the students participated in activities that they were confronted with the limitations of their conceptions. Not surprisingly, despite these activities, most of the student pre-conceptions about how solar cells work persisted. On the written post-assessment and post-interview, although there was evidence that student knowledge and understanding of solar cells had improved, there was evidence that many students still did not fully understand the relationship between the amount of light and the amount of energy produced.

One misconception within this sample is that both heat and light from the sun generate energy. Many students believed that both heat and light used by the solar cell produced energy. When students were pushed to think about whether the light or the heat had a greater contribution to the amount of energy produced by the solar cell, many expressed a belief that heat has a greater influence than light. This was particularly evident in our interviews where we posed scenarios that encouraged students to identify their thinking. In the pre-interview, none of the students could verbalize the relationship between light, heat, and the amount of energy generated by the solar cell. In the post-interview, 40% of the students were able to accurately verbalize the relationship between light, heat, and the amount of energy generated, but the remaining students (60%) verbalized a continued misconception. Students were able to recite the fact that a solar cell needs light to produce energy. However, when we provided students with hypothetical scenarios and asked them to identify which scenario would produce the most energy, many students' misconceptions were exposed. For example, we asked students to suppose that there were solar cells in two different locations and that there was the same amount of light in both locations, but in one location, it was hot (like Arizona) and in another location, it was cold (like Alaska). Students were asked to identify which location would produce more energy from a solar cell. Students with misconceptions about how solar cells work would identify the hot location as the one that would produce the most energy. They believed that although light was a factor in the amount of energy produced, heat also played a role. Students with a correct conception of how solar cells work would say that both locations would produce the same amount of energy because the amount of energy produced only depends on the amount of light being absorbed by the solar cell. Based on the post-interview, 60% of the students still had misconceptions even after participating in the solar cell activities.

Like other student misconceptions, students' conceptions about solar cells were persistent. These misconceptions were prevalent in the written assessments, individual interviews, and student work. Activities designed to address these misconceptions helped to guide some students to recognize the limitations of their misconceptions and form more accurate conceptions. Observing the activities did not necessarily lead to more accurate conceptions. Future research will analyze active student participation in solar energy activities that relate to more accurate conceptions. We are particularly interested in the extent to which teachers asked students to provide explanations and whether students were able to provide correct, complete explanations during these small-group opportunities.

The sample size for this study is limited in that the data are from four classrooms in a single school; and, most of the data focus on a single classroom within the school. We hope to expand this study to eighth grade students to learn more about the prevalence of misconceptions around solar cells. One hypothesis we would like to test out, for example, is whether these misconceptions persist with students who have experience in climates where the sun is shining and the temperature is low. There might be geographical considerations we need to account for that might make our sample particularly unique. Additional data will provide information about gaps in student understanding and suggest methods to guide students to a more coherent understanding of the topic.

This information will help us to better understand how to help students work toward more accurate conceptions of solar energy and acquire the knowledge they need to successfully participate in STEM fields. We plan to use this specific information in discussions with the four teachers at the middle school as we help them plan for engineering tasks that involve the use of solar cells to power a car.

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