AC 2010-478: INSPIRING FUTURE ELECTRICAL ENGINEERS THROUGH SCIENCE TEACHERS

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Hodges is currently pursuing his Master of Science in Science Education (MSSE) degree from Montana State University and is on track to graduate in summer of 2010. Hodges interests involve the development of effective methods of teaching science vocabulary to students with limited English comprehension.

Inspiring Future Electrical Engineers through Science Teachers

Abstract

An engineering course was developed for the Masters of Science in Science Education program that introduces science teachers to the concepts necessary to understand the principles governing the operation of silicon solar cells. The summer course stresses that engineering is applied science and uses multi-disciplinary understanding of the physical sciences to understand, develop, and fabricate solar cells. The teachers went into the clean room and completed the processing steps to produce functional solar cells, then they tested and characterized them. The teachers left with a souvenir wafer and course material that aided them in the introduction of subject matter into their curricula. Program assessment was conducted and course outcomes measured through teacher surveys.

Introduction

The Electrical and Computer Engineering (ECE) department at Montana State University (MSU) has created two new laboratory intensive courses in which undergraduate (EE407) and graduate students (EE505) are given the opportunity to go into a clean room and process a silicon wafer to produce functional electrical or micromechanical devices. The equipment to offer these courses was purchased with funds from a National Science Foundation Grant under the Course, Curriculum, and Laboratory Improvement (CCLI) program. The purchased equipment was installed in a clean room that is now part of the Montana Microfabrication Facility. These courses are well received by engineering students; students leave with a greater appreciation and understanding of the processes used to create the electronics that are essential to our everyday life. Several of these students were interested in the idea of fabricating solar cells using the same equipment and technology. This interest generated the idea that a course developed for science teachers could be offered to harvest this enthusiasm. The thought was that an appreciation for solar cells could be expanded to middle and high school science teachers by offering them the same opportunity to learn about the operation and fabrication of solar cells. In turn, these science teachers would further communicate this excitement and knowledge to their students, which creates an invaluable opportunity to positively impact the development of and interest in science in today's youth. Thus, a new engineering course was developed and added to the curriculum for the Master of Science in Science Education degree program at Montana State University.

Masters of Science in Science Education

The Master of Science in Science Education (MSSE) degree program was designed for science educators interested in pursuing graduate study while remaining employed. The majority of program students are practicing classroom teachers. Currently, there are about 350 science educators in the program.

The MSSE program was approved in May, 1996, by the Montana Board of Regents of Higher Education. As described by the MSEE website[1], the program is unusual in two important ways. First, it is an inter-college, interdisciplinary effort. Science and science education faculty in 14 departments across four colleges and the Division of Graduate Education at Montana State University (MSU) collaborate to offer the degree. Over 90 courses in Biology, Chemistry, Earth Science, Education, Health and Human Development, Land Resources and Environmental Science, Microbiology, Plant Sciences, Physics, Mathematics, and Engineering are available to science educators pursuing the MSSE degree.

The second unusual characteristic regarding the MSSE program is the hybrid nature of instructional delivery. About 80% of the courses and credits needed to complete the degree are offered by distance learning in structured interactive courses using asynchronous computer mediated instruction. MSU-Bozeman, through the MSSE program and the National Science Foundation-funded National Teachers Enhancement Network (NTEN) project, has gained valuable experience in offering on-line courses. MSSE and NTEN have almost three decades of combined experience in developing and offering online science courses to national and international audiences. MSSE serves science educators in all 50 states and in 17 countries.

In addition to its online offerings, a wide variety of lab and field based science courses are offered to MSSE students on the MSU campus during the summer months. Campus field courses offer significant opportunities to integrate learning experiences in the greater Yellowstone Ecosystem, which is home for Montana State University-Bozeman. Laboratory courses allow teachers to work in well-equipped labs with state-of-the-art laboratory equipment and with nationally and internationally known science researchers. Teachers thrive in this incredible environment, working and learning with world renowned faculty.

Those seeking the MSSE degree complete core courses in education (12 credits) and develop interdisciplinary combinations of graduate science courses (18 credits) from offerings in physics, chemistry, earth science, biology, plant sciences, and other science content areas now including engineering. Student background, teaching assignments, personal interest, and district requirements determine the makeup of the individualized programs of study. Thirty semester credits are required for the MSSE degree. Most students complete the degree in two or three years but six years for completion are allowed by the MSU Division of Graduate Education. Interdisciplinary efforts and incorporation of both science content and pedagogy have been encouraged during the development of courses as well as emphasis on the National Science Education Standards. Titles and descriptions of these courses can be found on the MSEE website[1].

The MSSE program can be completed with a single two-week visit to campus during the final summer of the program. A week-long session is required to present the culminating Capstone Project at the Symposium in Science Education and to fulfill the remaining requirements for the final education course. The second week on campus, which may occur any summer during the time the student is pursuing the degree, is to fulfill the on-campus field/lab course requirement. The MSSE campus courses are excellent models of using field and lab work to teach science. Students frequently comment that multiple campus field and lab courses provide the best experience so they are encouraged to spend as much time on campus as possible. The MSSE teachers are welcome to take as many campus courses as they wish.

All graduates complete and present a science education capstone project in their final year for which they receive guidance and advice from a three-person graduate committee consisting of at least one science education advisor and one science discipline advisor. The candidate's experience typically ends with the on-campus summer session, which includes the presentation and discussion of the results of the personalized capstone project. As of summer 2009, the program had graduated 413 students in its 12 years of existence.

Class Description

The MSU ECE department currently has numerous laboratories associated with courses that supplement the lectures. Two of the newest laboratories use the Montana Microfabrication Facility to give the students the opportunity to enhance their understanding of the processes and the physics that support the production of transistors and micromechanical devices [2,3]. The two major objectives of these laboratory intensive classes are to have the students learn the basic process steps that are used to produce functional transistor and micromechanical devices, and how these steps impact the performance of the microfabricated devices. The students then reinforce these concepts by actively going into the clean room and processing the wafers themselves.

Applying this same model to develop a new course in photovoltaics created instructional material that reinforced the operational theory with the fabrication processes required to produce practical solar cells. The creation of the Solar Cell Basics summer course trained science educators and encouraged them to instill the technical knowledge gained about solar cells to their own students.

Traditional solar cells are fabricated out of silicon. Silicon processing is accomplished by repeating four basic steps: thin film deposition, photolithography, etching and doping (Figure 1). These steps are repeated numerous times to build up the functional solar cell. Film deposition is done in many different methods. This course focuses on two of the simplest ways to produce thin films: thermal growth of silicon dioxide and evaporation of aluminum. Photolithography transfers a pattern that is generated on a mask to a photosensitive film that covers the top surface of the wafer. A mask aligner is used to position the mask relative to the wafer so that mask pattern is aligned with previous processing steps. Etching selectively removes material that is not protected by the photosensitive film. This transfers the pattern of the mask into the material on the surface of the wafer. Doping changes the electrical properties of the silicon so that the material can be engineered to perform in an anticipated way. Figure 2 shows students executing the steps in the flowchart of Figure 1.

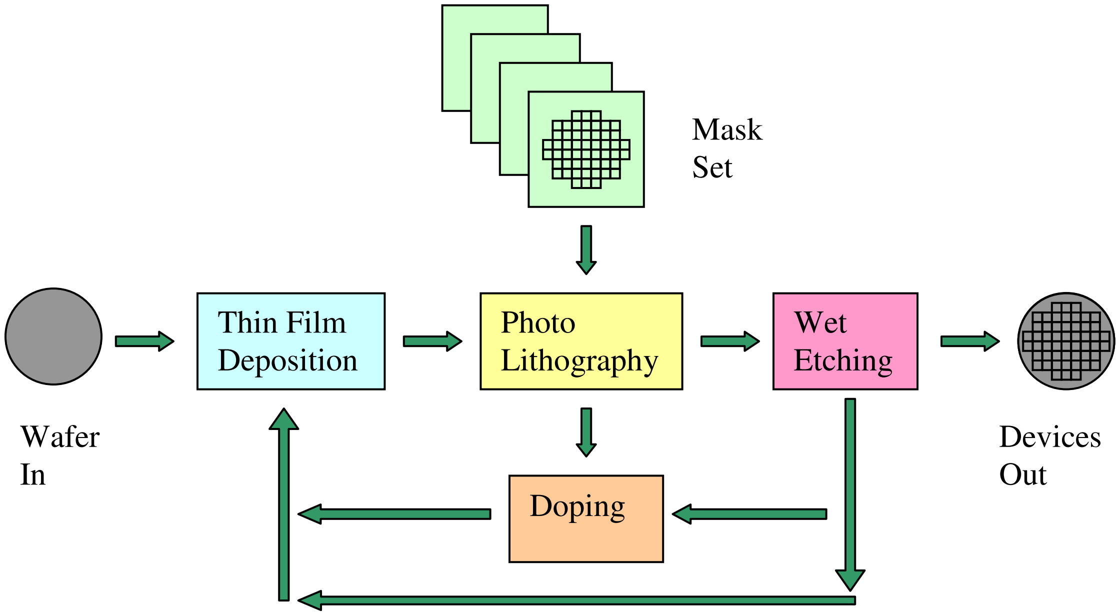

Figure 1. Process flowchart for microfabrication.

Current microfabrication courses use up to seven masks and require processing time spent over 14 weeks of the term. Industry uses over twenty masks and takes over two months of 24 hour production to finish processing a commercial wafer into integrated circuits. A reduced mask set, specifically designed for completing the solar cell in one week for the summer course was essential to successfully implementing this course. This reduced mask set still incorporated the basic processing steps and gave the pupil invaluable experience in the processing of silicon and fabricating solar cells.

Goals

The summer short course had three major goals:

1. **Provide an opportunity for science teachers to understand the fabrication and operation of solar cells.**

Professional learning is a lifelong endeavor, especially in the world of science and technology because of constant evolution and change. This course, Solar Cell Basics for Teachers, provides the opportunity for teachers to actively pursue professional development and better prepare themselves to motivate students to explore science and technology.

2. **Train and educate science teachers in the operating principles of photovoltaic systems.**

There has been a renewed interest in alternative energy and a growing demand for scientists and engineers trained in photovoltaic systems. Solar cells have been used for over four decades, and they provide electrical power to spacecraft and satellites on almost all NASA missions. Engineers familiar with photovoltaic systems are required for the success of these missions.

3. Increase awareness of engineering as a career option.

Engineering is not taught in the public high schools of Montana. Most students currently have no idea what an engineer does, though it can be a very rewarding career. By exposing science teachers to engineering, they are better prepared to provide educated answers about the possibility of careers in the field to potential students and future professionals.

Figure 2. Students going through the steps of the flowchart
Lower Left: Student gowning up to go into the clean room
Middle Left: The oxidation furnace used to produce a conformal silicon oxide coating covering the wafer
Upper Left: Evaporation System for metal deposition
Upper Middle: Image of a device being tested
Center: Student performing photolithography with the mask aligner
Lower Middle: Student setting the temperature on the diffusion furnace
Upper Right: Student etching the silicon dioxide from the silicon wafer
Lower Right: Student showing the completed wafer

Instructional Content

The MSSE Solar Cells Basics for Teachers was a two-credit course, offered for one week during the summer term. Each day was divided into two sixty minute lectures and two three-hour labs.

The course started with a safety lecture that described the hazards within the clean room environment, and then discussed the proper emergency actions that should be taken in case of an accident. The morning lecture first introduced the fabrication procedures that would be used for the day then covered the lecture scheduled for that time period. Table 1 shows the breakdown of the daily lectures and laboratory processing.

The processing starts with a p-type silicon wafer. The back side of the wafer is doped with Boron to create a p+ region that will make good contact with the aluminum back side electrode material. The oxide that grows during the doping process is removed then the front of the wafer is doped with phosphorus that creates the PN junction between the top n region and the p region of the substrate wafer. The wafer is then oxidized to create a quarter wave thickness of oxide that acts as an antireflective coating increasing the amount of light that penetrates into wafer. The oxide is patterned and removed where contact is needed between the silicon and metal layers. Aluminum is then evaporated onto the front surface and patterned to form the front side finger electrodes. Next, the backside is also coated with aluminum but no patterning is required as the whole back side of the wafer acts as the electrode. Figure 2 shows a cross sectional view of the silicon wafer as it progresses through the fabrication sequence starting in the left column and continuing in the right column.

Once the fabrication process was covered in lecture, then the operation of solar cells was discussed. The discussion began with a lecture on the nature of sunlight, first describing the wave and particle nature of light, followed by a description of sunlight modeled as blackbody radiation that is perturbed by the earth's atmosphere. It was stressed that the design and engineering of solar cells is optimized to capture as much of this light spectrum as possible. The more sunlight the solar cell converts to electrical energy, the higher the efficiency of the solar cell.

The materials required for absorbing the solar energy were discussed next. This discussion began with the fundamentals of atomic structure and the nature of atomic bonding, specifically the covalent bonds of the silicon lattice. The bond model was then developed where energy absorption breaks the covalent bonds between the silicon, allowing electrons to move through the lattice. It was then stressed that the motion of these free electrons is electrical current and that the number of free electrons can be engineered by doping the silicon, and thus modifying the conductivity of the semiconductor.

The band model of materials is then developed specifically applied to the silicon p-n junction. Students learned the significance of the band gap and the impact it plays in the absorption of light. This led into a discussion of the photovoltaic effect and how charge distributions create electric fields and electrical potential differences. The students were then introduced to the concept of electrical power generated by the product of the potential difference and current in the solar cell.

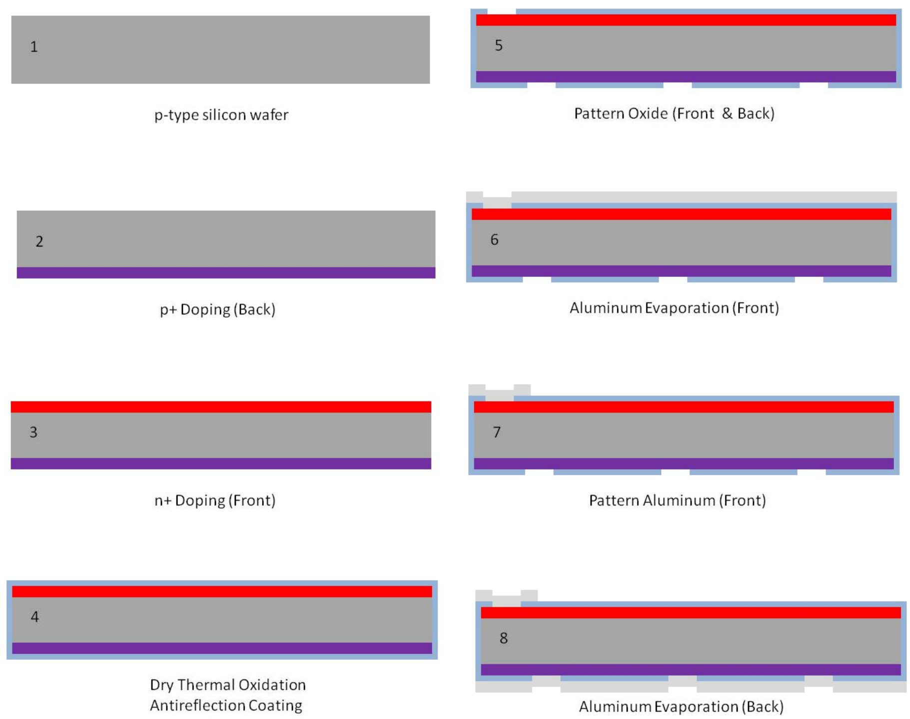

Figure 3. The fabrication sequence to produce a silicon solar cell.

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8-9	**Lecture #1** Introduction , Safety & Protocol	**Lecture #3** Fabrication II: Lithography, PVD & Etch	**Lecture #5** Material Fundamentals	**Lecture #7** Solar Cell Operation	**Lecture #9** Photovoltaic Systems
9-12	**Lab #1** P+ Rear Diffusion	**Lab#3** Dry Oxidation AR Coating	**Lab #5** Metalize Front Aluminum Evaporation	**Lab #7** Metalize Back Aluminum Evaporation	**Lab #9** Post-Anneal Characterization
12-1	**Lunch**	**Lunch**	**Lunch**	**Lunch**	**Lunch**
1-2	**Lecture #2** Fabrication I Thermal Processing	**Lecture #4** Nature of Sunlight	**Lecture #6** PN Junction	**Lecture #8** EE Fundamentals	**Lecture #10** Summary
2-5	**Lab #2** N+ Front Diffusion	**Lab #4** Photolithography Front Vias	**Lab #6** Photolithography Front Contacts	**Lab #8** Initial Tests & Anneal	Test & Remarks

Table 1. Week Schedule for the Solar Cell short course.

The course also introduced some fundamental concepts of electrical engineering dealing with voltages and currents. This allowed the students to comprehend the characterization process that was to follow and reinforced concepts learned in the previous lectures. Each wafer had four solar cells that had different designs that affect the performance of the solar cells. The students then measured the current and voltages out of the solar cell as the load was varied. They plotted the I-V curve and compared the curves of their four solar cells.

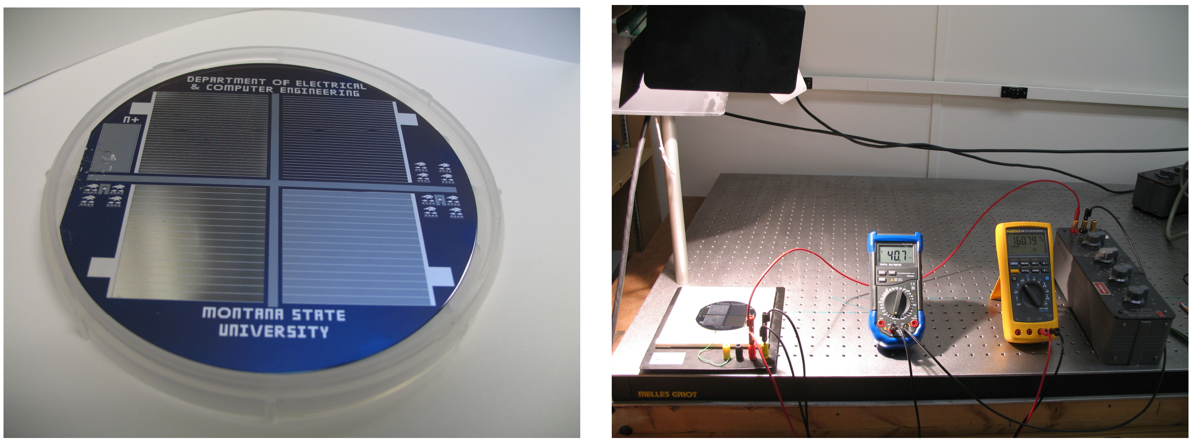

Figure 4. The fabricated wafer with 4 solar cells and the characterization set-up.

The final day lectures were spent discussing applications of solar cells and how they are incorporated into photovoltaic systems. This led into a discussion of the impact that photovoltaics will have in the future and the opportunities for electrical engineering students to contribute to the industry.

Solar Cells Follow-Up Survey Results

Several months after the solar cells summer course, the seven students were asked to respond to a web survey to give feedback about the course. Four of the students responded to the survey.

The teachers were asked to indicate their level of agreement to several questions about the course and about the effect of the course on their teaching. Their answers are shown in Table 2 below.

Answer Options	Strongly Agree	Agree Somewhat	Neutral	Disagree Somewhat	Strongly Disagree	Response Count
I know more about the link between science and engineering as a result of the summer solar cells course.	2	2	0	0	0	4
I know more about how solar cells operate and how they are made after the course.	4	0	0	0	0	4
I know more about what	1	2	1	0	0	4

engineers do after the summer solar cells course.						
I know more about how to use engineering examples and applications in my classroom as a result of the course.	1	2	1	0	0	4
I feel more comfortable using engineering applications and talking about engineering in my classroom after taking the course.	1	2	1	0	0	4
The course increased my knowledge of what careers are possible with a degree in engineering.	1	3	0	0	0	4

Table 2. Teacher Responses to Questions about the Solar Cells Summer Course

The teachers' responses were positive, indicating that they learned more about solar cells, about the link between science and engineering, about what engineers do, and about what careers are possible with a degree in engineering. They also indicated that they were more comfortable talking about engineering in their own classes and using engineering examples and applications.

When asked about which part of the summer course was most interesting, the teachers responded:

- Using all the equipment was great! It really was good to be hands on with everything. It really gave me insight to how things are done in a lab.
- Different compositions of solar cells, their costs, and efficiencies [most interesting]. I had believed there was basically one "type" of solar cell.
- The applications [were most interesting].
- Making the cells. Now I can discuss with students in both Chemistry and AP Environmental Science how the cells are made and how they work. I felt that they [solar cells] were a "black box" of sorts before taking the course.

Teachers were also asked to be specific about what they had adapted or planned to adapt to use in their courses. Three of the teachers had been able to use some content from the solar cells course:

- Energy and electron movement. Understanding how solar cells are made. Use of solar cells.
- I have a pre-engineering unit for my 9th grade physical science class. Materials from the solar cell course will be added in order to provide more information on what engineers do and how they are educated. Also, this year, the student design project will require the use of solar cells in their invention.
- My senior geology course spends the fourth quarter investigating geology-related issues on the Navajo Nation. In previous years we have investigated coal-fired electrical generating plants and uranium mining. This year we will be investigating the possible

construction and use of “greener” energy production methods (solar and wind). The solar cell course provided me with a wealth of materials for this upcoming unit.

When asked about how the summer course for teachers could be improved, the teachers had these helpful comments:

- Require students to take electricity and magnetism before this class to understand technical jargon.
- This might be better as a two-week course. The first week could include introductory solar cell theory and an overview of engineering (what is engineering, fields of engineering, education of engineers, and jobs for engineers). The overview of engineering would be extremely valuable as few science teachers have ever taken an engineering course. The second week could focus on the building of the solar cell.
- More about practical applications
- Perhaps creating kits that teachers could take back to their classrooms to allow students to test out different cells' performance under variable conditions - a true link both to how they work as well as the limitations to their implementation.

Testimonials

The students who took the class were asked if they wanted to contribute to this paper. Two of the seven students responded. Here are their testimonials:

Howard Tenenbaum

The solar cells course offered me a great opportunity to enhance my instruction in both my chemistry course and my AP Environmental Science course. In both cases, I am finding that students appear truly interested in the prospect of harnessing the sun’s energy in a way that contributes minimally to pollution while providing a huge alternative to the use of conventional fuels for the production of electrical power.

In the case of the chemistry course, when teaching students about atomic structure many of the students come to feel that this is esoteric stuff that is impossible to understand and could never contribute to their life experience. By focusing attention on the unique properties of the metalloids and the fabrication of Photovoltaic cells – and “seeing” the cells, students can better appreciate how using materials that are abundant on our planet can replace our reliance on fossil fuels and nuclear energy. Clearly using materials that are abundant and result in minimal pollution is a superior approach to gaining energy security here in the USA.

The level of interest in the topic is evident by the volume of questions that students have been generating during class sessions. From my observations, the students would probably like it if the entire course could be dedicated to making solar cells and finding uses for the electrical energy they produce.

For the AP Environmental Science course, the spin is different. For the AP Environmental Science course students consider alternative energy and how it may be able to replace conventional energy sources. They also consider the materials used in the fabrication of the solar cells in much the same way they consider how coal is mined and issues that are associated with the use of coal for energy production. By learning that most of the basic component materials for the Photovoltaic Cells (PV) are abundant on the planet and have minimal environmental impacts students can appreciate why PV technology might replace conventional energy sources.

As a result of the course, I was able to learn what the limitations of the PV technology are and what might be done to overcome some of those hurdles. I was also able to learn some of the basic issues that must be considered to install a PV system for a home. This is particularly important here in southern California where we get so much sunlight for most of the year. Students are keenly interested and take the information they get in class back to their homes. As students continue in their current unit they will see one of the cells we made this summer as well as assemble a full scale solar array. Students will also design and test solar ovens they make. Through all these activities students will be able to compare relative efficiencies of PV cells to other methods of harnessing renewable energy sources.

One of the great things about the course is that it gave me first-hand knowledge of the fabrication process as well as the testing process for evaluating the performance of the PV cells – having a first-hand learning experience myself translates into my students having a better learning experience. I feel much more comfortable to talk about this technology with both my chemistry students as well as my AP Environmental Science students. In the case of the chemistry students, the PV fabrication experience makes it easier to show them how their learning about electrons and the relative properties of atoms can be used to solve one of our country's greatest challenges. In the case of the AP Environmental Science course, the PV fabrication experience has left me with a much better understanding of the limitation of the technology as well as understanding where it can be best utilized.

Seth Hodges

I enrolled in the Solar Cell Basics course for a several reasons. As solar and wind power are becoming important topics of discussion on the Navajo Nation, I felt that I should have additional, newer information on the topic. My last undergraduate course that covered solar energy was taken almost a decade ago.

The primary use for the information would be as part of a current issues project in my senior geology course. Each year my seniors spend the fourth quarter investigating geology-related topics that directly affect the Navajo Nation and its people. In 2008, we investigated the pros and cons of building the Desert Rock Coal-fired Electrical Generating Plant. Last year we studied the benefits and problems associated with uranium mining in, and around, the Navajo Nation. For the fourth quarter this school year, we will be investigating the costs and benefits of investing in "greener" forms of energy. Additionally, I wanted to include alternative energy sources in both my 8th grade earth science course (energy resources unit) and 9th grade physical science course (electricity and magnetism unit and an introductory engineering project).

Lacking experience in engineering, I felt the course was a great opportunity to take a snapshot of what engineering students do in college. This will be a great assist in describing careers and education in engineering. I was able to gather a couple posters and fliers on engineering at MSU, which are now posted in my classroom.

I spent the first day of school this year providing a PowerPoint on "What I Did Last Summer." Photos and stories about the solar cell course took up much of the presentation. This presentation may be responsible for an increase in membership in our school's AISES chapter (American Indian Science and Engineering Society). A couple of our freshman students are now interested in investigating solar cell technology for next year's AISES science fair.

Conclusions and Recommedations

While the course had generally positive comments from the follow-up survey, it was felt that more should be done to highlight the electrical engineering aspect of the course. The course will again be offered in summer of 2010, and it will be modified to reflect the recommendations of the students in this initial offering. More time will be used to introduce electrical engineering measurement techniques and terminologies. Less classroom time will be used to discuss the fabrication process and this discussion will be moved to the laboratory sessions to fill down times during the processing. An overview lecture on electrical engineering will be developed and added, along with more examples and discussions of electrical engineering job positions and skills.

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