AC 2011-2900: ENGINEERING ENERGY SOLUTIONS: FACILITATING HANDS-ON

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Engineering Energy Solutions: Facilitating Hands-on Design Projects for Middle and High School Students via a Statewide Professional Development Program for Teachers

Introduction

As we challenge students to solve real-world energy problems, students are also embedded in the application of the engineering design process. Students research the science of wind energy as they design and test blades for a wind turbine. Students conduct scientific investigations on energy efficiency strategies and subsequently design an energy efficient classroom and school. These are just two examples of learning activities that allow the parallel pursuit of scientific inquiry and tasks that engender elements of the engineering design process in the Island Energy Inquiry professional development program for teachers and science curriculum. Students throughout the state of Hawaii are engineering energy solutions using hands-on kits and implementing real-world problem solving as a direct result of five Island Energy Inquiry professional development courses offered to teachers.

During a one-year period, ninety-two teachers throughout the state participated in the Island Energy Inquiry professional development (PD) courses. As a result, we estimate somewhere between seven to thirteen thousand students are being engaged in the engineering of energy solutions. In this paper, we will provide an analysis of both quantitative and qualitative data collected during the professional development courses. After providing background and justification for the need for energy science PD in Hawaii, a thorough description of the PD course format and curriculum is provided. We describe briefly the model for scientific inquiry integrated into the workshops and then summarize the engineering design process, highlighting the interrelationships between scientific inquiry and the engineering design process. This serves as the context for the data analysis and final conclusions. The following data sources will be presented and analyzed: 1) Participant data from surveys pre and post, 2) Workshop guest presenter data, and 3) Classroom implementation data submitted by teacher PD participants. All data is analyzed with an emphasis on assessment of the integration of the engineering design process, and the conclusion addresses strategies for further enhancing engineering education opportunities as Island Energy Inquiry program expands.

Developing Energy Related Engineering Skills in the Education to Workforce Pipeline

The state of Hawaii is the most dependent state in the nation on the importation of fossil fuel. Ninety percent of the state's energy is imported. Energy sustainability for this remote island chain will require reducing our reliance on imported fossil fuels and a significant increase in reliance on renewable energy sources in the islands such as wind, solar, geothermal, and wave energy. In 2008, Hawaii made a public/private commitment to achieve 70% clean energy by 2030. An estimated thirty percent of this involves increasing energy efficiency. Our state has one of the most ambitious goals in the nation, and, if achieved, could provide an example for the nation and world. [1]

We are certainly part of a national and international movement to address energy security and sustainability issues. At the 2011 Global Energy Summit, "global leaders from both developed and developing nations expressed their commitment towards developing clean, renewable energy for future generations."[2] There is much work to be done, and a skilled workforce will be required to make it happen. Nationally, job growth in the energy sector is projected to increase in correspondence with the increase of renewable energy project installations. For example, in the wind energy industry alone, job growth between 2005 and 2009 grew 39% annually, and it is projected to continue to grow at a similar rate. Similar projections for energy engineers, agricultural engineers, solar energy engineers, and several other energy-related engineering occupations have been published by the U.S. Dept. of Labor. [3]

Building an education to workforce technically skilled pipeline is critical to attaining goals internationally and here in Hawaii. The Women in Technology Project (WIT), a workforce development program which is part of a local economic development organization, has been building education programs in science, technology, engineering, and math (STEM) for K12 schools statewide for over ten years. In particular, WIT builds programs for underrepresented populations in STEM fields, including girls, women, and indigenous populations, seeking to increase equity for all. The Island Energy Inquiry program grew out of an annual Inquiry Science professional development event for middle and high school science teachers. Recognizing the need for developing skills in energy science, WIT developed the state's first renewable energy curriculum with customized hands-on kits, and we designed a professional development model which was first piloted on Maui then soon expanded to reach teachers statewide.

The Professional Development Course Model

The structure for the PD course for teachers includes the following: a two-day face-to-face workshop, 1-2 follow-up sessions online, ongoing support via website and/or blog during classroom implementation phase, a follow-up renewable energy field trip, and follow-up viewing of video presentations online with online threaded discussion submissions. Each course offered was co-facilitated by a team of PD specialists from WIT and from the College of Education. In addition, energy presentations by local engineers and energy industry representatives were a key component to all events. The Scientific Inquiry Process was explicitly taught, modeled, and facilitated in accordance with the Island Energy Inquiry curriculum and Teaching Science as Inquiry model. Participating teachers engaged in the actual student activities from the curriculum using the hands-on kits. All courses provided an option to earn a stipend or state department of education PD credit. Course completion requirements included:

1. Classroom Implementation of at least three lessons,
2. Development and submission of a Learning Results Portfolio which included documented evidence of student learning as well as teacher professional growth, and
3. Peer interaction through team work on projects face-to-face as well as online interaction at follow-up sessions, nurturing a professional learning community.

Strategies for equity in STEM learning environments and responsiveness to cultural diversity and history were integrated throughout the courses.

Program assessment tools used included both a pre-assessment survey and post-classroom implementation survey of all participants. In addition, each course ended with a final event that consisted of teachers sharing summaries and results from their classroom implementation of the curriculum and materials. A final course requirement is a Learning Results Portfolios to provide evidence of classroom implementation and changes in teacher practices.

The Curriculum

The Island Energy Inquiry science curriculum is focused on renewable energy and energy efficiency within the context of science inquiry. The curriculum used in the five teacher professional development events analyzed in this paper was the first edition published in June 2009. It was aligned to the state curriculum standards for science, with a generalized approach to keep it adaptable from grades 5-12. Specific grade level benchmark alignment was added in the next edition.[4] The curriculum relies heavily on the use of a customized hands-on kit teachers in the PD take back to the classroom and keep. The kit included miniature photovoltaic panels, a four foot wind turbine, energy auditing equipment, and more low-tech materials such as supplies to build pin-wheel turbine and laminate local energy maps.

The curriculum includes introductory contextual information about the importance of energy science education as well as an overview of the scientific inquiry process and explicit alignment to the state science standards. Interdisciplinary STEM connections are also outlined. Three modules are provided on the following topics: energy auditing, photovoltaic solar energy, and wind energy. Each module presents some background topical information for the teacher, however the theme is facilitating authentic inquiry by way of students getting hands on with research, building, designing, and testing right away. Student worksheets are in the form of lab reports with hypothesis development sections that help students clearly establish and control variables, data collection tables to facilitate multiple trials, and sections to encourage reflection, analysis, conclusion development, and asking of new questions. Several of the worksheets also outline initial specifications for the building of two different types of turbines, PV panel arrays, and energy efficient classrooms. This is one area where the engineering design process is embedded in the curriculum.

Scientific Inquiry and Engineering Design Interrelationships

The curriculum integrates the following scientific inquiry process steps and encourages continual repeating of them:

1. Have or obtain background information
2. State a problem and/or ask a question
3. Develop a testable hypothesis
4. Develop methods to test it (establish variables) and test it.
5. Analyze results and make conclusions

In authentic scientific inquiry, the process is not a finite number of steps, but rather, it is cyclical. The process continues to go around because, after making conclusions, new questions naturally arise. Perhaps the scientist develops a question about the possibility of changing the testing methods for the same hypothesis, or perhaps the scientist discovers something unexpected and wants to ask a new question entirely testing a new hypothesis. Various models of inquiry exist, but most emphasize initiating the process with the students themselves asking authentic questions, and then allowing time and resources to support students in exploring those questions. The teacher's role as facilitator is critical in this, as is the way that inquiry is modeled in any PD courses.

For the five events discussed here, the Teaching Science as Inquiry (TSI) framework established by the College of Education's Curriculum Research & Development Group was integrated. The central premise of TSI is that learning, including that done at the professional level through PD, is best accomplished through authentic application of knowledge and skills. When scientific learning resembles the actual process of science it enables students to better apply what they have learned in real-world situations.[5] Through TSI, teachers learn to help students understand not only basic scientific concepts, but also the process used to gain and refine those concepts over time. Teachers learn to help students evaluate and decide which tools and techniques to use, and teachers are encouraged to provide students the opportunity for social interaction, within the context of science, both inside the classroom and beyond. When teachers teach science through TSI-based inquiry, they effectively guide students' thinking and reasoning through the judicious use of discussion, insight and assistance – thereby teaching science as and through inquiry rather than by inquiry.[6] Moreover, as teachers help students engage in authentic scientific practice within the classroom they build students' integrity, diligence, fairness, curiosity, openness to new ideas, skepticism, and imagination.

The operating definition of engineering for this paper is, in short, the application of science and math to design solutions and tools for real application in society (and in further scientific research). The engineering design process is more specifically devising a system, component, or process to meet desired needs. It is a process which integrates basic sciences, mathematics, and the engineering sciences to convert resources to meet stated needs.[7]

"The goal of engineering is to solve practical problems through the development or use of technologies, based on the scientific knowledge gained through investigation."[8] In the context of energy science, scientific inquiry allows us better understand energy, and, often, we need new tools to help discover more answers. Engineers use scientific discoveries to design products and processes that meet society's needs for energy resources and energy efficiency. In some cases, engineers design products and tools to meet the needs of scientists. In summary, the following two interrelationships between science and engineering are the primary ways that we have confirmed that the engineering design process is embedded in our energy science curriculum and PD:

Type A: Teachers/students used their scientific findings as the basis to design something.
Type B: Teachers/students implemented the engineering design process in order to prepare to conduct scientific inquiry.

Expansion on how these two types of interrelationships were discovered as outcomes of the five professional development courses and the curriculum are discussed as a part of the data analysis that follows.

PD Preliminary Data: Participating Teachers and Guest Speakers

The five PD courses for teachers occurred over a year and a half, including classroom implementation phases. Based on initial registration and pre-assessment surveys, the five cohorts amounted to a total of 92 participants.

Table 1. PD Event Cohort and Participation Summary

Cohort	Dates	Location Offered; Target Region	Total Participants
A	July 2009	*Kahului, HI; Islands of Maui, Molokai, and Lanai*	26
B	October 2010	*Kihei, HI; Islands of Maui, Molokai, and Lanai*	18
C	March 2010	*Honolulu, HI; Island of Oahu*	16
D	April 2010	*Waimea, HI; Island of Hawaii*	19
E	May 2010	*Lihue, HI; Island of Kauai*	13
		Total	92

The initial pre-assessment survey asked teachers to state their grade levels taught and subject areas taught. Forty-six percent of participants taught at the high school level while the rest were middle school. In Cohorts A&B, four upper elementary school level teachers were allowed to participate. Interestingly, although it was advertised as a workshop for science teachers, only 70% of the 92 participants reported teaching science. Of these, nearly half mentioned teaching other subjects in addition to science. The table below provides the total counts of subject areas taught by participating teachers and their percentages overall.

Table 2. Participating Teachers - Subject Areas Taught

Subject Areas Taught	Times Mentioned in Registration Survey	% of 92 Total
Science	64	70%
Math	25	27%
Technology	13	14%
Career & Technical Education	3	3%
Engineering	3	3%
Social Studies	15	16%
Language Arts	12	13%
Special Education	5	5%
Other with 1-4 mentions - ELA, Auto Mechanics, Drama, Cooking, Music, PE, Business/Accounting	10	11%

Only 3% explicitly mention teaching engineering or pre-engineering. If we consider the top five rows of the table to be STEM subject areas, there were 108 mentions total by teachers. There is a surprising number of science teachers at middle and high school levels who also teach math.

In the qualitative analysis of what teachers hoped to learn, there was a consistent mention of wanting to learn about renewable energy and energy science as it is a rapidly evolving industry as well as career pathway for their students. A smaller percentage of comments specifically mentioned an interest in learning to effectively facilitate inquiry to better engage and inspire their students.

During the face-to-face portion of the workshops, there was a different series of guest presenters at each individual session due to geographic limitations as well as industry professionals' time constraints. For four of the five events, guest presentations were captured on video and shared online for additional viewing as well as use by students. In analyzing the professional backgrounds of the guest presenters, it is no surprise that of the twenty-three presenters, 61% are engineers. Others types of presenters were higher education science department faculty, scientists, or K-12 science education professionals. The organizations with which they were affiliated include a spread over three categories: 17% from local electricity utility companies (N= 4), 6% from K-12 or higher education (N=6), and 57% from other energy industry companies or consulting agencies (N=13). The significant finding here is the clear reality of the energy industry workforce consisting of a large percentage of engineers. It follows that our education programs ought to be building skills and career pathway awareness in engineering. The program is already doing this, and this confirms the need to continue and enhance further and more explicit engineering education.

PD Outcome Data: Teacher/Student Implementation in the Classroom

After the workshop experience, teachers entered into the classroom implementation phase, armed with the energy science and science inquiry curricula, the hands-on kits, and the first-hand experience learning from energy industry professionals. At the end of the classroom implementation phase, each course event had follow-up events which required sharing final presentations. The final two course requirements were to submit a Learning Results Porfolio and a post-assessment survey. Analysis of the PD outcomes includes the teacher final presentation data, learning results portfolio data, and post-implementation survey data.

Teachers were required to implement at least three lessons that implemented energy science concepts/curriculum shared at the workshop and/or inquiry science concepts/models shared at the workshop. Of the 92 teachers, there was some attrition during the implementation phase. From our correspondence with teachers that did not complete the course, we estimate that the majority of them decided to drop the course because they did not have time to complete the requirements of the Learning Results Portfolio. Many of them reported implementing activities in the classroom, but failed to submit evidence of this via the LRP. Therefore, final presentations from 60 teachers are included in the analysis that follows.[9]

Most teachers shared presentations in the form of a slideshow presentation that included pictures and specific objectives for lessons implemented. They were required to also share photos depicting student implementation and a reflection on level of achievement of student learning objectives. Recorded versions of the presentations were reviewed to assess mention and implications of the following: 92% of teachers presented on lessons related to core energy topics, 92% of teachers discussed inquiry directly, 50% discussed the use of the TSI model with their students, and 80% of teachers demonstrated use of the Island Energy Inquiry curriculum and/or kits.

Anecdotal evidence indicated that students who implemented the activities with full-use of the hands-on kit materials were engaged at a high level. An estimated 75% of the teachers made mention that students were so engaged, that they wish they had more time to allow further inquiry and design. Student engagement in learning activities refers to them being fully immersed in the learning experience. One of the desired outcomes of hands-on science and engineering learning experiences is for students to be so fully engaged in the process that they are unknowingly, seamlessly applying and developing new skills. Teachers who only lecture about content and provide rote worksheet type assignments will rarely describe their students as 'engaged at a high level'.

Teachers' post-classroom implementation presentations provided an opportunity for peer teachers to learn from one another and discover ways to adapt the curriculum activities in new ways, appropriate for different specific grade levels, subject areas, and learning styles. The Learning Results Portfolios are possibly the most detailed, documented evidence of classroom implementation. Teachers were required to submit three actual standards-based lesson plans, five student work samples, photos of students engaged in energy science inquiry, and reflection on both personal professional growth as well as change in student outcomes. The following quotes from teachers' reflections show the value and impact that the hands-on science inquiry and engineering had.

Table 3. Teacher Reflection on the Impact of Hands-on Learning & Inquiry

Direct Quotes from Teachers' LRP's
I think the activities that we participated in during the workshop provided concrete hands-on examples that our students need for a concept like energy efficiency and sustainability to actually connect to their lives.
We then went through an inquiry learning experience by building our own windmill using paper, straws, and string, so we could actually see our windmill work.
Having a hands-on inquiry based activity prior to the lecture helps gain interest in what you are doing as opposed to lecturing and then doing a hands-on activity.
The hands-on activity is a great example for them to see which type of light bulb is the better choice for them to be using in their homes.
We participated in a hands-on activity by building our own windmill.
This hands-on activity helped me to problem solve throughout the constructing process.
I have found that hands-on activities take a lot of planning and preparation to implement.
I can then use the larger windmill to further build upon their knowledge as they will have to do a lot of problem solving and use their higher order thinking skills.
My most important discovery through reflection is understanding the importance of incorporating different disciplines into the sciences.
The students were so excited to start the procedure we could hardly contain them.
It's so obvious that the students are enjoying using real objects to help them investigate what we are learning.

I also know that my students are very enthusiastic about science and love the inquiry based activities we have done so far.
I will use the paper and straw windmill activity to get my students engaged in how we can use windmills as a potential energy resource.

In the Pre-assessment and Post-assessment surveys, teachers were asked to rate their own level of skill in scientific inquiry in two ways. First, they were asked to rate how well they are able to facilitate scientific inquiry in the classroom. Secondly, they were asked to rate how well they teach the specific statewide curriculum standards for scientific inquiry. The table below shows response summaries from pre and post survey data from the first question: “How would you rate your overall skill level with facilitating scientific inquiry?”

Table 4. Teacher Pre-Assessment and Post-Assessment Data Comparison

How would you rate your overall skill level with facilitating scientific inquiry?	Results		
	Answer	PRE	POST
	Beginner	21%	13.5%
	Intermediate	29.5%	86%
	Advanced	3%	45.5%

There is clearly a perceived increase in skill level by teachers. While this data is subjective and qualitative, it is quite clear that teachers’ confidence levels in facilitating hands-on scientific inquiry increases after Island Energy Inquiry PD Event participation and subsequent classroom implementation.

Conclusions

Both in the PD workshop with teachers and in the classroom implementation phase, the following interrelationships between the science inquiry and the engineering design processes occurred. Note the type of interrelationships are, as previously mentioned, Type A: Participants used their scientific findings as the basis to design something, and Type B: Participants implemented the engineering design process in order to prepare to conduct scientific inquiry.

Table 4. Evidenced Interrelationships between Science and Engineering

Energy Topic	Kit Materials	Type	Inquiry Science	Engineering Design
Energy Auditing	Kill-a-Watt device; Light; Varying Light bulbs; surge protector; Table of Device Wattage	Type A	Research lighting efficiency of bulbs	Develop an energy efficiency play for the classroom or school
		Type A	Research ghost loads and use of surge protector to increase efficiency	

		Type A	Research device loads and potential energy efficiency by shutting off devices	
Solar PV Energy	Mini-PV Panels; Alligator clips; Multimeter to measure Volts/Amperes	Type A	Research potential of panels	Design a PV array
		Type B*	Research types of arrays	*(Required design of PV arrays)
Wind Energy	Low-Tech Paper Pin Wheel	Type B*	Research the amount of weight a turbine can lift	*(Required design and build of paper/straw/string turbine)
	Four Foot PVC Base Wind Turbine; multimeter to measure Volts/Amperes	Type B*	Research the amount of volts/amperes produced under certain conditions with specific blade types/pitch/number	*(Required build and design of turbine base and blades)

All of the energy science activities listed in the table above inherently include the engineering design process, and there is a balanced representation of both Types of interrelationships described. As evidenced in the final presentations from teachers and from their Learning Results Portfolios submitted, students practiced engineering skills while implementing on each of the energy topics from the curriculum teachers chose to implement.

The engineering design process has been a somewhat subtle and implicit component of the Island Energy Inquiry program events analyzed in this paper. Scientific inquiry has been of primary focus. However, based on the correlations in the table above, and the research done on our program to date, we have begun actively implementing a new approach in the current statewide Island Energy Inquiry workshop series.

The first of five events occurred only weeks before publishing this paper. In this first Island Energy Inquiry PD Event, the Scientific Inquiry Process was introduced along with the Engineering Design Process, and the two types of interrelationships were introduced to teachers. During the PD Event's activity reflection periods, discussions of both inquiry science and engineering were facilitated. In addition, a new component has been added to the Island Energy Inquiry program which involves graduate level engineering students serving as mentors at the PD Events and in classrooms during implementation.

As we continue to build and expand the Island Energy Inquiry program, the Engineering Design Process will become a prominent pedagogical component of the program and data will be collected in Pre- and Post- assessments to measure teacher understanding and skill level in facilitating engineering in the classroom. This and other data analysis will help us to continue to measure how Island Energy Inquiry events and curriculum are helping students to engineer energy solutions for our future.

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