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Board 156: Curricular-Modules Development Based on Summer Research Experiences for Teachers on Solar Energy (Work in Progress)

Daniel Garza
Mr. Cory Andrew Scarborough
Lovekesh Singh, Texas A&M University, Kingsville
Marsha Sowell, Texas A&M University, Kingsville
Dr. Mohammad Motaher Hossain, Texas A&M University, Kingsville

Mohammad Motaher Hossain is an Associate Professor in the Department of Mechanical & Industrial Engineering at Texas A&M University-Kingsville. His research mainly focuses on structure-property relationship in polymers, surface engineering, polymer tribology, contact mechanics, and fracture and failure analysis of polymeric materials. He received his Doctorate degree in Mechanical Engineering from Texas A&M University. Dr. Hossain is a frequent peer reviewer for a number of journals and served as a Technical Program Committee Co-Chair, and Session Chair for various technical conferences.

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Introduction

In the summer of 2023, middle and high school (Grades 6-12) STEM teachers in South Texas joined together in a 6-week summer research experience to create a dynamic, multidisciplinary environment where research, education, and outreach were integrated into a Community of Practice (COP). The purpose of this endeavor was to provide the teachers with opportunities to conduct authentic cutting-edge research and develop a series of innovative curricular modules for promoting renewable energy and data science in South Texas. According to the Texas Essential Knowledge and Skills (TEKS) guidelines, required to be followed by all Texas primary and secondary public schools, students in Grades 6-12 should learn various aspects of renewable and non-renewable energy resources [1] as well as data science [2]. As such, the 6-week summer activities for the STEM teachers were designed to develop in-depth understandings of data science and renewable energy as well as to explore effective pedagogies to support middle and high school (Grades 6-12) students' learning in the field and encourage them to pursue STEM majors and careers.

A COP theorizes that learning is a social process and, as presented by Lave and Wenger in 1991, distinguishes specific social structures for learning [3]. Communities of practice are purposefully developed to allow individuals to learn collectively within a shared domain. These communities include three important characteristics: a shared domain of interest; individuals participating together to help one another within the domain; and developing practice within the domain [4].

During the summer research experience, a community of practice was developed with a shared domain of learning about renewable energy and data science research to be put into practice through curricular modules by educators in middle and high schools. This COP consisted of Texas A&M University-Kingsville (TAMUK) engineering faculty members, an education faculty member, engineering graduate students, industrial advisors, and middle and high school STEM teachers. To create a shared domain within the COP, 10 middle and high school STEM teachers participated in 5 summer research projects focusing on renewable energy and data science. Each research project included a team of 2 teachers mentored by an engineering faculty member and graduate student as well as an industry professional. These research teams participated in hands-on research and used the research to create curricular modules for implementation in their own classroom the following academic year. Here, the research findings and curriculum development of one summer project that focused on solar energy are reported.

All members of the COP shared in professional development activities to support shared learning experiences. Throughout the six-week summer program, workshops on instructional coaching and course module development were led by the education faculty and lectures on data collection, modeling, visualization, and analysis were led by the engineering faculty. Webinars with industry advisors and field trips supported the links between research practices and STEM fields to the greater community. The members of the COP had weekly meetings to share their progress and discuss ways to help one another overcome challenges in their research and curricular module development.

As education practitioners, the members of the COP developed curricular modules to be implemented within their own classroom as well as to share with one another to implement in a broader context. Despite the increased interest in STEM integration in K-12 schools to increase students' interest and preparation for the STEM workforce, the research on professional development in this area is limited [5]. As such, the design of the summer research experience drew from the seven principles of effective general teacher professional development: 1) content focused, 2) utilized active learning, 3) supported collaboration, 4) modeled effective practices, 5) provided coaching and expert support, 6) offered opportunities for feedback and reflection, and 7) was of sustained duration [6].

As specialists in renewable energy and data science, engineering faculty and graduate students as well as industry advisors provided a content focus and model for effective practices in researching specific STEM content areas. This was accomplished by giving teacher-participants hands-on active learning opportunities to explore the research process. Boz [5] found this type of support was key to professional development that led teachers from theory to actual implementation of practice. Education specialists provided coaching, support, and feedback for the creation of content modules. Collaboration and sustained duration elements were fulfilled with the creation of a COP that spanned not only the summer research experience, but also throughout the academic year. In both the summer and during the following academic year, the COP provided support in the implementation of the curricular modules in the middle and high school classrooms to continue improving skills in the teaching of renewable resources and data science. In multiple studies, this COP has been found to be key in teachers adopting new pedagogical practices [5-7].

Research Experience and Findings

As mentioned earlier, out of the 5 summer research projects, this paper specifically discusses the curricular modules developed from the summer research experiences on solar energy. The teacher participants in the project conducted a comprehensive investigation into solar radiation data, accessible on the solar position and intensity (SOLPOS) calculator available on National Renewable Energy Laboratory (NREL) websites [8], to understand its significance on the positioning and enhancing the solar panel efficiency. How the introduction of texture on the surface could increase the efficiency of solar cells by minimizing reflection and maximizing absorption of incident sunlight through multiple internal reflections [9-12] was also studied.

The electricity generated from a photovoltaic system can be estimated by [13]:

$$E = A \times r \times H \times PR \tag{1}$$

Where, E is the energy output from photovoltaic cell (W-hr), A is the area of photovoltaic cell (m^2), r is the efficiency of photovoltaic cell (%), H is the solar irradiance (W/m^2), PR is the performance rating (Industrial standard = 0.75 [13]). Solar irradiance data required in Equation 1 was obtained from SOLPOS [8] for extraterrestrial tilted irradiance. Furthermore, necessary inputs for SOLPOS including latitude, longitude, date, time interval, time zone, and ambient temperature were also provided to obtain the data at 30-minute increments. TAMUK Dotterweich Engineering Building was considered as the test site and the solar irradiance data was obtained for the entire year of 2022. The solar panel chosen was REC's Alpha series "Black 370" model [14], which has an efficiency of 21.2% and an area of 72 in × 40 in [15]. Once the data from SOLPOS was downloaded, MS Excel was used to perform mathematical routines including solving for output; identifying optimal time and tilt angles that maximize output; and plotting relevant features. Using MATLAB, a model of multiple reflections with a textured tilted surface was generated and compared to the output of a similarly tilted flat surface experiencing the same incident angle.

Based on the methodology mentioned above, the energy output by hour and by day, respectively, was calculated using Equation 1 and the solar irradiance data obtained from the SOLPOS for solar panel with 0° tilt (horizontal/no tilt), 18.43° tilt, and 33.69° tilt. The results show that the maximum energy output is between 1-2 PM, regardless of the tilt. With no tilt, the average solar panel output peaked between June and July. With an 18.43° tilt, the output was relatively steady. With a tilt of 33.69°, the highest output was from October-December. The total monthly output for an entire south facing roof of 450 sq. ft. with an 18.43° tilt was also calculated. This angle was chosen because it is the minimum angle allowed by Texas Windstorm for asphalt shingles. The monthly performance for this setup averages out to 1,340.68 kW-hr per month. When textured surface is considered for the solar panel, instead of the flat surface, the sunlight absorption is increased considerably. The MATLAB simulation for ray tracing of multiple reflections for hemispherical protrusion and cavity texture on a solar panel shows a 27% -30% increase in sunlight absorption compared to flat surface solar panel, as shown in Figure 1.

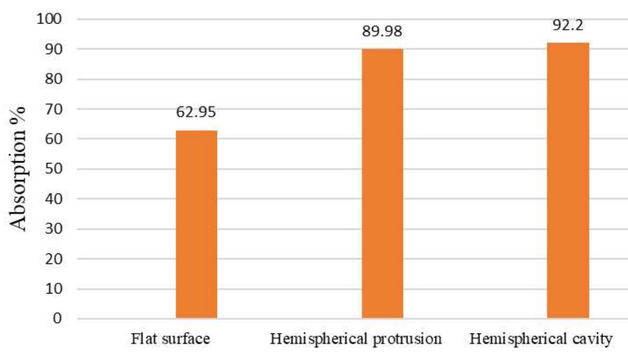

Figure 1: Absorption in silicon solar cell with different top surfaces.

Curricular Modules Developed for Grades 9-12 Classroom

During the six weeks of summer research, the teacher participants gained experience on various aspects of solar energy research as well as the usage of computer software in modeling, visualizing, and analyzing big data. Based on the summer research experiences and findings, teacher participants developed curricular modules during the summer to be implemented the following school year. The curricular modules were refined, and the research experiences were broadened through the shared learning experiences in the COP as the other summer projects in the COP focused on curriculum development from research on other renewable resources. All curriculum modules support Texas Essential Knowledge and Skills (TEKS) [1-2]: 112.45 Physics (Adopted in 2020) and AP Physics 1 & 2 Learning Objectives (2020). Research relevant to high school course work is primarily focused on solar energy fundamentals, applications of circuits to power households, the concept of flux, utilizing Snell's Law, and data science.

<u>Curricular Module 1</u>: Vernier Solar Panel Investigation and Comparison with SOLPOS Database

This activity was designed to help students investigate energy transformations and how the angle of photovoltaic panels relative to the sun affects power output. Students will gain an understanding of solar energy, power, and renewable energy. Students will record data necessary for the NREL SOLPOS Calculator including date, angle, and ambient energy. Students will then download and compare the collected angle data to local information provided by SOLPOS. Students will then use the SOLPOS data within Excel and perform various routines in order to calculate the available energy produced at various times within MS Excel. Students will continue to use SOLPOS to determine solar energy potential of major cities and compare the effects of latitude and longitude on solar energy availability throughout a given year.

Objectives:
1) Students will use Vernier Solar Panel to calculate power at different incident angles.
2) Students will determine the relationship between the angle of the sun and the magnitude of solar energy harvested.
3) Students will compare the energy calculated from Vernier Solar Panels to NREL SOLPOS Calculator.
4) Students will use NREL SOLPOS data within MS Excel to calculate energy output at various times.
5) Students will use NREL SOLPOS Calculator to compare solar energy of different major cities at various latitudes and longitudes and determine a relationship between latitude and longitude, and solar energy availability.

Curricular Module 2: Using Circuit Boards to Model Series and Parallel Circuits to Compare Household Consumption
Students in all physics courses can design circuits in series and parallel and compare the power for each circuit while investigating properties of each circuit type. Moreover, using the solar power from the Vernier Solar Panel input, students can measure and determine household requirements for solar panels. In the advanced courses, students can store energy from solar panels in the capacitors and investigate energy storage. Students in all courses can do a research project on battery limitations.

Objectives:
1) Students will design and compare power output for series and parallel circuits. Students will explain why houses have both series and parallel circuits.
2) Students will determine the kW-hr generated by solar panels and determine the cost efficiency of solar panels in South Texas using MS Excel.
3) Students will charge capacitors using solar panels and determine the time constant of each capacitor.
4) Students will charge capacitors using solar panels and determine how the arrangement of capacitors determines the total energy stored.
5) Students will research why batteries are non-ideal and current research for improving efficiency.

Curricular Module 3: Analyzing Refraction and Study the Effects of Multiple Reflections on a Textured Solar Panel Surface
Students will create a textured mold using a 3D printer to form a Jell-O mold. Students will first use a flat/smooth surface to model Snell's law and predict what happens when light enters a new medium. An extension would include students shining a laser onto an untextured Jell-O mold

and a textured Jell-O mold and observe and discuss the process and effects of multiple reflections on solar panels. Students will shine assorted color lasers onto different color Jell-O molds and observe and discuss the effects of absorption.

Objectives:
1) Students will measure the incident light and refracted light within a Jell-O mold to determine the index of refraction of Jell-O according to Snell's Law.
2) Students will investigate and discuss the impact of multiple reflections on a solar panel.
3) Students will investigate and discuss the phenomena of absorption using lasers of assorted colors and different color Jell-O molds. Students will discuss how the absorption of certain wavelengths can be beneficial on organic solar cells.

Timeline for Implementation
The need to follow a prescribed district pacing guide requires content to be covered at a certain time during the school year. Curricular modules 1 and 2 are scheduled to be implemented around the week of April 4th and module 3 is scheduled to be implemented around the week of April 28th. Results and reflection on curricular module implementation are thus pending at this time. The results and reflection on curricular module implementation will be discussed in detail during the conference presentation.

Conclusions and Continuing Work
In this paper, how the 6-week summer research experiences on solar energy and data science enabled the middle and high school STEM teachers to develop innovative curricular modules to improve student learning in the field is discussed. The summer research activities focused on investigating the solar energy output throughout a year by analyzing the solar radiation big data available on the NREL SOLPOS website. How the introduction of hemispherical surface texture on a photovoltaic cell can increase sunlight absorption, and, therefore, the efficiency of the cell was also studied. Based on the research experiences and outcomes, several curricular modules have been developed for grades 9-12 following the state curriculum guidelines.

In collaboration with the university engineering faculty, industry advisor and engineering graduate student, the 6-week summer activities thus provided hands-on research experiences on solar energy and data sciences for the STEM teachers, resulting in meaningful research findings. The teachers developed curricular modules based on their research in collaboration with an education faculty member of the university. The curricular modules developed during the summer program are currently being implemented in the classroom. Follow up activities, including school visits to observe the implementation of course modules, students' response, findings and reflection on curricular module implementation are planned with specific timeline, and will be discussed in the conference presentation.

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