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PILOTING PHOTONICS CURRICULUM IN STAFF DEVELOPMENT

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ABSTRACT

The paper's goal is to inform outreach coordinators and scientists of strategies used to develop a Light Emitting Diode (LED) curriculum module for high school students. Field-testing the weeklong LED curriculum, teachers acquired new instructional strategies to develop students career and global workforce skills in STEM disciplines. The National Science Foundation (NSF) Innovative Technology Experiences for Students and Teachers (ITEST) funded program session will highlight initial findings of the developmental process, review data of the pilot study with middle and high school teachers participating in a teacher workshop and student program offered by The Science House of North Carolina State University.

Keywords: photonics investigations, curriculum development, teacher professional development, underrepresented minorities (URM), informal science setting, science, technology engineering, and mathematics (STEM) competencies, college preparatory skills

1. INTRODUCTION

A key step in the preparation of students for the science and technology workplace is high school physics, normally taken in the senior year in North Carolina. While the national Physics enrollment rate has in the last decade increased to about 28%ⁱ, in North Carolina only 12,689 out of 76,940 (6%) graduating students took high school physicsⁱⁱ. There is a dire need to expose high school students to physics, and photonics provides the perfect environment, one rich in multiple disciplines, rigor, and interconnectedness with students' daily life.

The 13 rural and urban counties served by the current Photonics Leaders II (PLII) Program include a population representative of the entire state, with about 23% African American, 7% Hispanic, 1.3% American Indian and 1.9% Asian studentsⁱⁱⁱ. For these counties, the 9th-12th grade average retention rate of 61.9% falls below the statewide average of 64.3%, with a range of 44.1 to 74.8% which aligns with the county per capita income range. Of those that do graduate from high school, about 43% attend four-year colleges, and 38% attend community colleges or technical schools. The 4-year college-going rate significantly lags behind the 2004 national average of 67%^{iv}. PLII program addresses this trend.

As a land-grant university and one of 76 U.S. colleges and universities selected by the Carnegie Foundation for the Advancement of Teaching for its new Community Engagement classification, NCSU is charged with improving opportunities for the people, communities and industries of North Carolina. It therefore is critical for our K-12 initiatives like Photonics Leaders II to pursue outreach and engagement with underrepresented minorities (URM) high school students and teacher professional development to promote STEM career opportunities and 21st century skills. According to *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, the National Academy of Engineering noted the importance of improving the recruitment and retention of minority students^v. A student-centered environment allows learners to explore, investigate, research, develop and achieve in a meaningful STEM and information, communication and technology (ICT) intensive setting. Multiple evidence-based strategies must be employed to encourage and expose more students and their parents to consider STEM and ICT-intensive fields. PLII Program is designed to expand upon lessons learned from our successful Photonics Leaders Program (PLI), and incorporate a virtual component to enhance students' skills through documentation and

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analysis of students' dispositions, skills and knowledge needed by students to productively participate in the changing STEM workforce.

The need to prepare students for the STEM careers and physics also directs attention to teacher professional development or staff development within the ever dynamic global society. The PLII program model provides a unique laboratory to investigate a program model grounded in developing competencies and skills for transition into the global society. Through immersion in a rich and rigorous scientific learning environment, teachers and students are provided support for growth and enhancement through cooperative learning and collaboration with peers to develop solutions to real problems.

This paper emphasizes our development of the PLII program model and dissemination efforts by means of a STEM based research and development curriculum module. Refinements of the module have included professional development efforts with high school students. Feedback and discoveries made during these pursuits are shared.

2. WHAT IS THE STEM LED RESEARCH AND DEVELOPMENT MODULE?

This laboratory and technical education module is designed to impart STEM principles to participants at the high school level. The STEM principles, many of which are often under-addressed in a conventional high school program, addresses several technical, career preparatory, and college preparatory objectives. The primary objectives of this module are as follows:

1. Understand the operation and efficiencies of modern light sources including an incandescent bulb and a light emitting diode (LED)
2. Measure, interpret, and analyze characterization parameters of optical systems and mathematically convert radiometric quantities to photometric quantities
3. Design, construct, and troubleshoot simple electronic circuits
4. Develop proper research methods including efficient navigation of the internet and university libraries
5. Identify measurable parameters to match a hypothesis (scientific method)
6. Prepare technical documentation for assigned tasks as a team member
7. Communicate technical data and analysis to a non-technical audience

The module requires a commitment of five consecutive days of five hours of instruction. However, the days may occur non-consecutively with minor adjustments or from an integrated thematic approach whereby Science, Mathematics, English and Engineering Design classroom teachers cover necessary content and skills needed to progress throughout the module. Computer access for word processing and spreadsheet software is required. Also, participants are expected to commit to at least one to two hours per day outside of the scheduled time for both independent and small group work.

2.1 MODULE OBJECTIVES AND SKILLS

This module aims to further develop the STEM skills of the target audience in addition to honing their potential for success in both the workplace and in a collegiate degree program. Participants are given a myriad of opportunities to learn new skills to which exposure is minimal in a high school setting such as analyzing raw photonic data and presenting technical information to an audience of varied backgrounds. The primary focus of this module (teaching technical and STEM-related skills) affords students the chance to work with college-level laboratory equipment including photodetectors, LEDs, and electronic components. This module is supported by a strong mathematics and research components grounded in data analysis, device engineering, and topical research. Below are several of the skills and objectives conveyed to participants throughout this module.

- A. Employability and College-Preparatory Skills
 - o Work cooperatively with others
 - o Follow laboratory safety rules and regulations

- Navigate the internet to gather information
- Use appropriate word processing, spreadsheet, and presentation software
- Maintain daily real-time laboratory notebooks
- Present technical information clearly and concisely in written and oral form
- Work responsibly with minimal supervision
- Be able to interpret and evaluate graphical and tabular data
- Use materials and resources efficiently
- Understand how component skills and tasks support the achievement of goals

B. Technical and STEM Skills

- Know characteristics of different light sources
- Identify measurable parameters to match the statement-of-work specifics
- Understand how to identify/design technical tasks for supervisory reviews
- Recommend development and fabrication of components necessary for a system that meets specs
- Prepare technical documentation for assigned tasks
- Develop and communicate operation procedures for given system
- Troubleshoot and communicate system problems for given system
- Set up and align an optical system according to given specifications
- Identify the correct optics for the intended application
- Follow proper methods for optical inspection and cleaning
- Use a variety of soldering tools and materials
- Measure and interpret characterization parameters of LEDs
- Operate digital multimeters
- Operate semiconductor photodetectors
- Calculate power density

The skills and objectives of the STEM Research and Development LED module aligns with the Partnership of 21st Century Skills (P21) initiative which emphasizes fusing core content of the three Rs (reading, writing, and arithmetic) with the four Cs (communication, collaboration, critical thinking and creativity) to develop 21st skill century readiness for every student. The same focus must also guide staff and professional development of individuals working with students^{vi}.

3. LED MODULE DEVELOPMENT PROCESS

A photonic content specialist was hired by the PLII project staff and given the charge to create a STEM module that represented the PLII program model of developing students scientific knowledge, technical, communication, and writing skills for college and global workforce development. A draft was submitted to principal investigators and recommendations were made to restructure the module for a set period of time, to outline overall objectives, and to describe sample activities. Upon modifications, the draft was shared with the PLII Advisory Committee which consist of ten professionals with expertise from Physics research and education, electrical and computer engineering, curriculum development, a technology, biomedical engineering, education, and programmatic design. Suggestions from the committee included adding clear objectives and goals for activities, incorporating some guidance and support throughout the research design experience which leads to overall end product and finding a balance between technical jargon and inquiry activities to engage learners into the content. These suggestions were added to the curriculum module and elements of the module were introduced in the PLII teacher professional development in March 2010 and PLII Student Program Staff Development in May 2010. Suggestions and recommendations from the two workshop experiences were integrated into the curriculum to develop the WolfPack Engineering Design Challenge and curriculum materials for the PLII Summer 2010 student program based on STEM LED module.

The module scenario lead participants through the research and development process within an engineering design company under the direction of a technical program manager. The students are charged with

creating a new lighting project for an aerospace application. The students are lead through the following steps:

1. Research the available off the shelf (OTS) light sources to determine fabrication, assembly, applications, operational parameters, etc.
2. Learn how to characterize and test light sources.
3. Characterize and test incandescent, compact fluorescent, and LED sources and gather data.
4. Analyze the collected data to compare and contrast parameters of importance for all sources.
5. Explore methods of enhancing the best OTS light source and characterize and analyze the enhanced device(s).
6. Assemble and present final report to the technical program manager and prepare for questioning.

Supporting materials and investigations guided the organization of the student learning experience, collaborative efforts, product development, and progression throughout the module and development of the following engineering design challenge components: a) Introduction & Background Research, b) Problem statement, c) Procedure, d) Data Collection, e) Results, f) Presentation, and g) Written Report. Three major parts framed the curriculum module activities and established the precedence for the oral presentation and written report. They are:

1. Part One: Constructing LED Circuits and Measuring Voltage and Current
2. Part Two: Construct and Troubleshoot Advanced LED Circuits
3. Part Three: Electrical and Optical Characterization of Light Sources

Part one introduced simple circuitry, electronic components, breadboards and multimeters. While, Part Two covered reading schematic designs, construction of advanced circuits and troubleshooting skills. Part three extended the experience by directing students to delve deeper into the data collected and formulate explanations to address the current challenge at hand. Participants had to commit to a solution and justify their decision based on data and results. Most recently, the module was piloted with high school students within the PLII program and teachers participants of the project. This section provides a summary of these efforts and student/teacher feedback where appropriate.

4. STEM LED MODULE IMPLEMENTATION AND PILOTING PROCESS

The PLII project staff and the curriculum developer designed the implementation and piloting efforts schedule. An iterative process was employed to support ongoing modifications as needed to increase usability and applicability in schools and informal programs. The schedule included introducing sample components of the module in the Optics and Photonics Professional Development for middle and high school teachers to get immediate feedback or reactions from teachers about the need for these resources and gauge their interests in integrating materials into their classrooms. Also, the curriculum was delivered in the PLII Student Program teacher professional development session to prepare teachers to deliver the materials to high school juniors and seniors. This section will provide initial findings from curriculum module pilot and implementation efforts with middle and high school teachers.

4.1 TEACHER PROFESSIONAL DEVELOPMENT IMPLEMENTATION

The first piloting effort was with a selection of high school science and math teachers. Due to time constraints, the entire module was not piloted with the participants. Rather, the primary activities from the module were extracted and the participants were encouraged to proceed as the students would. The chosen activities were LED Circuit Construction/Troubleshooting and Characterization of Light Sources. Efforts were made to treat the session in the same manner as would be presented to future students. Participants were given the same materials, presentations, and time limits with these activities as the students would receive in later piloting sessions and, presumably, module teaching sessions.

The LED Circuit Construction/Troubleshooting activity charged the participants first with successfully wiring a series LED circuit consisting of a battery, a resistor, an LED, and wire. Breadboards were provided on which to construct the circuit. Terms such as polarity and current flow were introduced. The second charge of the activity was for the participants to measure voltage and current across and through the

various elements. This introduced multimeters and units such as Volts and Amperes. The third charge of the activity was to repeat the first two but with a parallel circuit of two LEDs. The intentions of this activity were varied: to determine the time it would take for a participant to understand a simple circuit diagram and then physically realize the circuit on a breadboard; to assess participants' understanding of series and parallel circuits; to determine participants' familiarity and comfort in properly operating multimeters; and to gather feedback concerning the procedure quality and depth of exploration from the teachers' standpoint.

In a similar fashion, the second activity, Characterization of Light Sources, was issued to the participants. It consisted of measuring both the optical power (with an optical power meter) and the electrical power (with a multimeter) of several light sources (e.g. LEDs, incandescent bulbs, compact fluorescent bulbs). The goal was to then determine and compare the efficacy of the sources. Participants were all new to using optical power meters as well as calculating efficacy. The activity resulted, aside from feedback, in a fair assessment of a novice's success rate with an optical power meter. This activity is central to the overall module's success and piloting it with inexperienced participants was crucial to crafting the procedures for student use.

4.2 STUDENT PROGRAM CURRICULUM IMPLEMENTATION IN AN INFORMAL SETTING

The following describes the students' experience in piloting the LED/lighting system design module with 54 rising sophomores and juniors over the course of five seventy-minute class periods (nearly consecutive) in PLII program. Students worked with randomly selected partners. Before performing Part I of the module students were required to conduct some background research on the history, function, and efficiency of three common light sources (incandescent bulb, compact fluorescent bulb, and LED). Most students completed this background research without a problem.

4.21 PART I CONSTRUCTING LED CIRCUITS AND MEASURING VOLTAGE AND CURRENT

During Part I students were required to use basic circuits to light a commercial-off-the-shelf (COTS) LED using a solderless breadboard and to measure the voltage and current at various locations using a multimeter. The completion of this Part took approximately 2.5 seventy-minute class periods. In order to perform this task, the students needed to have a background in basic circuitry and be able to identify circuit component in symbols and diagrams, physically and symbolically. The students initially struggled with the challenge of building a functional circuit, but were successful after being shown a photograph of a functional circuit as a guide. The use of this photograph was helpful, but eventually did become a crutch for many of the students who realized that every activity had a corresponding photo. After struggling with the conceptualization of the written circuit diagram, a few minutes of the class was devoted to explaining breadboards setup in a way that would help them understand that the current was flowing through metal-to-metal connections between the battery, breadboard, wires, etc. This seemed to help the students, and some even used similar diagrams in their oral presentation of the material. In addition, time was taken to describe parallel vs. series circuits concepts in terms of voltage drop and current flow, how to identify the resistance of a resistor, and how to appropriately use a multimeter in current mode. Many students struggled with the idea of putting the multimeter in series in order to measure current and that the multimeter was essentially just another circuit component.

4.22 PART II CONSTRUCT AND TROUBLESHOT ADVANCE LED CIRCUITS

This part of the module was an "advanced circuits" troubleshooting exercise. Students were shown five written circuit diagrams (some incorrect) and required to predict whether or not the LEDs would light up. If they suspected the circuit was incorrect, they were required to identify and fix the error by drawing the correct circuit. After this, they were instructed to build the circuit that was given and (if necessary) the corresponding correction circuit that they drew. This part took approximately half of one seventy-minute class period. Although most students were unable to finish in this amount of time, it was necessary to shorten this section in an effort to make time for the experimental exercises in Part III. Any student who did not finish Part II in class were required to complete it for homework and were not required to build the physical circuits because of a lack of materials for take home.

4.23 PART III ELECTRICAL AND OPTICAL CHARACTERIZATION OF LIGHT

In this final classroom exercise of the LED module, previous knowledge from Parts I and Part II was essential to understanding. This part took approximately two seventy-minute class periods, but more time would have been beneficial for inquiry-based learning. In this section, the students explored the power consumption and efficacy of the three different light sources. After working with LEDs and small voltage sources (3-6V battery sources), they were introduced to the high voltage consuming light sources: incandescent bulbs and compact fluorescent bulbs. Since they had performed background research, many students had a good idea about the efficacy difference between these sources. Students took electrical power consumption measurements by noting the wattage of the source bulb (or for the LED, by using $P=IV$ from their previous experience with multimeters). Optical power measurements were recorded using digital photometers. A brief overview of the functionality and proper use of the photometer was required. Most students had no problem using the equipment. They were given correction factors to adjust the luminous flux of each source. Students were all successful at collecting the data and understanding the difference between electrical power consumption and optical power output and the idea of a light source's luminous efficacy. However, they had difficulty in understanding and interpreting their results. This could have been changed by having the students share their raw data at the board into a large "collective class spreadsheet.

4.24. PRESENTATION OF RESULTS

Students were required to follow up this activity with a written report and an oral presentation. Written reports were required to be formally written using the typical lab report format. National Science Foundation LabWrite could have been used, but was an optional tool. Approximately 10 out of 50 students submitted LabWrite reports. Oral presentations were limited to five minutes each and both team members were required to present. Approximately sixteen out of twenty two groups used a power point presentation. Several other groups used visual aids such as board drawn circuit diagrams, physical lights/lamps, pictures, schematics and videos of their circuit construction. Most students proved that they understood circuits and the differences between optical output of the various light sources. However, few students gave presentations that indicated that they really grasped the final interpretation step of the importance of electrical power consumption and it's effective relationship with luminous efficacy and cost efficiency.

4.25 TEACHER PILOTING FINDINGS

Piloting the module with high school teachers resulted in several levels of feedback and created interest in the teaching community as word of the module spread. Teacher feedback resulted in major and minor module improvements: adding photos and images to the procedures to aid the more visual learners, partitioning several of the instruction blocks into smaller and more manageable questions and tasks, encouraging the instructor to avoid broad and open-ended questions (e.g. "Why did the circuit not work as expected?") with direct and closed-form questions leading the student to a similar outcome (e.g. "If your circuit did not allow the LED to light, first make sure the LED and resistor are in series. Then, check the battery and wire connections. Now does the LED light? If it does not, list at least two reasons for the malfunction. Think about polarity and what it means to be in series.").

4.26 STUDENT IMPLEMENTATION FINDINGS

Piloting the module with high schools students resulted in several levels of feedback and created an interest in students to investigate challenging materials in small groups and a safe supportive environment. The inquiry activities paired with short teacher-led explanative sessions assisted students with progressing through the advanced activities with a novice degree of success. Time allotment for the implementation of the module components could be extended to allow students more time to engage in the curriculum, develop a deeper understanding of advanced materials and additional time for preparation of reports and presentations. Overall the students were continually engaged in the activities, learned college level material, and honed their presentations skills.

5. CONCLUSIONS

Creating the LED module was not a one-step process. Continually improving and correcting the component elements provides for the highest quality instructive tool. Following the initial design, opinions from outside the design team were desired. An iterative process of design-testing-feedback-design correction was implemented (a design-feedback loop), resulting in improvements to the module overall.

Field testing (piloting) the LED module with both high school teachers and high school students provided valuable feedback regarding the quality, effectiveness, and expectations of this program as a whole. Teachers were able to suggest alternative ways of presenting new information, to discuss potentially confusing aspects of the procedures, and to give indications of the time required to teach and perform the various skills and activities contained within the module. On the other hand, analysis of student performance during and following the piloting session primarily allowed for the determination of learning, i.e., did the students extract and absorb the primary instructional objectives? Based on the student experiences discussed in section 4.2, several changes and improvements to the module can be made. These include the amount of time given for each activity (typically more), the quantity of pre-activity lecture/instruction (class demonstrations would help), the time allotted for post-activity class discussion (group review of data collection is desired), and the ratio of students to instructors (generally two groups of two or three students to each instructor is optimal).

The piloting efforts were a major component of the design-feedback loop and the quality of the module would suffer without them. It is generally understood that results of an activity will greatly vary from class to class. Because of this, any high-quality STEM module would benefit from a similar design-feedback loop. This module is in many ways novel in its attempt to fuse photonics, leading-edge technology, research principles, design methodologies, and advanced STEM topics. As such, implementing the design-feedback loop is paramount to its success and results in a continually improvement and cohesive photonic module suitable for dissemination.

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