Work in Progress: Data-Rich Learning Environments for Engineering Education

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Abstract - **Green Research for Incorporating Data in the Classroom (GRID$_C$) is a National Science Foundation project designed to improve instructional practices in the curricula areas of science, technology, engineering, and mathematics (STEM). The project uses data collected from renewable energy technologies at the NC Solar House, and enables students in engineering and education to analyze, synthesize, and evaluate downloadable data. Students and instructors create data-driven and conceptual models to explain information obtained from the project's website using a variety of methods involved in technical data presentation. This paper explains the GRID$_C$ project and how students in engineering and pre-service technology, engineering and design teacher education develop higher-order thinking skills. Preliminary research has been conducted on the effective use of these materials in college level environmental engineering classes and technical animation courses in engineering graphics. This research provides a base for continued research and development on using data-rich learning environments to further develop higher-order thinking skills for students across the country.**

Index Terms - Data-driven models, Renewable energy, STEM education, Critical thinking.

INTRODUCTION

The purpose of the Green Research for Incorporating Data in the Classroom (GRID$_C$) project is to develop curriculum to teach science, technology, engineering and mathematics (STEM) concepts using data collected from renewable energy technologies at the NC Solar House located on the campus of North Carolina State University (NC State). The intent of this project is to enhance instruction and improve learning, while addressing a highly relevant social issue: renewable energy.

Researchers have shown that curricula based on performance data of renewable energy technologies provide students with valuable knowledge and skills that can be used for professional growth and decision-making. Data-driven decision-making is a critical skill used in engineering and education [1]-[2]. As technological and social systems become more complex, the aptitude for data-driven decision-making becomes even more critical. Research on technological problem solving, critical thinking, novice/expert performance, and metacognition reveals that students must understand factual, conceptual and procedural knowledge, apply their knowledge to learn by doing, and then reflect on the process that led to the solution [3]-[4]. The GRID$_C$ project developed instructional units grounded in these concepts, while incorporating the use of renewable energy data collected through GRID$_C$ resources in the units. The concepts learned in this project by both engineering and pre-service technology, engineering, and design teacher education students are paramount for fundamental understandings of data and conceptual technical presentation development.

THE DATA ACQUISITION SYSTEM

The GRID$_C$ data acquisition system gathers renewable energy data from the house and other units (e.g., garage and research annex) on the grounds of the NC Solar House. The NC Solar House was first opened to the public in 1981, and is today, one of the most visible and visited solar buildings in the United States.

The monitoring system records meteorological data (i.e., irradiance, ambient and module temperature, wind speed and direction, module temperature, relative humidity, rain gauge, barometric pressure), photovoltaic data (i.e., AC/DC power, current, voltage, and energy, panel temperature), hot water data (i.e., flow rate, in/out temperate, energy), and hydrogen fuel cell data (i.e., in/out power, current and voltage, energy). The Solar House was established for research purposes for NC State's College of Engineering in the 1980's, and has since become an educational/community outreach mechanism and an important partner with the Technology, Engineering, and Design Teacher Education Program at NC State.

CURRICULUM DEVELOPMENT

To develop students' higher order thinking skills in the context of a data-rich learning environment, units were developed using the data acquired through the GRID$_C$ data acquisition system. In developing these units, the researchers considered that students must understand factual, conceptual and procedural knowledge, apply their knowledge to learn by doing, and then reflect on the process that led to the solution [3]-[4].

Factual and conceptual knowledge includes an understanding of the systems, subsystems and components of the technology under study. This knowledge forms the basic understanding needed before proceeding with the design and problem solving process [5].

Procedural knowledge includes an understanding of the engineering design and/or problem solving processes that lead to innovative solutions [6]-[7]. These processes include equations used to calculate system performance, transform data, make predictions, and implement problem-solving processes such as troubleshooting and project management that help engineers, designers and technicians reach solutions.

For students to develop higher order thinking skills, they must have the opportunity to apply their content and process knowledge [8]-[10]. This is particularly important for students studying fields related to engineering, technology, and education. Performance data from the variety of renewable energy systems proposed for this project provide opportunities for students to analyze and evaluate system variables within the context of their disciplines. The nature of the data used in this study provides students with the opportunity to analyze, evaluate and predict while applying concepts in a variety of situations.

Instructional units using this data have been implemented in various courses at NC State and Pitt Community College, including:

- Design of Solar Heating Systems: This course involves the analysis and design of active and passive solar thermal systems for residential and small commercial buildings. The course provides an overview of solar insulation, flat plate collectors, thermal storage, heat exchanges, controls, performance calculations, and photovoltaics.
- Construction Technology: This course provides an overview of residential and commercial structures and their construction. Students use drawings and models completed in a laboratory environment to simulate construction methods.
- Current Trends in Technical/Engineering Graphics Education: This course discusses the current trends in technology, techniques, and theories relating to technical graphics education. Students in this course were asked to design and develop animation clips explaining data trends. For example, students were able to visually display the impact of sun intensity and angle throughout a single day on the level of electricity generated by PV panels.

METHODOLOGY

Each instructional unit was implemented by the instructor assigned to the course. Alternative versions of a multiple choice test were developed by a panel of content experts. Each class began with a pretest consisting of general renewable energy knowledge items. Upon completion of each unit, the posttest knowledge questions were administered. Data collected with pre/posttests were archived for statistical analysis and reporting. The preliminary study involved 118 observations of which 78 were from courses in engineering and technology, engineering and design education. Initial results indicate gains in students' knowledge of renewable energy systems. Table 1 presents the summary statistics for the student sample. A paired t-test is used for the analysis. The results indicate significant gains in post-test renewable energy general knowledge scores ($t(96) = 9.41$, $p < 0.001$).

TABLE I
SUMMARY STATISTICS

	Mean	Std Dev.	Min	Max	Median
General Knowledge Pre-test	6.33	2.06	1.71	11	6.6
General Knowledge Post-test	8.25	1.85	2.4	11.4	8.57

Students' awareness of their cognitive processes as they approach and solve problems was evaluated using the metacognitive inventory. The Metacognitive Inventory (MI) was developed using 6 items from the Problem Solving Inventory (PSI) and 20 items from the State Metacognitive Inventory (SMI), with slight modifications. This inventory was designed such that it may be used in the varied situations in which the developed curricula are implemented. The items cover six categories of approach-avoidance, awareness, cognitive strategy, confidence, planning, and self-checking. The results indicate significant gains in metacognitive performance, as measured by the MI ($t(58) = 2.19$, $p < 0.001$).

CONCLUSION

The preliminary analysis shows significant gains in post-test renewable energy general knowledge scores and metacognition. This indicates that the use of real-time renewable energy data was effective in instruction and providing students with valuable knowledge and skills that can be used for decision-making. The results confirm the claims of previous studies that using real world data enhances instruction in various fields.

In addition to gathering more student data, the future brings new opportunities for collaboration with various companies within the energy and transportation industries. Such collaboration will expand $GRID_C$'s data acquisition system to include transportation data, as well as wind energy data. Broadening the data acquisition system will further enhance students' opportunities to conduct comparative analysis and aggregate data for decision-making. Although this project is in its initial stage of development, the researchers already identify positive results for both engineering and education. Most notably, the project has had a significant effect on the technology, engineering and design education teacher education program and its newly developed 21st century skills-based curriculum. The researchers hope that the project will influence other teacher education programs in STEM related disciplines to incorporate similar practices.

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