AC 2011-638: TEACHING DESIGN AND TECHNICAL GRAPHICS IN A GREEN ENVIRONMENT

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Dr. DeLuca is an Associate Professor of Technology Education at North Carolina State University. He has been a technology education teacher at the middle school, high school, undergraduate and graduate levels for over 30 years, and has extensive teaching, research, and curriculum development experience. His research includes the study of thinking processes, teaching methods, and activities that improve technological problem-solving performance and creativity. He has expertise in developing technology education curriculum that integrates science, technology, engineering and mathematics (STEM) concepts. Currently, Dr. DeLuca is the Principle Investigator of the GRIDc: Green Research for Incorporating Data in the Classroom project (Phase 1, 0737180; Phase 2, 0920268). The purpose of this NSF CCLI project is to develop curricula to teach STEM concepts associated with renewable energy technologies by providing a living laboratory of performance data from numerous renewable energy systems. The overarching goal of the project is to develop undergraduate students' higher-order thinking skills in the context of a data-rich learning environment. In addition, he is Co-PI of the NSF ITEST funded project GRADUATE: Games Requiring Advanced Developmental Understanding and Achievement in Technological Endeavors (0833452). This project researches the use of game design to teach STEM concepts. Dr. DeLuca has a B.A. in Industrial Arts Education from the California University of Pennsylvania, and an M.A. and Ed.D. in Technology Education from West Virginia University.

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Teaching Design and Technical Graphics in a Green Environment

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 a variety of renewable energy technologies and enables students and teachers from both secondary and post-secondary education to access downloadable data and analyze, synthesize, and evaluate the data. One aspect of this project is to teach students in both engineering education and pre-service teacher education for technology, engineering and design education to visually explain data for targeted groups. Students and teachers take the information and create both 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 develop good visual skills in areas of presentation, data-driven and conceptual modeling using the information and data collected from the website. Preliminary research has been conducted on the effective use of these materials in college level engineering classes and in a technical animation course for graphic communications. Research and analysis has taken place as to how students take data of this type and create both data-driven and conceptual models using a design brief format. The research being conducted during this project will provide a base for continued research and development on using data-rich learning environments to develop good thinking and visual skills for both pre-engineering and engineering students throughout the country.

Introduction

The goal of the $GRID_C$ project is to develop students' higher order thinking skills in the context of a data-rich learning environment. The project enhances student opportunities to aggregate data and conduct comparative analyses for decision making through the use of data obtained through the project's established data acquisition system; develops reliable and valid instrumentation for assessing students' understanding of a common core of knowledge associated with renewable energy sources; and promotes the dissemination and adaptations of the developed curriculum through various partnerships with colleges and businesses. Also, one major goal of this project is to have students develop good technical visualization and presentation skills using a design brief format.

Researchers have shown the value of using real world data to enhance instruction in mathematics, science and social studies.[1,2] In this project, real-time data on renewable energy technologies are collected from multiple systems and stored at a single location, the NC State Solar House, enabling faculty and students to analyze, synthesize, and evaluate data in a variety of contexts. The NC State Department of Science, Technology, Engineering and Mathematics Education, Department of Mechanical and Aerospace Engineering, Department of Civil, Construction, and Environmental Engineering, and Pitt Community College have developed course curricula and activities that use these data to enhance the learning of undergraduate students with broad application in undergraduate STEM education. The partnership among the university, community colleges, and businesses will advance the study of renewable energy technologies among diverse students.

The Data Acquisition System

The NC State University Solar House was opened to the public in 1981 and is one of the most visible and visited solar buildings in the United States. The monitoring system records, among its data, 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 project team has recently broadened the data available to students by incorporating the following wind turbines into the project:

- Bergey 10-kW, Jockey's Ridge State Park, Nags Head, NC-- power: wild AC from turbine, 240V 60Hz AC from inverter; energy: ~1,250 kWh (per month estimated); wind speed: ~6 m/s (based on AWS TrueWind model data)
- Bergey 10-kW, the Outer Banks Brewing Station, Kill Devil Hills, NC-- power: wild AC from turbine, 240V 60Hz AC from inverter; energy ~1,000 kWh (per month estimated); wind speed: ~5.5 m/s (based on AWS TrueWind model data).

Data from these systems are collected and uploaded to an online data acquisition system, where daily, monthly, and yearly information may be viewed graphically, or downloaded in a spreadsheet format. The aggregated $GRID_C$ data, available on the project's website (www.$GRID_C$.net) is used by instructors to develop instructional units to be implemented in various undergraduate and graduate level courses. Furthermore, K-12 teachers are now using this data in their classrooms.

Curriculum Development

Data-driven decision making is a critical skill used in engineering and education.[3,4] As technological and social systems become more complex, the aptitude for data-driven decision making becomes even more critical. Data made publicly available through $GRID_C$ provide a tremendous educational tool for STEM students. Rather than simply reviewing journal papers or reports, they can analyze the data visually and build models to answer relevant questions. Analysis using recorded time series data gives students the opportunity to formulate sound, data driven judgments based on technical visualizations about the performance of renewables.

An advantage of using data derived from renewable energy technologies as a content area is that undergraduate students have the prerequisite knowledge to understand the technology and related data because the data reflect the performance of the technologies based on earth science concepts. Moreover, since basic concepts of earth science are applied to the design of technologies that capture solar and wind energy, many of the concepts that are taught in earth science courses allow for cross discipline instruction—science, technology, engineering, and mathematics. Engineering students, for instance, can use mathematical models to predict the performance of systems, while pre-service teachers acquire knowledge of how renewable energy technologies work through the creation and analysis of technical visualizations.

The $GRID_C$ project team provided individual and group training sessions for the educators involved in curriculum development and design. Each session included a detailed description of the project's curriculum design goals, and involved discussions on factual, conceptual and procedural knowledge, knowledge application, and student reflection. Handouts were provided on methodology, instrumentation, procedure and assessing learning outcomes. The sessions gave instructors an opportunity to state their questions and concerns, and discuss their long term curriculum development plans.

The goal of the project is to develop students' higher order thinking skills, problem solving, technical visualization skills, and decision making skills in the context of a data-rich learning environment. Research on technological problem solving, critical thinking, novice/expert performance and metacognition reveal a common thread for developing these skills. 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.[5, 6]

Factual and Conceptual Knowledge: This knowledge includes an understanding of the systems, subsystems and components of the technology under study. What is the basic design, how does it function and what are the expected outputs? This knowledge, gained through lecture, readings or personal research, forms the basic understanding needed before proceeding with the design and problem solving process.[7]

Procedural Knowledge: This knowledge includes an understanding of the engineering design and/or problem solving processes that lead to innovative solutions. The processes and strategies used to solve problems and make decisions must be understood.[8,9] These processes include equations used to calculate system performance, transform data, and make predictions, and problem-solving processes such as troubleshooting and project management. A major process focus is the use of technical and engineering graphics.

Knowledge Application: To develop higher order thinking skills, students must have the opportunity to apply their content, process knowledge, visual application,[10, 11, 12] and learn from errors.[13] Performance data from the variety of renewable energy systems proposed for this project provide opportunities for engineers, architects, and teachers to analyze and evaluate system variables within the context of their disciplines.

Reflect: Researchers have discussed the importance of making students' thinking visible.[5] The nature of the data to be collected and used in this project supports development of thinking skills allowing students to reflect on the thought process. Students will have the opportunity to analyze, evaluate and predict while applying concepts in a variety of situations. Reflection should also include looking back on the process that led to decisions.[14] What metacognitive processes were used to reach solutions?

Instructional units were developed for the following courses:

- TED 221 Construction Technology, NC State University, College of Education, Department of STEM Education: 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.

- TED 532 Current Trends in Technical Graphics Education, NC State University College of Education, Department of STEM Education: This graduate level course discusses the current trends in technology, techniques, and theories relating to technical graphics education with emphasis on graphics education and visual theory. The course is centered on assigned readings and student-researched presentations on topical subjects; readings are drawn from journals and texts, on-line databases and articles, and current news media sources.

- EMS 373 Instructional Science Materials, NC State University, College of Education, Department of STEM Education: This course teaches students to develop and select teaching materials that reflect concepts of content, with an emphasis in middle and secondary school science. The course provides an overview of experimental and laboratory approaches, including the use of microcomputer and video technologies.

- MAE 421 Design of Solar Heating Systems, NC State University, College Engineering, Department of Mechanical and Aerospace Engineering: 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, suncharts, and photovoltaics. Computer-aided design is used in the design phase of this course.

- CST 293-Selected Topics in Energy Efficient Building and Design, Pitt Community College, Construction and Industrial Technology Division: This course familiarizes students with building principles that form the basis of energy efficient building and design. Students are introduced to passive solar design, thermal analysis, indoor air quality, and studying the house as system.

Methodology

Student Assessment

Each instructional unit was implemented by the instructor assigned to the course. To determine if the desired learning objectives were achieved, the following research method was employed. With the introduction of each unit, students were instructed on the unit’s learning objectives and required activities, and the class began with a pretest consisting of general renewable energy knowledge items and a metacognitive inventory. During the unit, students kept a journal. Upon completion of each unit, the posttest knowledge questions and the metacognitive inventory were administered. Data collected with pre/posttests, journals, forums, technical sketches and activities requiring knowledge application were archived for statistical analysis and reporting.

Two assessment instruments have been piloted with students, one to measure students' metacognitive perception of their problem-solving competencies and the other to measure students' knowledge of common constructs and facts pertaining to renewable energy technologies. A Metacognitive Inventory (MI) was developed using 6 items from the Problem Solving Inventory (PSI)[15] and 20 items from the State Metacognitive Inventory (SMI)[16] to evaluate students' awareness of their cognitive processes as they approach and solve problems. The PSI is a 35-item test, which uses the Likert scale response options to assess individuals' awareness of their style of solving life problems such as relationship conflicts and career choices. The SMI, a 20-item test which also makes use of Likert scale response options, is used to assess the extent to which students are aware of thinking skills they use to complete tests. The project team modified the selected PSI and SMI items such that the MI 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 second assessment tool consists of 12 multiple choice items, aimed at evaluating students' general knowledge of renewable energy technologies.

Participants

The sample consists of 118 individuals. Student data was collected from a variety of undergraduate and graduate courses at NC State University and a course at Pitt Community College. Given the mix of community college students and university students enrolled in lower and upper level courses, subjects varied in age and class rank.

Diversity

The instructional modules developed were reviewed to ensure that they broaden opportunities and enable the equitable participation of women, nontraditional age groups, underrepresented minorities, and persons with disabilities. Use of the database and implementation of the instructional modules to increase the participation of women in technology and engineering will be a priority. Notably, the partnership in this proposal with Pitt Community College enhances the involvement of diverse populations in project activities. North Carolina Community College System has throughout its history served nontraditional age groups through its successful outreach to adults seeking education, training and retraining for the workforce, including basic skills and literacy education, occupational and pre-baccalaureate programs. The community colleges represent a population of over 44,000 students for 2005-2006, where females have consistently outnumbered males 2 to 1 over the past five years. Racial diversity in these community colleges is also noteworthy: 26% of the student population is black; 0.6%, American Indian; 2.5%, Asian; and 3.3%, Latino.[17, 18]

Results

In one course, the renewable energy general knowledge post-test questions were not administered by the course instructor, leaving researchers with a base of 112 observations. Table 1 provides descriptive statistics for the renewable energy general knowledge pre- and post-tests. The tests were graded out of 12 possible points.

Table 1
Descriptive Statistics for the Renewable Energy General Knowledge Pre- and Post-Tests

	Mean	Std Deviation	Minimum	Maximum	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

Following appropriate normality tests, a paired t-test was used to determine improvements in students' general knowledge. The results indicate significant gains in post-test renewable energy general knowledge scores ($t(96) = 9.41$, $p < 0.001$).

In a second course, the instructor distributed, but did not ask students to complete the MI at the beginning of the unit. Therefore, many students submitted their pre-MIs at the same time as their post-MIs. This resulted in the loss of fifty observations in the analysis of the MI and its individual items. Table 2 provides descriptive statistics for the MI pre- and post-tests.

Table 2
Descriptive Statistics for the Metacognitive Inventory (MI) Pre- and Post-Tests

	Mean	Std. Deviation	Minimum	Maximum	Median
MI Pre-test	3.98	0.41	2.85	4.96	3.96
MI Post-test	4.07	0.45	2.92	5	4.04

A paired t-test is used for the analysis. The results indicate significant gains in metacognitive performance, as measured by the MI ($t(58) = 2.19$, $p < 0.001$).

A Wilcoxon signed-rank test was performed on each of the 26 MI items. The MI made use of 5-point Likert scale response options. Six items showed significant gains in student perceptions, primarily in items from the category of ‘self-checking.’ Using Wilcoxon signed-rank tests in the category of self-checking, the items: “After I solve a problem, I analyze what went right or what went wrong,” “I almost always know how much of an assignment I have left to complete,” and “I check my accuracy as I progress through assignments” showed significant gains from pre- to post-tests. The following items also indicated significant gains: “I am usually able to think up creative or effective alternatives to solve a problem” from the category of ‘confidence,’ “I think through the meaning of assignments before I begin” from the category of ‘cognitive strategy,’ and “I am aware of which thinking techniques and strategies to use and when to use them” from the category of ‘awareness.’ Surprisingly, the following item from the category of awareness showed a decrease in perceived frequency of use: “I am aware of the need to plan my course of action.”

Discussion

The present analyses show significant gains in post-test renewable energy general knowledge scores. 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, including those related to engineering design graphics.

The researchers also found significant gains in metacognitive performance, as measured by the metacognitive inventory. The metcognitive inventory makes the thinking process visible, thereby allowing researchers to see the significant increase in students' reflections on their thought processes. This outcome is of particular importance as research on technological problem solving, critical thinking, novice/expert performance and metacognition has shown that students must understand factual, conceptual and procedural knowledge, apply their knowledge to learn by doing (i.e. creating visualizations), and then reflect on the process that led to the solution.

Detailed analyses of the MI showed significant gains for certain items. The majority of gains were in the category of 'self-checking.' Students were found to check the accuracy of their work as they progressed through assignments and reflect on problems, analyzing what went right or what went wrong. Again, the use of visualization and the development of these skills were integral for students full understanding of the engineering design process.

Significant gains were found in other MI categories as well. Students reported a greater ability to think up creative or effective alternatives to solve a problem, which showed a significant increase in the area of 'confidence.' They also reported thinking through the meaning of assignments before beginning, showing a development of a 'cognitive strategy.' Finally, in the category of 'awareness,' students reported becoming more aware of which thinking techniques and strategies to use and when to use them. However, within the same category of 'awareness' students showed a decrease in awareness of their need to plan a course of action. Collection of more data will allow for a deeper evaluation of these statements.

In addition to gathering more student data, the future brings new opportunities for collaboration with various companies within the energy and transportation industries. Refinements to the curriculum will be introduced to demonstrate the effectiveness of an integrated, data-rich curriculum to teach STEM concepts and develop metacognitive skills. These findings have potential to be expanded upon through further study utilizing treatment and control methods for comparisons of non-data-rich learning environments. Through the various courses offered among the partnering institutions, this curriculum will reach a sizeable and diverse population of students, better enabling them to learn about renewable energy technologies by understanding the variables and variable relationships that are controlled by the technologies' design and function. As the results suggest, the $GRID_C$ research project has national implications for improving STEM education, and will provide a platform for continued research and development of instructional material that improve STEM education. More research is needed in how technical graphics, through STEM education, and the use and understanding of visualization processes enhances students cognitive and metacognitive abilities.

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