DIVERSITY AND INQUIRY IN K-12 PHYSICAL SCIENCE TEACHING: DEFYING THE FEMALE HISPANIC "STEREOTYPE THREAT"

Sandra B. Davis
Carla J. Thompson
Giang-Nguyen Nguyen
University of West Florida

Although recent national efforts to increase participation of females and minorities in science, technology, engineering, and mathematics (STEM) fields in education have been rekindled in 2012 through the emphasis on the 40th Anniversary of Title IX by the President Obama administration, major increases in the participation of these underrepresented groups in the sciences have been documented only in the biological sciences (Drew, 2011; French, 2012). One reason posited for explaining the increase in participation of females in the biological sciences is the emphasis of the biological sciences and medical fields on helping people or nurturing career fields. Opposing this rationale are the physical sciences which are perceived as difficult content involving considerable knowledge in mathematics. Teacher preparation in the physical sciences requires considerable attention to inquiry-based learning as well as addressing factors contributing to the lack of representation of females and minorities in physical sciences fields.

The "stereotype threat" phenomenon relates to actions often associated with underrepresented groups in math and science fields, such as females, minorities, and rural students. For example, unconscious gender and ethnicity stereotyping comments and actions may occur in classrooms by teachers and students that may prevent female and minority students from joining the Community of Learners (COL). Promoting diversity among COLs, alleviating stereotypes, and encouraging underrepresented groups in their active participation within COLs focused on inquiry-based teaching and learning environments are considerations that prompted the current case study effort. The 6E Learning Model in graduate science education founded on the conceptual framework of the National Science Education Standards (NSES) and involving a sequence of six phases provided the venue for the case study.
Background and Rationale

Three major areas of consideration provided the background and rationale for the case study: (1) the historical trends of non-representation of female and minority students in science education and STEM fields; (2) the conceptual framework of the 6E Learning Model for infusing inquiry-based learning into a graduate science education setting; and (3) the emerging research findings focused on the impact of “stereotype threat” in science education. Each of these areas is discussed relative to the rationale for the case study.

Historically, females and minority students have demonstrated little participation in STEM fields and/or career paths. Federal regulations, including the enactment of Title IX in 1972 by the U.S. Government, call for gender equity in education, especially in STEM education arenas (U.S. Department of Education, 2012). Although there has been an increase of almost 6% in the number of STEM degrees awarded to women since 2000, the number of female STEM graduates with STEM degrees and certificates in 2009 was only 31%. The number of females graduating with Bachelor’s Degrees in physical science in 2009-2010 was 41% as compared with 59% for males with bachelor degrees in the physical sciences (U.S. Department of Education, p. 2). Therefore, the need for examining a focus audience of females and minorities within a physical science education environment for the case study setting was supported by current national statistics highlighting disparities in gender equity participation in education.

The second area of consideration that provided the impetus for the case study was the conceptual framework and research-based evidence supporting the use of the 6E Learning Model for inquiry-based learning. Inquiry-based learning procedures related to scientific activities are conducted before, during, and after experiments. The processes of data driven analyses include observation, drawing inferences, and formulating evaluative findings. Findings are interpreted and examined relative to previous inquiry efforts and reported within the context of the evaluation outcomes.

When implementing the 6E Learning Model (Peters & Stout, 2011), there are two ways to measure student learning: written evaluation and performance assessment. Students may supply a written summary of the activity as a discussion segment of the experiment. Students can add
completed data and results of the experiment as another discussion point. This information may be recorded in an online learning discussion environment. When students physically apply what they have learned, concepts will be internalized (Stamp & O'Brien, 2005). Relating science activities to real life experiences such as the science inquiry example used in the case study, creating electric circuits, provides the real-world connection to physical science concepts. Thomas (2000) claimed teachers, like students, require experience in both didactic and performance tasks to sustain engagement and continued motivation. This notion supports the idea of the COL in the graduate science course. Adaption of the 6E Learning Model can independently reproduce an activity and check for transfer and internalization of knowledge at each level after the base domain is established (Stamp & O'Brien, 2005).

The third area of consideration that provided the rationale for the case study was the emerging research findings focused on the impact of stereotype threats in science education. The stereotype threat has been demonstrated in previous research efforts focused in mathematics and science fields with underrepresented groups, such as females, minorities, and rural students (Weinburg, 1995). Previous research findings have indicated substantial evidence that the "stereotype threat" may prevent female and minority students from joining the COL or may inhibit learners' self-esteem levels (Gorlick, 2009). These emerging findings provided a strong rationale for the need for the case study focus on stereotype threat.

**Conceptual Framework: Inquiry-based Learning and the 6E Learning Model**

Inquiry-based learning is often approached using the 6E model. The 6E model has a base domain of engagement followed by exploration, explanation, elaboration, evaluation, and extensions. This model is consistent with how students learn science (Stamp & O'Brien, 2005). During the engagement phase, students are either presented a question of interest to explore, or they develop their own questions to explore. During this base domain phase, students are encouraged to be inventive and use trial and error (Stamp & O'Brien, 2005). The exploration phase of the model allows students to work within their "Zone of Proximal Development" (Vygotsky, 1978), and view themselves as scientists (Peters & Stout, 2011). During the explanation phase, students answer questions
that were presented at the beginning of the inquiry lesson. Students offer their own explanations to the class about their findings during the inquiry process. The elaboration phase allows students of diverse needs time to reflect on what has been learned through the inquiry process. Students can modify any misconceptions they had as well as make connections to previous ideas (Peters & Stout, 2011). The evaluation phase allows the teacher to determine how the student understands using authentic indicators and question prompts (Peters & Stout, 2011).

The 6E Model used in this research is explained in five steps with extensions being the sixth step involving continuous applications. Step 1: Engagement involves activating a potential base domain of engagement by describing the goals and assessment plan (evaluation) that are to be reached through the beginning use of engagement. Students should be able to discern between the use of observation and inference during step 1. Step 2: Exploration consists of students developing hypotheses through exploration. During step 2, the engagement challenge guides students into developing hypotheses and procedures to identify and link appropriate equipment and operational procedure needs. Step 3: Explanation is comprised of students making connections to what is occurring. Step 3 includes explanations of the quantitative and qualitative observations that are generated. Question prompts for understanding begin to occur based on the observations and inferences generated during step 3. Step 4: Elaboration involves students providing additional inferences developed from the base domain of engagement. Step 4 also involves students developing additional conceptual relationships, inferences, and hypotheses.

Step 5: Evaluation consists of students reflecting and self-assessing their understanding. Step 5 also consists of students interacting with one another through reflective discussions. Step 6: Extension challenges students to extend their understanding of the concepts to real world applications beyond the activity or task confronted during the 6E process. Step 6 also provides opportunities for students to transfer their learning to new venues and applications. The 6E Learning Model was used as the conceptual inquiry-based learning framework for the current case study analysis.
Characteristics of Female Minority Science Learning Including the “Stereotype Threat”

Previous research efforts have found that negative stereotypes affect women’s performance and aspirations in math and science through a phenomenon called “stereotype threat” (Nguyen & Ryan, 2008). Stereotypes about female performance have been shown to have a negative impact on student performance (Steele, 1997; Steele & Aronson, 1995). Stanford’s Greg Walton and Waterloo’s Steven Spencer tested nearly 19,000 students in the United States, Canada, France, Germany, and Sweden. They found that when “stereotype threat” (often embedded in standardized testing and general classroom environments) is minimized, ethnic minorities and women outperform non-minorities and men at the same level of past performance (Gorlick, 2009). Nguyen and Ryan (2008) found that stereotype threat causes a broad range of African-American and Hispanic students to underperform on the Stanford Achievement Test by about 40 points. Additionally, the stereotype threat lowers many women’s scores on the math portion of the SAT by approximately 20 points (Gorlick, 2009).

Stereotype threat research efforts have shown the consequences of the threat extend beyond underachievement on academic tasks. For example, students influenced by the stereotype threat may demonstrate self-handicapping strategies, such as reduced practice time for tasks and a reduced sense of belonging to the stereotyped domain (Steele & Aronson, 1995). These research indicators support the importance of the COL, especially for minorities and females.

In addition, previous research studies indicate inquiry-based learning allows underrepresented groups such as Hispanic females to ponder and think like scientists to solve everyday problems (Nguyen & Ryan, 2008). Inquiry-based learning related to physical science in daily living provide a natural focus of interest for underrepresented groups traditionally not pursuing physical science education. A COL consisting of minority Hispanics, African Americans, and other women may be the key venue for underrepresented student groups successfully focusing on the incremental understanding of physical science through a structured inquiry method.
Methodology

This research involved nine female graduate students enrolled in a science education course for pre-service teachers focused on a physical science task involving electrical circuits. The 6E Learning Model was utilized in the study for a two-fold purpose: (1) to guide students' learning about electric circuits through an inquiry-based learning effort directed by the 6E approach (engage, explore, explain, elaborate, evaluate, and extend) and (2) to provide the procedural approach for the acquisition of qualitative data obtained at pivotal points within the case study analysis. By focusing on student statements at different stages in the learning sequence, the researcher examined to what extent each of the steps of thinking identified specific data pertinent to themes of diversity, inquiry, and stereotype threats as well as information grounded in rich descriptions of relational interactions of the nine females observed in the study.

Description of Procedures

The lesson of designing electric circuits in this study has been described and utilized in detail elsewhere (Dudeck, 1997). The teaching of the lesson was online and occurred over 14 days in a threaded discussion forum for a 13 week online science methods course at a university in Northwest Florida. Science kits had been provided to all graduate students within the first two weeks of the course. The 6E Learning Model was used for the first two lessons to establish base domains and evaluation of each lesson. There were no requests for assistance during the first two weeks' experiments in the course and open-ended question prompts were used by the instructor.

The third week of the course focused on an introduction to electric circuits. The aim of teaching this lesson was for students to develop a qualitative and quantitative understanding of electric circuits as a system in which the following terms were understood to be interdependent: circuit, voltage, current, conduction, power source, and resistance.

Other focus components represented in the course included the following areas: (a) students needed to recognize that a change at one point in a circuit has an immediate impact on the whole circuit when constructing series circuits; (b) students established a base domain of engagement through discussions about vocabulary usage and the equipment identification; (c) students continued to work through the 6E
Learning Model until the explanation phase was reached; and (d) students assisted each other with any preconceived notions and created a positive learning environment.

Data Collection

The 6E Learning Model was utilized as the primary data collection method for obtaining information relative to the process of inquiry-based learning and specific to the case study analysis using the unit of instruction in physical science devoted to the task of building an electrical circuit. Each of the 6E Learning Model procedures with accompanying data collected from observations of the nine female students enrolled in the pre-service physical science education course is discussed relative to the observed behaviors of the students.

Step 1: Engagement. When students examined an electric circuit diagram for the first time, there were many pieces of equipment needed to relate back to the diagram. In order to activate the base domain of engagement, students worked together to understand concepts and rules of electric circuits. They began with generating ideas and experiences related to bills, meter readings, appliances, and measuring voltage. Most students discussed the lack of electricity and electrical blackouts. Safety was a vital theme along with a discussion of the local power company.

Step 2: Exploration. Students hypothesized a connection or link between the wires and the batteries. Previous domains of thought were considered by the students. The target goal within this phase was the exploration thinking connection between the bulb, wire, and battery. Students were not using the vocabulary at this point, and the term resistance was not related to wire. Some interdependencies of concepts were still not recognized by the students. The basic idea of creating a system was apparent which included a power source, a power transmission, and a power consumer.

Step 3: Explanation. The students suggested to each other that the electric current had resistance. The equipment was connected, and the bulbs lighted. There were students who understood the relationships between resistance and the electric circuit. There were other students who did not recognize the relationships and asked their husbands or Olivia, a Hispanic female student in the class, for assistance in recognizing the relationships. Olivia became the expert for her peers to explain the flow of
electrons. The students who asked for Olivia’s assistance indicated they knew Olivia would make the connections and explain information to them in terms they could understand. Olivia was recognized by her peers as the mentor for the physical science task of developing an electrical circuit. The explanation phase of the 6E model was observed to be the step at which four of the nine female students employed the help of a female Hispanic peer and assisted the researcher in creating relational nets describing Olivia’s learning in the 6E inquiry steps.

**Step 4: Elaboration.** The students began to noticeably make sense of the simple electric circuit development and operation through Olivia’s assistance and group discussions. Observed student inferences were noted. Students were asked to test their electric circuits by making measurements of the equipment used to develop initial hypotheses. Students tested their hypotheses using different electrical circuit designs. The females worked together to create a dimly lit circuit and another circuit with brightly lit bulbs. After these simulations were completed, a discussion ensued as to how both were constructed, and a diagram of each design was completed.

**Step 5: Evaluation.** The evaluation was ongoing as students were asked to make different simple electric circuits and light all bulbs. The process of evaluation was extended to the researchers’ requests for the processes involved in making the bulbs light using the appropriate vocabulary terms.

Olivia suggested for parallel circuits: “More bulbs in parallel should mean less resistance and higher current. I cannot believe I can relate this to power outages at home. It is beginning to make sense.”

**Step 6: Extensions.** Students began to discuss the amount of money spent on cooling their homes in Florida during the summer months. This led to the idea of researching innovative ideas for alternative sources of energy.

Students’ threaded discussions and other written statements characterized learning extensions. For example: “I would like to invite a Gulf Power professional to my classroom to discuss energy and alternative sources for generating electricity. I wonder about the scale of how they operate their plants?”
Analysis of Data

The researchers examined learning processes using the 6E model for constructing individual simple electric circuits. Students' discussions were evaluated at four of the 6E phases followed by instructor questions at each phase. Informal narrative inquiry was the primary qualitative research approach for measuring the success of the simple circuits’ lesson by comparing phases of active participation in the threaded class discussions. Relational themes were identified using data gathered at the four phases of development of understanding simple electric circuits. Specific relational nets were created for Olivia’s electric circuits. The researcher concentrated on the learning processes observed in the discussion for parallel circuits since discussions regarding series circuits and parallel circuits were similar (Paatz, 2002).

Results and Conclusions

Results of the case study analysis are presented relative to the emerging themes from the students’ threaded discussion transcriptions. Themes with supportive findings include: (a) Olivia’s prior knowledge concerning electric circuits; (b) Olivia’s explanation phase for electric circuits; (c) Olivia’s exploration phase for electric circuits; (d) Triangulation of data results, and (e) Future implications for K-12 science teachers.

Olivia’s Prior Knowledge Concerning Electric Circuits

When questioned about her prior knowledge during evaluation at the explain phase, Olivia demonstrated a limited understanding of electric circuits in her discussion:

I don’t remember a lot of this from my elementary years. I remember just “faking” it. I always asked someone in the class to help me out. I have to admit it was easier to understand the instructor’s explanation of the current flow.

She knew that a closed circuit was necessary to make the bulb light. Olivia had common misconceptions of electric circuits and was not sure about the terms voltage and resistance. The battery was seen as the “constant supplier of current” and independent of the other equipment.
Olivia’s Explanation Phase for Parallel Circuits

The explain phase of the 6E Learning Model was a new content area demonstrated by four of the nine students in the study. The researcher asked herself if the “infer based on observation” needed to be stressed more with the class (National Research Council, 1996, p. 230). With this idea in mind, the question became “What big picture misunderstandings, essential questions, and potential misconceptions” need to be addressed (Wiggins & McTighe, 2005)?” This was evidenced in the relational theme of Olivia’s discussion:

What I learned was patience! I finally asked my husband to help me maintain all my connections to keep all light bulbs working at the same time. When I finished my parallel electric circuit, my husband tried to correct me—the batteries in the parallel design might be series—but the bulbs are okay. Silly guy! He was wrong.

Olivia’s Exploration Phase for Electric Circuits

Olivia used her knowledge about parallel circuits as a starting point for dealing with the explore phase without too much difficulty. She addressed the potential misunderstanding of resistance by hypothesizing...
the battery provides some sort of resistance which is eventually used up in the parallel circuit. When asked how resistance affected the bulbs, Olivia was not sure but was able to explain it to her classmates the next day.

When the instructor asked the students to rebuild and examine electric circuits, they became interested in constructing a diagram of their circuits. Additionally, they assisted each other and compared their parallel circuits. The students supported one another and were very structured in their task of who had the knowledge in each phase of explain and explore. The four female students who sought help from Olivia’s expertise expressed strong confidence in leading the way for their classmates. Olivia stated “The brightness of the bulbs in a parallel circuit should be independent of their number” (Threaded Discussion, August 2011). This hypothesis was agreed upon by all her peers. Olivia’s approach in this discussion showed the connection between the base domain or engagement phase to the explain phase.

Figure 2. Higher Order Relational Net depicting the final target domain as a result of hypothetical extensions from Olivia’s question prompts and inquiry discussions. The dashed lines indicate partial knowledge.
Triangulation of Data Results

With all data sources triangulated, four of the nine female graduate students demonstrated a correct simple electric circuit through threaded discussions and posted diagrams after receiving Olivia’s assistance. Students’ confidence levels and knowledge levels of electric circuits improved as evidenced in their discussions within the explanation phase of the 6E learning model.

Olivia took the lead to demonstrate both series and parallel circuits. Her approach to redesigning her simple circuits correctly and formulating a hypothesis was displayed when provided with this inquiry mode of learning in which didactic instruction was paired with written and performance evaluation. Students demonstrated a “scaffolding” learning effect within the explain phase and explore phase of the 6E learning model. Olivia had reached the “Zone of Proximal Development” (Vygotsky, 1978). She was able to work with her peers after she internalized the learning or gained autonomous control of the concept. The graduate students experienced greater learning by working with Olivia in a participatory environment. The females were more comfortable and confident in their ability to collaborate on the construction of new hypotheses for their circuits which Olivia now referred to as electric current.

The students’ threaded discussions revealed greater depth in understanding of content and deeper understandings of their own instruction after working with Olivia and interacting within the 6E inquiry-based Learning Model. Students expressed greater personal satisfaction in their learning experiences after working with Olivia and after experiencing the 6E Learning Model. Students participating in the study developed their communication skills and were able to perform more confidently socially within the class threaded discussions than before the course began. In addition, written and performance tasks were somewhat improved at the end of the course, perhaps due to the subject taught (i.e., physics).

According to Peters (2010), the exploration phase of the 6E Learning Model promotes inquiry-based science learning which is consistent with how students learn. The characteristics of this phase provided suggestions to the researcher when students first encountered the idea of observation to inference: (a) Cultural mediation helps students to
form new concepts or modify existing spontaneous or scientific concepts;
(b) Students work within the Zone of Proximal Development as they
explore questions developed in the base domain of engagement;
(c) Students may begin view themselves as a group of scientists who are
engaging in a scientific process and promoting positive dispositions.
Results of the current case study analysis provide strong support for the
sustainability of using the 6E Learning Model to begin the transition from
direct instruction to inquiry-based science.

Support for the defiance and dispelling of the “stereotype threat” is
also evidenced in the results of the case study outcomes. Olivia stressed
the importance for positive female role models in the sciences during their
fifth grade of elementary schooling in order to do science. The researcher
speculated this was due to Olivia’s lack of understanding of the
dependence on using and applying exploration when solving problems
instead of the single influence of a female science teacher. Therefore, the
integration of the 6E Learning Model as an instrumental approach for
dispelling the stereotype threat in physical science education is supported
by the current study.

Future Implications for K-12 Science Teachers

Lessons learned from Olivia’s behaviors and professional actions
hold strong implications for teachers in K-12 science and math
classrooms. The case study explored the use of an inquiry-based
experience in a graduate science education course which utilized the 6E
model and the request by a Hispanic female, Olivia, in the COL to assist
the other females in creating electric circuits, one project assignment
established for the course.

Our plan begins with changes on how to teach electric circuits and
expands to adding the backwards design of application (Wiggins &
McTighe, 2005). Once this is accomplished, the curriculum design will be
implemented. The new data driven inquiry problems will be well defined
in the base domain of engagement in order to gain a secure understanding
of the broad and unsystematic knowledge (Johnson, 1987). The additional
phases of the 6E Learning Model are significant in the timetable for
teaching in order to overcome students’ misconceptions of simple electric
circuits. Using her skill and performance in physical science and utilizing
the 6E Learning Model of inquiry-based learning, Olivia expertly defied
and dispelled the “stereotype threat.” Lessons learned from Olivia’s
behaviors and professional actions hold strong implications for teachers in K-12 science and mathematics classrooms.

In this case study, Olivia was more confident in her ability to conduct the electronic circuit because she expressed enjoyment in doing the task (Bong & Skaalvik, 2003). By identifying an individual student’s self-efficacy, the instructor can provide some directions to structure classrooms that promote their self-perceptions, which in turn fosters their understanding. Particularly, Olivia’s self-concept about science built her confidence in her ability to create simple circuits. The emergence of Olivia’s assistance during the simple circuit lesson has not been evidenced in science classes with males being the higher achievers in performance-based science (Jovanovich & King, 1998). This has occurred with exemplary science teachers being sensitive to females’ encouragement for increased participation. Other researchers who study teaching and learning strategies with gender differences in mind (e.g., Weinburgh, 1995) will state there is a difference in pre-existing knowledge between girls and boys and their different ways of learning. It has also been suggested females and minorities’ self-confidence in physics and technology are lower when in a classroom setting with males due to a decline of interest from lower secondary education experiences.

We believe lessons should be scaffold with female students being grouped together as a COL to complete more open-ended tasks and ultimately design hypotheses to test in everyday physical science. The cooperation, discussion, and question-answer method in this culture was productive and applicable to improving learning. However, this will be a process as science teaching continues to change and minority female students construct new knowledge within a broader framework of teacher commitment to gender equity in STEM education. The researchers’ goal is to increase opportunities for work on challenging problems in physical science using the 6E learning model.

Researchers who study teaching and learning strategies with gender differences in mind (e.g., Weinburgh, 1995) indicate males have a more positive attitude towards the physical sciences than females. Females and minorities who experience early interventions with specific classroom strategies demonstrate improved attitudes towards the physical sciences (Weinburgh, 1995). The results of this case study analysis provide some evidence in support of students’ attitudes influenced by students
developing strong relationships with the content, COLs, and students’ own everyday experiences.

Our research findings extend the literature which is consistent with previous research foci. Early intervention might help narrow the gap between gender and performance in science and mathematics (Wilkins, 2004; Wilkins & Ma, 2003). Furthermore, there must be clear articulation concerning stereotype threat in all mathematics and science education teacher preparation programs which are aligned with NCATE accreditation standards.

References


60

