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Editor: Dr. Genevieve Brown
College of Education
Sam Houston State University

Editor: Dr. Beverly J. Irby
College of Education
Sam Houston State University

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Learning about the Human Aspect of the Scientific Enterprise: Gender Differences in Conceptions of Scientific Knowledge

Dr. Erin E. Peters Burton

Abstract

Calls for new ways to teach science include an emphasis on the human endeavor of science and for making science more relevant to a feminine perspective. This quasi-experimental intervention study of 166 middle school students approaches the teaching of the nature of science in an explicit and reflective way that also enhances the humanistic perspective of scientific knowledge construction. Girls in the experimental group significantly outperformed both boys in the experimental group and boys and girls in the comparison group on nature of science knowledge and on content knowledge. Differences were also found in the qualitative results. Girls saw the process of cognition as a group endeavor, whereas boys reported the process as being generated by themselves, with guidance from books or from the teacher. Additionally, girls in the experimental group tended to rely more on evidence in making conclusions and boys relied more on authority when they developed the “big ideas” in their inquiry.

Keywords: Nature of science, scientific inquiry, gender issues in science, science cognition.

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Introduction

Since the launching of Sputnik, reports from the U.S. Government have indicated that there is a critical shortage of elementary and secondary students who are interested in science (see National Research Council, 2007; National Commission on Mathematics and Science Teaching for the 21st century, 2000; National Research Council, 1998). Especially notable is the lack of girls and women who pursue science as a career (NCES, 2001). Although government is aware of the shortage of students interested in science, efforts have not improved the poor scores from students in the United States when compared to other countries (TIMSS, 1999, 2003, 2007). Younger U.S. students tend to score equally with other industrialized countries, but as students progress through the grade levels, older students rank much lower than other countries. It can be interpreted from these test scores that as students reach the secondary level of education, they become less interested in learning about science.

One possible connection to students' lack of interest in science in the United States is the way in which science is taught in secondary school and in college. College students who do not consider themselves "science-minded" have chosen to leave the field of science because of the competitive and isolating way in which science is taught (Seymour, 1995; Tobias, 1990). The perception that science is isolating and unfriendly is also evident in the finding that girls in secondary school feel that science is irrelevant to them because of the isolating and competitive methods of science instruction (Baker & Leary, 1995), and tend to have low self-efficacy in their performance in science class, especially in the physical sciences (Britner, 2008). The purpose of this study was to test a unique teaching method that emphasizes the human endeavor of pursuing scientific knowledge as a possible relief to the isolating and inhospitable methods of teaching science, to compare the academic performance of girls and boys and an exploration into the cognition boys and girls use to make sense of scientific activities.

The Shortage of Women in Science

The absence of women in science is a persistent problem that reduces the amount of progress that can be made in the field of science. Lack of women in the field means limited perspectives in generating scientific knowledge (Blickenstaff, 2005). Synthesis of the research on why girls and women do not pursue science points to nine possible reasons: (a) biological differences between men and women, (b) girls' lack of academic preparation for a science career, (c) girls' poor attitude toward science and lack of positive experiences with science in childhood, (d) the absence of female scientists as role models, (e) science curricula are irrelevant to many girls, (f) the pedagogy of science classes favors male students, (g) a 'chilly climate' exists for girls in science classes, (h) cultural pressure on girls to conform to traditional gender roles, and (i) an inherent masculine worldview in scientific epistemology (Blickenstaff, 2005).

Much of the research done to explore the reasons for the lack of girls and women in science cannot explain fully the phenomena. Although some cognitive difference between men and women were found in two meta-analyses by Janet Shibley Hyde in 1996, the differences in spatial perception ($d=.43$) and mathematical ability ($d=.45$) cannot alone explain the 20 to 1 ratio of men to women found in scientific careers. Girls' and women's lack of preparation for studying advanced science has not convincingly been shown to be a barrier to a science career. Girls are

well-prepared to pursue science courses, but still choose to avoid them (Cole, 1997; Erwin & Marutto, 1998). Neither biological differences nor lack of academic preparation can account for the low number of girls and women who are involved in scientific pursuits.

Examining other factors, such as attitudes toward science, role models, pedagogy, and scientific epistemology leads us to more substantial contributions to the reasons behind girls' and women's dislike of science. Weinburgh (1995) conducted a meta-analysis of girls' and boys' attitudes toward science and found that boys had a more positive attitude toward science ($d=0.20$), especially in general science and earth science ($d=0.34$). Baker and Leary (1995) interviewed 40 girls about their experiences in science and found that girls noticed a lack of role models and could not imagine themselves as scientists. Additionally, they found that girls were more interested in biological sciences rather than physical science because they had a need to care for humans and animals. In an investigation of 1500 physics students in 16 universities across the United States, it was found that women were more successful if they took a high school course that emphasized depth rather than breadth of the subject (Hazari, Tai & Sadler, 2007). The quality of teaching at the university level also has an impact on the perseverance of girls and women in science. Seymour (1995) found that students who have switched from a science major to a non-science major, 90% of the students had a concern about the pedagogy. The students reported that the instructors were not easily approachable, and they over used competition in the grading system to the detriment of collaboration among students. These findings were corroborated by Tobias (1990) who found that undergraduate students who switched majors felt isolated in their studies. Lastly, it has been extensively argued by authors such as Evelyn Fox-Keller, Jane Gilbert, Sandra Harding, and Donna Haraway that science inherently has ways of knowing that exclude a feminine perspective. Henwood (1996) on scientific epistemology revealed the deeply gendered nature of scientific knowledge. Because science is based upon positivist objective rationality, the subject of science in school tends to be unattractive to girls and women (Harding, 1991; Kerr, 2001). There is a large body of evidence that points to the need for a different type of teaching science if we intend to improve girls' attitudes toward science and increase the number of women who pursue science as a career.

Inclusive Ways to Teach Science

Calls for new ways to teach science include an emphasis on the human endeavor of science and for making science more relevant to a feminine perspective. Among other conclusions, Blickenstaff (2005) suggested that given the factors that influence the number of women pursuing science careers, curriculum developers should create assignments that emphasize quality of life issues in science and illustrate that the scientific enterprise can provide careers that focus on caring. Gilbert (2001) put forward the idea that to challenge the assumptions that go along with science and its masculine roots, we seek new meanings for "women" and "science" to create spaces that women can truly intellectually engage with the scientific enterprise.

Jones, Howe, and Rua (1999) found that the girls rarely engaged in science experiences outside of a classroom setting and propose that curriculum take that into account. Taasooobshirazi and Carr (2008), in their work on gender and expertise in physics, advised that a more authentic view of expertise in subjects like physics be taken so that females do not continue to be derailed

in their success early in their school careers. In creating new ways to teach science that focus on the human element, we can develop programs that will allow young women to maintain their feminine perspective, rather than having to adopt an artificial masculine identity.

Emphasizing the Scientific Enterprise in Curriculum

Curriculum emphasizing hands-on activities that illustrate how humans endeavor to gain scientific knowledge may show students that science is a social and creative undertaking, and help girls to envision science as a career choice. Scientific inquiry is a curricular choice that can make the subject of science more collaborative, engaging, and authentic (National Research Council, 1996, American Association for the Advancement of Science, 1993), but has been historically difficult to put into practice (Bybee, 2000; Costenson & Lawson, 1986; DeBoer, 2004). Although it is intuitive to think that just by conducting scientific inquiry that students will understand how scientists operate, there is a body of research demonstrating that explicit, reflective instruction in the nature of science has been found to be more effective in expressing the scientific enterprise to students (Gess-Newsome, 2002; Khishfe & Abd-El-Khalick, 2002). The nature of science can be defined as the inherent guidelines which scientists use to obtain and verify knowledge in their field (Lederman, 1992). Curriculum that teaches the nature of science demonstrates that the endeavor of constructing scientific knowledge requires particular habits of mind that are simultaneously organized, creative, and rigorous. It shows that scientists do not act alone, but have social networks to help with thinking through problems. Lastly, this type of curriculum would make clear that all scientific claims are backed up with empirical evidence, and that historical factors have played a role in the progress of scientific knowledge discovery. Making nature of science knowledge explicit and reflective diminishes the mysterious process of obtaining scientific knowledge to students, especially girls, and emphasizes the human side of doing science.

In this study, I explored the effectiveness of teaching the explicit, reflective nature of science through a self-regulatory model where students can compare their results of inquiry to the ways scientists work. The self-regulatory model frames the discipline of science in a human context rather than a factual context. Additionally, the self-regulatory model of teaching the nature of science requires students to be self-reflective about their work and can enhance self-efficacy in science learning because of the supportive methods in the model. Several measures of academic success have shown improvement using self-regulated learning strategies (Zimmerman, 1989) including strategy use (Pressley, Goodchild, Fleet, Sajchowski, & Evans, 1987; Weinstein & Underwood, 1985), intrinsic motivation (Ryan, Connell & Deci, 1984), academic studying (Thomas & Rohwer, 1986), classroom interaction (Rohrkember, 1989; Wang & Peverly, 1986), use of instructional media (Henderson, 1986), metacognitive engagement (Corno & Mandinach, 1983), and self-monitoring learning (Ghatala, 1986; Paris, Cross & Lipson, 1984). The intervention in this study approaches the teaching of the nature of science in an explicit and reflective way that enhances the humanistic perspective of scientific knowledge construction.

The following research questions were central to the study: RQ1: Do comparison and experimental groups differ as a function of gender on science students' content knowledge, nature of science knowledge, and self-regulatory efficacy of learning? RQ 2: How do male and

female students report the process of cognition when participating in Metacognitive Prompting Intervention-Science?

Methods

An embedded mixed-methodology was chosen for this study because the research questions involved both the processes of the students (investigated through qualitative techniques) and the outcomes of the students (investigated through quantitative techniques). I employed a quasi-experimental design over two years. This research was not originally intended to discern responses by gender, but later became a natural progression of the work. Students in the experimental group (n = 37 girls, n=42 boys) and comparison group (n=41 girls, n=46 boys) were pre-tested on content knowledge, nature of science knowledge, and self-regulatory efficacy of learning. All classes were taught by the same teacher who was instructed in educational research so that contamination between the different strategies employed by the different groups would not occur. Each class had approximately equal numbers of girls and boys, a deliberate decision by the teachers on the middle school team. During the class, students worked in groups comprised of both girls and boys assigned by the teacher. I visited the classroom daily over the six weeks of the unit each year for two years of the study to maintain fidelity of the teacher to the intended interventions.

Study Setting and Participants

Over two years, 166 students from an urban middle school in the mid-Atlantic region of the United States participated in the study. The middle school serves 928 students, grades six through eight. Seventeen percent of students from this school receive free or reduced price for lunches. The sample population consisted of 7.9% Black students, 10.7% Hispanic students, and 69.2% White students, and 12.2% mixed racial identification.

Study Design

The four modules of instructional material in which the intervention was placed were based on guided scientific inquiry (National Research Council, 1996). Both the experimental group (N=79) and the comparison group (N=87) were given four sequential guided inquiry lessons on electricity and magnetism. The lessons were taught for 45 minutes each day over a 6-week period and had three main pedagogical elements: (a) student prior knowledge, (b) hands-on activities prompting the construction of knowledge about scientific content and processes of the specific content, and (c) student-generated summary of three overarching principles guiding the physical phenomena (National Research Council, 1996). Student prior knowledge was generated in each of the four lessons. A think-pair-share paradigm was used at the beginning of the lesson, and students were asked to write their thoughts individually for three minutes about the topic to be studied for the “think” portion, share ideas with a partner for five minutes for the “pair” portion, and participated in a whole class discussion for the “share” portion. The second section of the lesson consisted of the hands-on activities that were designed to have students observe the phenomena, write descriptions of the physical interactions in the inquiry, and organize an explanation for the core physical interactions in the activity. Lastly, students were expected to use higher-order thinking by describing three or four big ideas that characterize the behavior of

the phenomena, backing up their descriptions with empirical evidence. Students worked in the same assigned co-ed groups of three or four for the entire inquiry lab.

Although both groups were given identical content knowledge and science process tasks, each group was given a different way to develop nature of science knowledge. The experimental group was given checklists and questions that facilitated the scrutiny of their science process work with the guidelines of scientific inquiry (Metacognitive Prompting Intervention – Science or MPI-S). The comparison group learned about the nature of science implicitly through the collaborative hands-on science, and was given additional content questions to account for equal time-on-task. The checklists and questions given to the experimental group, based on the self-regulation work of Zimmerman (2000), attempted to model scientific thinking for a specific aspect of the nature of science, and to teach students to align their decisions during the inquiry with the guidelines inherently used in the scientific community. MPI-S focused only on the nature of science, and was free of content instruction. To show how the checklists and questions were content free, an example of the checklists and questions for the empirical aspect of the nature of science is provided here. The first prompt is an example of an empirical observation made by a scientist that includes detailed descriptions and standard units. The second prompt is a checklist for students to compare their decisions in the inquiry to the empirical nature of science. The third prompt is a short checklist for students to align their work with the nature of science and a short list of questions asking about student reasoning for the validity of their empirical evidence. Lastly, the fourth prompt is a longer list of questions probing students' rationales in their decisions about inquiry processes and construction of knowledge based on empirical evidence. MPI-S was given to the students iteratively to encourage repeated practice in the training. Overall, students were to use the first prompt as a model to do their work, the checklists to reflect on the alignment to the scientific enterprise to their work, and the questions to demonstrate rationale for their decisions regarding valid, empirical data.

Quantitative Data Sources

Mixed methodology was chosen for this study to explain the student outcomes of the intervention through quantitative results, as well as explaining the processes the students used to achieve the outcomes with qualitative results. Quantitative data were gathered from pre-and post-tests of nature of science knowledge, content knowledge, and self-efficacy of learning. Qualitative data were gathered from student work products, think aloud protocols, and focus group interviews.

Test of Electricity-Magnetism Knowledge (TEMK). This test assesses individual attainment of content in the topics of magnetism, static electricity, current electricity, and electromagnetism using 19 short response items. Each question on the TEMK was open-ended and used visual, logical, and analytical forms of communication to assess the content goals. The assessment was designed by the researcher and was evaluated for content and construct validity by a team of national award winning teachers who taught physical science with the same age group of students as the participants. The Cronbach alpha reliability on the TEMK scoring was measured at .82, indicating high reliability within the test. In order to determine content validity, two questions were chosen from the same grade level test that was designed for the National Assessment of Educational Progress or NAEP (National Center for Educational Statistics, 2007).

The NAEP, otherwise known as “The Nation’s Report Card” in the United States, is given to a random sample of students nationally and represents the level of content knowledge for students across that country (National Center for Educational Statistics, 2007). A sample item from the TEMK is “Why are some materials magnetic while others are not?” The rating criteria for the NAEP were identical to the rating criteria for the TEMK content test for this study. An omitted answer received a 0, a partially correct answer received a 1, an answer that was essentially correct but had a minor flaw received a 2, and a completely correct answer received a 3. Raters of this assessment were given a code book that indicated the level of answers for each score. Forty percent of the questions on the TEMK were randomly given to three other raters to determine inter-rater reliability with a Cohen’s kappa statistic which was found to be .92, indicating substantial agreement.

The Views of the Nature of Science- Form B (VNOS –B). The VNOS-B (Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002) assessed student understanding of inherent guidelines used to conduct science and consists of seven open-ended questions corresponding to the seven identified aspects of the nature of science: a) scientific knowledge is durable, yet tentative, b) empirical evidence is used to support ideas in science, c) social and historical factors play a role in the construction of scientific knowledge, d) laws and theories play a central role in developing scientific knowledge, yet they have different functions, e) accurate record keeping, peer review and replication of experiments help to validate scientific ideas, f) science is a creative endeavor, and g) science and technology are not the same, but they impact each other (McComas, Almazroa, & Clough, 2005; Lederman, 1992). Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) argue that nature of science knowledge is best gathered using qualitative methods, and because free-response best represents student knowledge. Each answer on the VNOS-B was ranked using a 0-3 scale: 0 representing no answer, 1 representing novice knowledge, 2 representing emerging knowledge, and 3 representing proficient knowledge using a rubric designed from the research literature recommendations. Because the nature of science tends to be more tenuous than content knowledge, 100% of the responses were used to calculate inter-rater reliability. Cohen’s kappa analysis of the reliability resulted in .94 which indicates a substantial agreement. In addition to the scoring rubric, questions from the VNOS-B were included in the focus group interviews, as suggested in the literature (Lederman, Abd-El-Khalick, Bell, & Schwartz 2002).

Self-Efficacy for Learning Form (SELF). The SELF scale (Zimmerman & Kitsantas, 2005) is a 19-item survey designed to test student self-efficacy for learning. The items ask students to determine their ability to complete self-regulated learning strategies on a percentage scale divided into increments of ten percent, ranging from “Definitely Cannot Do It” to “Definitely Can Do It”. It is designed to have students self-report on a variety of situations that require academic self-regulatory efficacy such as reading, note taking, test taking, writing, and studying. High scores on this scale represent a high ability to be self-regulatory in academic strategies. This scale has a reliability coefficient of .97 and was highly correlated to teacher reports on students.

Qualitative Data Collection Methods

In order to triangulate data and to capture the process students used to produce the learning outcomes, qualitative data was collected and analyzed. Sources of qualitative data were student written products, think-aloud protocols, and focus group interviews.

Student products from inquiry units. Student learning outcomes for the inquiry units, given to both the experimental and the comparison groups, focused on observable phenomena in electricity and magnetism. For example, the first module guided students to investigate interactions between permanent magnets that were oddly shaped. Students were challenged to use empirical evidence to determine the location of the poles of the magnets, and then to determine the role of domains in magnetic orientation. The completed student products resulted in written responses to student prior knowledge, open-ended content questions, explanation of processes to obtain results, summarization of findings into enduring understandings and how the evidence from the activities support their ideas, and a reflection on student cognition during the inquiry. Two other trained science educators who were not directly involved with the project coded 80% of the student products (randomly selected) using the code-book developed by the researcher which resulted in a Cohen's kappa of .92 agreement in coding.

Think aloud protocol. Think aloud protocols are used to draw out student thinking that may not be apparent on the surface of a field observation (Ericsson and Simon, 1993). Students were instructed to talk aloud about what they were thinking throughout the course of one of the lessons, instead of focusing on the answer to the problem. During the think aloud protocol, the researcher would probe student thinking when students mentioned that they changed their minds based on evidence or on communicating with other students in their group. Randomly selected students from each group, six students per group for each year of the study, were videotaped while they performed an investigation from the intervention. The total number of students involved in the think aloud protocols over two years was twenty-four, 14 girls and 10 boys.

Focus group interview. A focus group was chosen as a method of data collection because based on the researchers experience with eighth grade students, they often feel more comfortable communicating as a group rather than as an individual. After each of the two years of the intervention, six members were randomly chosen from the explicit group and six members were randomly chosen from the implicit group to participate in focus group interviews, totaling 12 members of the experimental group (7 girls and 5 boys) and 12 members of the comparison group (6 girls and 6 boys). The members of the focus groups were not the same students as the members of the think aloud groups. A semi-structured protocol was needed due to the flexibility to explore phenomena that emerged. Sample questions from the semi-structured protocol were (a) How did you act like a scientist in that lesson? (b) How do you think science class is different from English, history or math class? (c) How can you think about your thinking? (d) What does it mean to you to think like a scientist? (e) Are there other ways of thinking? (f) Do scientists behave differently than other people? Two additional researchers independently open-coded transcripts of the think alouds and the focus group interviews for categories, which were grouped into themes. The interrater reliability among three researchers was a Cohen's kappa of .73

agreement among the themes. The researchers met to discuss the coding and adjust the themes until there was a Cohen's kappa of .90 for consensus agreement.

Narrative data from the think aloud and the focus group interviews were transcribed using the software, Transana. Data was open coded verbatim (Strauss & Corbin, 1998) to maintain fidelity of the message of the participants then axially coded to consolidate themes (Gibbs, 2002). An educational researcher, a teacher educator, and a science teacher independently coded the student work products and the interviews. There was initially an 88% agreement among the codes that emerged for the three coders, and after discussion and collapsing of the codes into larger categories, the agreement among the three coders reached 94%.

Results

Because both girls and boys participated in the experimental and comparison groups, initial analysis focused on groups differences, which is a factor in reducing expectancy effects in studying gender as a variable. After this preliminary analysis demonstrated significant differences between the entire experimental group and the entire comparison group, girls in the experimental group were compared to the boys in the experimental group on all measures. Figure 1 illustrates the process of analysis for this project.

Girls in the experimental group ($M = 2.73$, $SD = 0.41$) significantly outperformed boys ($M = 1.63$, $SD = 0.40$) in the experimental group on content knowledge $F(1,79) = 5.14$, $p < .01$ and on nature of science knowledge $F(1,79) = 13.18$, $p < .01$. However, there were no significant differences between girls and boys in the experimental group on self-regulatory efficacy $F(1,79) = .19$, $p = .91$. Overall, the experimental group (boys and girls) outperformed the control group (boys and girls) in content knowledge $F(1, 166) = 12.77$, $p < .01$, and nature of science knowledge $F(1, 166) = 38.95$, $p < .01$, but no significant differences occurred for self-regulatory efficacy $F(1, 166) = .322$, $p = .57$. Considering that the both genders in the experimental group outperformed both genders in the comparison group and girls in the experimental group outperformed boys in the experimental group significantly, girls in the experimental group demonstrated the greatest positive change of all subgroups.

The qualitative data explains of the processes that girls and boys in the experimental group used in learning the nature of scientific knowledge. The work given to the students during the inquiry, otherwise known as student work products, included questions about how students utilized cognition in the activities and the nature of their knowledge. Themes clearly emerged when the answers given by girls and boys in the student product were analyzed separately and placed on a matrix.

Six queries that addressed the nature of scientific knowledge were asked at the end of each activity: (a) Explain how your observations would be clear to other people, (b) Are you behaving more like a scientist (an expert)? Explain. (c) Did you initially ignore any observations or data? (d) Are your data organized clearly to illustrate your point? (e) Is there a similarity among the facts that lead to a "big idea" or conclusion? And (f) How did you use creativity to arrive at your conclusions? Although boys and girls worked together to achieve consensus on

results and explanations during the activity, the questions about cognition were assigned as homework and each student answered them individually. Each question with representative results of the emergent themes will be discussed below.

Explain How your Observations Would be Clear to Other People

Girls who responded to this question defined clarity as either being generated by group consensus, indicated by the word “we” in their writing, or as being accepted to an outside audience, indicated by the word “they” in their response. Boys who responded depended on the decisiveness of the phenomena, such as the change in strength of a magnet, or on the competency of their abilities, indicated by the word “I” in the majority of responses. For example, the girls rationalized the clarity of their responses by indicated the ability of a group of people to understand them, “...because we organized it well enough to understand,” “...because we applied what we know and we tried to cover the purpose,” and “...because we discussed with our group.” The girls also indicated that clarity could be achieved by imagining what an outside audience would think of their display of data, “they would think it was clear” and “another class could read it and see what we did.” In only one case out of 37 did a girl use the pronoun “I” in her response to this question rather than the pronoun “we”.

The responses of the boys for this question were markedly different, as they focused on either the clarity of observation arising from the distinctiveness of the phenomena or from their own ability. Some of the boys described the phenomena again to emphasize the clarity (or lack of clarity) of their observations, “...because the magnet rubbed against the scissors more and it became more magnetic,” and “...one of the numbers was an outlier, so someone might get confused.” A large majority of the responses from boys for this question rationalized the clarity because of their high competence in describing phenomena, “because I said how things were done and used descriptive words,” “...because I proved it with the experiment,” “...because my observations can be explained with my data”, and “...because I stated them clearly.” Language indicating the consideration of a group of people occurred only once in 42 responses from boys, “...because our data did not make sense...” Themes that emerged showed that girls tended to depend on group interaction, and boys tended to rely on physical phenomena or their own ability to determine clarity of observations.

Are You Behaving More Like a Scientist (An Expert)? Explain.

Another very clear difference emerged between responses of girls and of boys when asked if they felt they had more expert knowledge as a result of participating in the activities. Thirty-five out of 37 girls responded positively. For example, “Yes because now I think about past labs I may have done, I also think from other people’s perspectives and I don’t ever leave out information.” The remaining two responses from the girls were “maybe” and “just a little.” Whereas the majority of boys (38 out of 42) responded negatively and did not feel as though they were more expert. Sample responses from boys state, “I’m not sure, I always thought like this but I never wrote it down” and “No, you need to know a lot more to be an expert.” Only one boy answered in a positive way, “Yes because we done more experiments and answer more questions about the investigation.” These results indicate that there is a very strong difference between girls and boys regarding the perception of the level of expertise of a scientist.

Did You Initially Ignore any Observations or Data?

When asked about their ability to be more inclusive of detail in their observations as the activities went on, the majority of girls responded that they could have improved their initial observations, while the majority of boys responded that they wouldn't have changed their initial observations because it was factual. Of the responses from the girls, 33 indicated that they could have improved their data collection, one indicated that it wouldn't have changed, and three left the question blank. Representative examples of responses from girls are as follows, "Probably but not on purpose," "Yes, I could have been more detailed," and "Yes, I could have labeled them better." More boys left the question blank (n=12) but from the boys who answered, the majority answered in very definite terms that what they initially observed was accurate and would not be changed. Sample responses from the boys state, "It was only what I saw," "I stuck to the science part," and "No, I didn't." Girls in this study tend to be in some way aware of bias due to prior experiences in observation, but boys were much more concrete in their perception of the validity of observation.

Are Your Data Organized Clearly to Illustrate Your Point?

All boys and all girls responded affirmatively to this question, but the reasons for their answers were different and mirrored the girls' tendency toward tentativeness and the boys' tendency toward convergent answers. Most of the girls described a specific concept that the data were illustrating. For example, "Yes, because it showed the concept of connecting and how it happened." However, six of the girls who responded made concessions about how they could have accomplished more, such as "Yes, but it could have been more complete," and "Yes, but I didn't do as much of the work as I could have." The boys answered positively, but never mentioned that the data could have been displayed in other ways. Their responses indicated a perception of knowledge as static, such as, "Yes, because they're drawn like the display was," "Yes, because it showed the observations in a descriptive way," "Yes because I proved the facts and things in the lab," and "Yes, the data was strong to the point." All of the responses of the boys reasoned that an accepted procedure was followed which therefore led to an organized data display. The way the boys responded (a positivist orientation) and the way the girls responded (a more tentative, conceptual orientation) corroborates the results of the gender differences in the responses of the other cognitive question asked about data collection and display. The responses of the girls and boys resulted in similar answers to the other question about data, "*Did you initially ignore any observations or data?*" Where the boys answered in a more self-directed right/wrong way and the girls showed more tendencies for knowledge to be dependent on perspectives.

Is There a Similarity Among the Facts that Lead to a "Big Idea" or Conclusion?

This question yielded the most distinct results of all of the questions regarding cognition. All girls answered yes and explained a concept found in the activities. Only one boy out of 42 answered yes and all other boys answered no without any explanation. This is a surprising difference because boys and girls worked together during the activity, but the girls distinctly saw a trend in the data and the boys did not. Representative answers from the girls include, "The facts

could explain that the farther away the coils the less amount of magnetism” and “The stronger the magnet the more paperclips picked up as in coils.” Boys had less complete answers than the girls. One boy did answer, “Yes the numbers were similar,” but all other boys answered “no” without any elaboration. Based on the answers to this question, girls clearly saw a link between the activity and the theory driving the activity, where the boys did not see similarities among the facts found during the activity to lead to a conclusion.

How Did You Use Creativity to Arrive at Your Conclusions?

Again, girls and boys approached this question differently. Girls reported being creative by choosing which variables to change, such as “By coming up with different variables,” “For the variables we used # of coils and space between,” and “We tested the effect of the current with three different amounts of batteries and coils.” Boys answered in a more conceptual way and demonstrated that they regarded creativity in science as thinking more about why the phenomena happened. Sample answers from the boys include, “I used creativity by keeping an open mind,” “Just see what is going on,” and “I imagined the domains and what they were organized in the power of the magnet/nail.” In this case, girls answered in a more procedural way and the boys answered in a more conceptual way.

Focus Group and Think Aloud Results

Qualitative data from the focus groups and the think aloud protocol parallels the differences found between girls and boys in the cognitive questioning from the student work products. The focus groups and think alouds were conducted with boys and girls together, but the responses of boys and girls were analyzed separately. For the purposes of this study, the experimental boy and experimental girls were the only responses taken into consideration. The purpose of the focus groups was to probe student understanding of the nature of scientific knowledge, and the processes students used to access and construct knowledge. The girls in the experimental group tended to answer questions about the characteristics of scientists with answers that were more aligned with the nature of science, but boys did not show same inclination. When girls were asked to indicate characteristics of scientists, they answered, “scientists have great imaginations . . . when they don’t know how to do it, they try things until they can show it” (Creative NOS), “science is more than just facts, you can elaborate on them” (Empirical NOS), and “when you have more technology you can use it to change theories” (Tentative NOS). Boys overwhelmingly responded to questions asking about the characteristics of scientists by elaborating on their appearance, “scientists wear white lab coats and have crazy hair... they work in their labs a lot.”

As seen in the cognitive questioning, girls in the experimental group tended to rely more on evidence in making conclusions and boys relied more on authority when they developed the “big ideas” in their inquiry. In the co-ed groups, the students often came to different conclusions based on the same evidence. Part of the task of the inquiry was for each lab group of three or four students to come to consensus about the conclusions based on the data they collected. Students in the think aloud protocols and focus groups discussed the ways they worked out the conflicts in the groups. As with the qualitative analysis of the questions, only the experimental group was considered because of their exposure to the explicit means of learning the nature of

science. All seven girls described that their way to resolve discrepancies with the conclusions was to return to the physical data and perform the investigation again, “When we had a disagreement, we kind of figured out what made sense and what didn’t make sense. Eventually we all came to an agreement that we didn’t do something right. Then we went back and changed it.” Four of the five boys in the focus group, reported that they were convinced that the conclusion was appropriate only when the teacher indicated the “right” answer, “We waited until the class discussions at the end. Then Ms. White (the pseudonym for the teacher) told us what the answer was.” This trend is analogous to the gender differences found in the cognition questions where boys answered in a more authoritative way and the girls indicated that perception played a role in their conceptualization of the data.

Discussion

Results of the exploration of differences between 8th grade girls and boys in learning nature of science knowledge given explicit, reflective learning prompts show clear differences in both outcomes and processes. Girls significantly outperformed boys on the content and nature of science knowledge measures, discussed different learning processes in the interviews, and answered questions about their cognition differently even though mixed gender groups performed the science inquiry together. However, the boys and girls did not show significant differences in the self-regulatory efficacy measure. A discussion of the qualitative and quantitative results, organized by research question, follows.

RQ1: Do Comparison and Experimental Groups Differ as a Function of Gender on Science Students’ Content Knowledge, Nature of Science Knowledge, and Self-Regulatory Efficacy of Learning?

Given the same intervention prompting nature of science knowledge in an explicit, reflective manner, girls outscored boys on the content test which focused on the major concepts of electricity and magnetism. Content knowledge in the intervention was developed through connecting new hands-on experiences to prior knowledge and making conclusions about the major ideas that governed the hands-on experiences. To a large extent, students had to work collaboratively to develop a consensus about what data to collect, how to organize the data, and how to develop conclusions about the trends found in the data. Groups, all of which were populated by both girls and boys, designed a peer review system to make sure their ideas were valid. All members of the group had to agree that the actions taken in the activity as well as the reasons for the actions taken during the activity were sound. As reported in the cognition questions, girls oriented their expertise of electricity and magnetism knowledge toward the group, evidenced by their frequent use of the word “we”. Girls seemed to easily accept the construction of knowledge through the group, and reported depending on the group to discuss and confirm information. Boys, conversely, reported their orientation of knowledge acquisition as being generated by the interaction of themselves with the content. This is evidenced in their answers to the cognition questions being dominated by the use of the word “I” as the source of information. Additionally, the qualitative data showed girls ability to form “big ideas” from hands-on experiences, and the boys did not think they could develop overriding ideas from several different hands-on activities. Finally, the evidence in the interviews points to the girls’ ability to construct knowledge in a group. Girls reported that they relied on evidence to solve any

discrepancies their group had while taking data. Boys reported that they relied mainly on authority, in the form of a book or of a teacher, to solve difficulties they encountered in the activities. Boys tended to orient themselves to finding the one right answer that was provided by an expert. Girls may have increased content knowledge because the intervention was designed to draw heavily on group interactions to develop knowledge. Girls reported being more comfortable with this type of learning, and they were able to accept knowledge that was developed by a group.

The performance of girls over boys on learning nature of science knowledge may be attributed to the metacognitive prompts, because they described the processes of developing scientific knowledge as a human endeavor. The metacognitive prompts explicitly described the scientific enterprise as being influenced by human bias, being collaborative, and being creative. The prompts were designed to override the thinking the science is conducted entirely by the scientific method and to show that the process of acquiring scientific knowledge is more iterative than linear. The girls reported the prompts as being helpful to revise their work in the hands-on activities. A representative comment from the focus group from a girl reported, "I thought about the checklists and realize that I didn't do something as well as I could have. I thought about how I might explain it to other people and I wrote it in more detail." Also, girls realized that the data generated in the hands-on activities could be improved upon, where as the boys were satisfied with their display of data if it led to a convergent answer. This evidence points to girls' ability to recognize the tentative nature of science which states that the scientific knowledge we have now is largely stable, but can be changed given compelling data. When asked about the role of creativity in science, girls answered in a more procedural way, and boys answered more conceptually, but not oriented specifically toward science. Although the girls saw some creativity in science generated by their design of the hands-on activities, the boys tended to connect their responses about creativity with school work, rather than with science. For example, the boys reported that you can be creative in science by keeping an open mind. Finally, evidence that illustrates how girls comprehended nature of science knowledge is seen in the interview responses. Girls tended to talk about what scientist did in an everyday capacity. Boys described the appearance of scientists as being "mad scientists", a phenomena also seen in the Draw-A-Scientist Test (Chambers, 1983). All of the indications of comprehension of nature of science knowledge from girls tended to show scientists and scientific endeavors as more human.

Self-regulatory efficacy measures did not show any differences between girls and boys. This may be because 8th graders not exposed to the ways scientists do their work (Hogan, 2000) and the students were learning nature of science knowledge for the first time. Students, especially young students, do not immediately display self-efficacy when learning something new (Bandura, 1997). Research using prompting to enhance writing skills (Nuckles, Hubner & Renkl, 2009) also showed no increase in self-efficacy with undergraduate psychology students, which corroborates the findings of this study. Boys and girls at the eighth grade level were not very confident in learning independently whether they were given a prompting intervention or not.

RQ 2: How do Male and Female Students Report the Process of Cognition when Participating in Metacognitive Prompting Intervention-Science?

Overall, girls and boys reported different processes of cognition when given prompts to align their hands-on work with the methods of scientists. Girls saw the process of cognition as a group endeavor, whereas boys reported the process as being generated by themselves, with guidance from books or from the teacher. Even though the girls and boys worked in mixed groups, the girls proceeded through the activities utilizing physical evidence to develop general ideas about the behaviors of electricity and magnets. Boys conducted the activities using physical means, but did not rely on their results to generate their knowledge about magnets and electricity. Rather they referenced authoritative sources and confirmed the big ideas they found in the data with what was published in books or by confirming the idea with the teacher. The ways they generated knowledge were linked to the ways in which boys and girls communicated the knowledge. Girls tended to provide rational about the correctness of their answers by group consensus and boys provided the rational about the correctness of their answers by showing that the ideas they generated matched what was known by the scientific community. The intervention (MPI-S) seemed to be successful in illustrating science as a human endeavor and as a result engaged girls so that they gained more content knowledge and knowledge about the nature of science.

Implications

It is well documented that the United States is suffering a shortage of scientists, especially women scientists (NCES, 2001). Even students who begin their undergraduate studies in the sciences often become unhappy with the culture of learning in science. Students, especially female students, become disillusioned with the competitive, isolating way that science classes are conducted at universities (Tobias, 1990). Showing students early in their schooling that science need not be linear and the scientific enterprise is a human endeavor may encourage more students to pursue science as a career. MPI-S can be one way to scaffold student understanding to show that science is creative and social, which is different than the traditional model. The development of scientific knowledge is often taught at the K-12 level as a spontaneous, brilliant thought of a singular genius. For example, there are many textbooks that teach the idea that an apple dropping on Newton's head as the source of the idea for the law of gravity. Most students cannot relate to this because they think they are not smart enough. Teaching the nature of science with prompts shows the enterprise of science in more human terms, and can illustrate to students that being "scientific-minded" does not mean you need to be a genius. This realization can open up new career paths in science for students who had not previously considered it.

Prompting students to check their thinking against the way the discipline's expectations can have implications for engaging students who do not consider themselves "science – minded". Students do not often have an understanding of the scientific community or the process of construction and verification of knowledge in science (DeSautels & Larochelle, 2006; Hogan & Maglienti, 2001). Students who use MPI-S gain experience in checking their thinking against scientific thinking which helps them to understand what knowledge is scientific and what knowledge is not scientific. This method explicitly connects the knowledge that students are learning with ways knowledge is generated and validated, opening the opportunity for students to

become independent learners. For girls especially, prompting nature of science knowledge may have a positive impact on the ways the value the discipline of science.

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Biography

Dr. Erin E. Peters Burton is an Assistant Professor of Educational Psychology and Science Education at George Mason University in Fairfax, Virginia, USA, and her research interests include cognition of science, self-regulation of scientific epistemologies, social justice in science education, and assessment of nature of science knowledge. Her research agenda is derived from 15 years of experience as an electrical engineer, a secondary science teacher, and an Albert Einstein Distinguished Educator Fellow at the National Aeronautics and Space Administration.