

ABSTRACT

Title of the Dissertation: A CASE-STUDY OF A SOCIO-SCIENTIFIC ISSUES CURRICULAR AND PEDAGOGICAL INTERVENTION IN AN UNDERGRADUATE MICROBIOLOGY COURSE: A FOCUS ON INFORMAL REASONING

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The purpose of this investigation was to measure specific ways a student interest SSI-based curricular and pedagogical affects undergraduates' ability informally reason. The delimited components of informal reasoning measured were undergraduates' Nature of Science conceptualizations and ability to evaluate scientific information. The socio-scientific issues (SSI) theoretical framework used in this case-study has been advocated as a means for improving students' functional scientific literacy.

This investigation focused on the laboratory component of an undergraduate microbiology course in spring 2008. There were 26 participants. The instruments used in this study included: 1) [Individual](#) and [Group](#) research projects, 2) [journals](#), 3) laboratory write-ups, 4) a laboratory quiz, 5) anonymous evaluations, and 6) a pre/post article exercise. All instruments yielded qualitative data, which were coded using the qualitative software NVivo7. Data analyses were subjected to instrumental triangulation, inter-rater reliability, and member-checking.

It was determined that undergraduates' epistemological knowledge of scientific discovery, processes, and justification matured in response to the intervention.

Specifically, students realized: 1) differences between facts, theories, and opinions; 2) testable questions are not definitively proven; 3) there is no stepwise scientific process; and 4) lack of data weakens a claim. It was determined that this knowledge influenced participants' beliefs and ability to informally reason. For instance, students exhibited more critical evaluations of scientific information. It was also found that undergraduates' prior opinions had changed over the semester. Further, the student interest aspect of this framework engaged learners by offering participants several opportunities to influentially examine microbiology issues that affected their life.

The investigation provided empirically based insights into the ways undergraduates' interest and functional scientific literacy can be promoted. The investigation advanced what was known about using SSI-based frameworks to the post-secondary learner context. Outstanding questions remain for investigation. For example, is this type of student interest SSI-based intervention broadly applicable (i.e, in other science disciplines and grade levels)? And, what challenges would teachers in diverse contexts encounter when implementing a SSI-based theoretical framework?

A CASE-STUDY OF A SOCIO-SCIENTIFIC ISSUES CURRICULAR AND
PEDAGOGICAL INTERVENTION IN AN UNDERGRADUATE MICROBIOLOGY
COURSE: A FOCUS ON INFORMAL REASONING

By

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A Case-study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning

CHAPTER 1: Introduction

Research Questions

The guiding question of this doctoral dissertation was “How does a socio-scientific issues (SSI) curricular and pedagogical intervention, including a student interest-focus, affect undergraduates’ ability to informally reason?” The following sub-research questions have provided data to understand more about the usefulness and limitations of a student interest SSI learning environment when informally reasoning.

- 1) What effects did this curricular and pedagogical intervention have on undergraduates’ evaluations of socio-scientific information?
- 2) What effects did this curricular and pedagogical intervention have on undergraduates’ Nature of Science (NOS) conceptualizations?

Introductory Background

Zeidler, Sadler, and others have promoted a SSI-based framework to improve students’ decision-making skills, NOS conceptualizations, moral development, and ability to evaluate scientific information (Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). Examples of SSI include research on DNA/genetics, the health effects of diets/nutrition, medical treatments of diseases, and environmental concerns (Kolsto, et al., 2006; Sadler, Amirshokohi, Kazempour, & Allspaw, 2006; Zeidler, Sadler, Applebaum, & Callahan, 2009). In general, SSI are complex societal problems scientists have analyzed but are still subject to human

interpretations and ethical considerations. Consequently, the SSI movement has sought to develop an individual's ability to make more informed decisions about current science issues with societal implications (Sadler, 2004; Zeidler & Keefer, 2003; Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009).

Informal reasoning, has been defined by Perkins (1985, p. 562) and Mean and Voss (1996, p. 140), among other cognitive and developmental physiologists, as the process of considering a claim where the reasoner weighs and synthesizes the pros and cons to arrive at the best sound judgment. Perkins (1985, p. 562) and Mean and Voss (1996, p. 140) have claimed that most reasoning people do everyday is considered informal and often revolves around complex issues that lack clear-cut solutions. Informal reasoning assumes people's positions change as additional information becomes available and they ponder causes, consequences, positions, and alternatives. Sadler's (2004a, p. 515) review of SSI literature has shown how SSI have been used to measure a person's ability to informally reason by studying participants' 1) evaluation of scientific information, 2) NOS conceptualizations, 3) conceptual knowledge, and 4) socio-scientific argumentation. The first two of these themes have been used to delimit the focus of this doctoral dissertation.

The setting of this study took place in an undergraduate microbiology course at a major research-extensive Mid-Atlantic university. The focus of this doctoral dissertation was to understand the affects of a transformed laboratory curriculum, which began in the summer of 2006. The redesigned laboratory aspect of this course was made possible by the support of [Project Nexus](#), a Maryland upper

elementary/middle school science teacher professional continuum model (Project Nexus, 2005). The National Science Foundation has funded [Project Nexus](#) as one of their Teacher Professional Continuum Programs (Project Nexus, 2005). The overarching objective was to increase undergraduates' interest and understanding of how science plays into their everyday life. This was accomplished by infusing student interest SSI-based learning opportunities into the laboratory curriculum. The following sections further discuss the rationale behind this study as well as foreshadow the significant contributions of this doctoral dissertation to the educational research community.

Rational

In rationalizing the importance of this student interest SSI-based curricular and pedagogical intervention, I have broken this section into three main components of this study. First I have focused upon the theoretical framework of this investigation, SSI perspective. Within this first component, I discuss the importance of including social dilemmas with conceptual ties to science when designing science curricula. Specifically, I have delimited my focus into subheadings about why learners need to develop their ability to evaluate scientific information and NOS conceptualizations. In the second component, I focus on the value of understanding more about student interest-based curricula. The final component serves to tie the first two together by rationalizing why it is important to promote science in today's society.

The Need to Include Social Dilemmas with Conceptual Ties to Science in Curricula

According to the National Science Board (NSB) (2006e) "knowledge of basic scientific facts and concepts is necessary not only for an understanding of science and

technology related issues but also for good citizenship.” Although most Americans have felt uncomfortable with their understanding of science and demonstrated an inability to answer simple science-related questions, many have still supported science and technology advancements (NSB, 2006e). Surveys have also indicated that citizens have expressed concerns about how scientific research seemingly overlooks moral values of society (NSB, 2006e). Resultantly, science education reform has been focused on promoting learning environments that advance students’ curiosity, open-mindedness, and informed skepticism about scientific discoveries (AAAS, 1989; NSB, 2006b).

The term scientific literacy can be used to broadly encapsulate a functional understanding of science knowledge to answer questions about everyday life not just theoretical science, preparing young people for life beyond school (DeBoer 1991, p. 174). However, the development of science curricula that successfully engage and prepare students to become scientifically literate members of society is still being shaped. Zeidler and Keefer (2003, p. 8), among others, have contended the SSI-based framework is one way to achieve a functional understanding of science knowledge to answer questions about everyday life (Kolsto, et al., 2006; Sadler, 2004; Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009).

Evaluation of Scientific Information Influence on Informal Reasoning

Informal reasoning is a topic which has grown in importance with respect to preparing students for life beyond academe (Perkins, 1985, p. 562; Means & Voss, 1996, p. 139; Wu & Tsai, 2007, p. 1164). Educators have proposed that many of the reasoning tasks in everyday and academic life are informal in nature (Perkins, 1985;

Means & Voss, 1996). Perkins (1985, p. 562) has noted that “decision-making situations from purchasing a car to resolving which experimental design to use typically require people to reason out the pros and cons of the options.”

Studies that have examined participants’ informal reasoning have shown that participants often fail to comprehensively evaluate those science issues that affect their life (Sadler, 2004, p. 528). For instance, the study by Tytler, Duggan, and Gott (2001) showed that non-scientist members of a community in the UK who were against burning Recycled Liquid Fuel (RLF) in cement kilns relied on common sense, circumstantial evidence, and personal experience when making public decisions. Although these citizens recognized the importance of scientific evidence, it was found that they infrequently supported their positions with this class of evidence. Another example came from Sadler, Chambers, and Zeidler (2004). These authors have shown that many high-school students favored the global warming socio-scientific perspective that aligned with their prior beliefs (Sadler, Chambers, & Zeidler, 2004). Given that Sadler, Chambers, and Zeidler (2004) found the majority of their participants did not have the skill to identify and explain the use of data, they argued that participants failed to comprehensively evaluate the global warming issue. Resultantly, Sadler, Chambers, and Zeidler (2004) and Tytler, Duggan, and Gott (2001) contended that science curricula need to address the tendency for individuals to informally reason based on prior experiences and beliefs, rather than contemplation of evidence. These researchers have been concerned that far too often science educational settings have promoted learners’ dichotomization of their personal beliefs

and scientific knowledge, resulting in biased decisions (Sadler, Chambers, & Zeidler, 2004; Tytler, Duggan, and Gott, 2001).

These studies along with the findings of others (Bell, & Lederman, 2003; Kolsto, 2001a; Kolsto, 2001b; Zeidler, Walker, Ackett, & Simmons, 2002) highlight the importance of discovering curricula that foster students' recognition, interpretation, and use of scientific information. The SSI-based framework has been argued as useful model to create such pragmatic learning environments (Sadler, Barab, Scott, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zeidler, Sadler, Simmons, & Howes, 2005).

However, there has yet to be a study that has examined the effects of a SSI-based curricular framework on undergraduates' evaluation of scientific information. In fact, SSI-based curricular interventions are a relatively new area of research (Sadler, 2004, p. 515; Zeidler, Sadler, Applebaum, & Callahan, 2009). Those studies that have been identified as SSI interventions have explored primary or secondary learners and have varied in scope and effectiveness (e. g. Jimenez-Aleixandre & Pereiro-Munoz, 2002; Patronis, Potari, & Spiliotopoulou, 1999; Walker & Zeidler, 2007). For instance, Jimenez-Aleixandre and Pereiro-Munoz (2002) showed that students developed skills to analyze different dimensions of data and demonstrated integration of their conceptual knowledge to synthesize and evaluate potential solutions. However, Walker and Zeidler (2007) reported that participants, at the end of a 7-week SSI-based learning exercise, incorrectly used factual-based knowledge in their reasoning. These authors found that although students possessed an understanding of the tentative and social aspects of scientific discovery; participants

only justified their reasons with their factual-based knowledge, disclosing their lack of conceptual understanding (Walker & Zeidler, 2007). These findings have suggested that more research is needed to understand what components of a SSI-based curricular treatment are central to developing individuals' use of scientific information when informally reasoning.

NOS Conceptualizations Influence on Informal Reasoning

It has been acknowledged that there are many different ways to define the NOS (Lederman, 2007). In my dissertation, I have decided to define the NOS to align with current influential science educational researchers such as Lederman, Bell, and Abd-El-Khalick. According to their philosophical perspective the NOS, also the epistemology of science or science as a way of knowing, has been defined as processes, values, and assumptions inherent to scientific knowledge (Bell & Lederman, 2003, p. 353; Bell, Lederman, & Abd-El-Khalick, 2000, p. 564). These values and assumptions include concepts such as empirically based (based on and/or derived from observations of the natural world), subjective (theory laden), tentative (subject to change), as well as having social and cultural connections (Bell & Lederman, 2003, Bell, Lederman, & Abd-El-Khalick, 2000). Researchers who have investigated NOS conceptualizations have recognized the importance of developing learners' sophisticated knowledge of the epistemology of science (Abd-El-Khalick, Bell, & Lederman, 1998; Bell & Lederman, 2003; Lederman, 2007; McComas et al., 2000). Science educators and researchers who have advocated for the use of SSI-based curricula have contended that these learning environments foster an awareness of NOS conceptualizations, which in turn helps to develop learners decision-making

skills (Zeidler & Keefer, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zeidler, Sadler, Simmons, & Howes, 2005).

However, there is a debate among science education researchers about how a person's informal reasoning is affected by their NOS conceptualizations (e.g., Bell & Lederman, 2003; Sadler, Chambers, & Zeidler, 2004; Smith & Wenk, 2006). For instance, Bell and Lederman (2003), among other science education researchers, have proposed that social/political issues, ethical considerations, and personal beliefs dominate over formal NOS conceptualizations when making decisions (Grace & Ratcliffe, 2002; Ratcliffe, 1997). Others have contended that students dichotomize personal beliefs and their formal knowledge about the epistemology of professional science when informally reasoning (Sadler, Chambers, & Zeidler, 2004; Walker & Zeidler, 2007). Still others have asserted that there is an interaction between individuals' formal knowledge of the NOS and people's beliefs, which influences their learning and reasoning about science (Hogan, 2000; Smith & Wenk, 2006; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006; Yang, 2005). Consequently, researchers have argued that further delineation of the role NOS conceptualizations have on people informal reasoning is needed (Bell & Lederman, 2003; Hogan, 2000; Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002).

Additionally, researchers have questioned if students' informal reasoning, emotional reactions, and NOS conceptualizations would vary significantly with different SSI (Zeidler, Walker, Ackett, & Simmons, 2002). Currently there is a gap in the literature with respect to how SSI-based interventions explicitly affect students' understandings of the NOS (Zeidler, Sadler, Applebaum, & Callahan, 2009).

Motivating Students to Achieve Scientific Literacy

Science educators and researchers have acknowledged that "learning with understanding for all" (Anderson, 2001) is another goal of the current reform movement (Basu & Barton, 2007; Calabrese Barton, 2001; Lee & Luykx, 2007; Rivet & Krajcik, 2004). Sadler (2004a, p. 525) has argued that students' exclusion of scientific knowledge from their personal knowledge highlights the need to make school science more relevant to students' lives. In addition to promoting learners' skills to evaluate scientific information and their NOS conceptualizations the SSI initiative has also sought to make school science more relevant to students' lives by examining complex societal problems affecting learners' lives (Cajas, 1999; Pedretti & Hodson, 1995; Sadler, 2004a). However, Zeidler, Walker, Ackett, and Simmons (2002) have revealed that the presentation of SSI does not necessarily promote personal connections between students and science content. Sadler (2004a, p. 525) has challenged researchers to design studies that examine if and how meaningful personal connections can be established using SSI. Sadler (2004a, p. 525) has identified meaningful personal connections as encouraging students' interest in and ability to integrate scientific knowledge.

Seiler (2006) has defined student interest-focused curriculum as responsive to or emergent from student interests. This type of learning environment has been connected with opportunities for students to influence their learning based upon questions, curiosities, passions, or circumstances that influence them. Similarly, contextualized instruction has been defined as creating educational environments where real-world problems, which are meaningful to students, are used to stimulate learning (Rivet & Krajcik, 2008). Motivational constructs have also been defined as

academic activities meaningful and worthwhile to learners (Brophy, 1987, p. 205). Whether one is using the term student interests, contextualized instruction, or motivational constructs, studies have provided evidence showing motivation is an integral aspect to the construction of knowledge (Koballa & Glynn, 2007; Palmer, 2005; Sadler, 2004). However, recent reviews of science education research have also acknowledged that there is a lack of empirical evidence supporting curricular strategies that have been found to stimulate students' interest (Koballa & Glynn, 2007; Palmer, 2005; Sadler, 2004).

The limited research that has been done to identify components that stimulate students learning science has suggested that providing environments that relate science to students' identities engage learners (Palmer, 2005; Rivet & Krajcik, 2008; Seiler, 2001, 2002, 2006). Relating science to students' identities can be done by making connections to learners' experiences, examples, analogies, and values (e.g., Baram-Tsabari, Sethi, Bry, & Yarden, 2006; Basu & Barton, 2007; Matthews & Smith, 1994). For example, Basu and Barton's (2007) ethnographic study illustrated how 3 high-school students, in an after school program, sustained an interest in science because they felt they had authentic opportunities to shape their projects and were able to see connections to their everyday lives. More recently, Rivet and Krajcik (2008) focused on 11 middle school students learning of science during a 10-week curricular unit. These authors found a positive relationship between students' understanding of science and their tendency to contextualize their learning. It was found that relating science to students' prior knowledge and everyday experiences positively correlated with their learning (Rivet & Krajcik, 2008). However, there are

still many questions that can be asked about how to foster students' interest in science to help them make more informed decisions. For instance, most of the empirical data on educational settings engaging students to understand science has focused on primary and secondary learners (e.g., Aikenhead, 1997; Rivet & Krajcik, 2008; Seiler, 2001, 2002, 2006). Thus, how can postsecondary learning environments be structured to stimulate students' interest while developing their knowledge of science? Further, it has been suggested that in addition to promoting learners' skills to evaluate scientific information and their NOS conceptualizations, the SSI initiative has been argued as a means to making science more relevant to students' lives (Cajas, 1999; Pedretti & Hodson, 1995; Sadler, 2004; Zeidler, Sadler, Applebaum, & Callahan, 2009). However, empirical data supporting this contention is missing from the research literature (Sadler, 2004a).

Combining a student interest-focus with a SSI-based curriculum may be a way to promote personal connections between students and science content. Currently, there is a gap in the research literature examining how meaningful personal connections can be integrated into SSI-based curricula to foster scientific literacy (Sadler, 2004a).

Promoting a Scientifically Skilled Society

Today's world is more science and technology driven than ever before and society continues to influence as well as evolve with our changing times. There are over 2.7 billion searches performed on Google each month (Fisch, 2007; Sullivan, 2006). The amount of technical information is doubling every 2 years (Oblinger, 2007). It is predicted that a supercomputer will be built that exceeds the computations capability of the human brain by 2013 (Col. Day, 2007; LTG Croom,

2007). Consequently, it can be argued that our youth are not in need of facts but the tools to access and discern information to make more educated decisions tomorrow. How do we help students become more scientifically literate 21st century learners? What are effective strategies for introducing students to the exponentially growing amount of scientific information? How do we empower learners to resolve questions about science issues that influence their life? These are undoubtedly major challenges that science education reformers face today.

According to the National Science Board (NSB, 2006d), a wide variety of jobs beyond science and engineering occupations have been using science and engineering skills, and studies have projected this trend is going to increase (NSB, 2006d). For example, 66% of science and engineering degree holders in non-science and engineering occupations, such as management and marketing occupations, have stated their jobs relate to their degrees (NSB, 2006d). Both national and international organizations have expressed concerns for the lack of interest children are expressing in science and engineering as science and technology expands beyond these professions (NSB, 2006c). Thus, developing educational settings that foster interest and understanding of science is important as society advances into this new technologically advanced era.

Additionally, it can be argued that teachers play an intricate role in facilitating diverse students' interest in and understanding of science (Lee, & Luykx, 2007). According to the Science and Engineering Indicators (NSB, 2006a) college graduates who become teachers tend to take fewer rigorous academic courses in high-school and have lower scores on achievement tests and entrance examinations. Since the

National Commission on Excellence in Education's publication, *A Nation at Risk* (1983), many states have used education reform policies with higher standards for teacher preparation. The No Child Left Behind Act of 2001 (NCLB) has further endorsed states advocating increases in the performance of future teachers through requirements that ensure all classrooms have highly qualified teachers in all core academic subjects (U.S. Department of Education, 2001). Consequently, examining science courses that foster and scaffold prospective teachers' interest in science as well as develop skills to insightfully reason scientific issues is important for future generations.

Significance

Questions still exist with respect to how a curriculum incorporating SSI will achieve the goal of scientific literacy. Currently, designing and examining SSI-based curricular frameworks is a relatively new area of research (Sadler, 2004; Zeidler, Sadler, Applebaum, & Callahan, 2009). In this section, I outline the significance of this doctoral dissertational research to educators and researchers interested in promoting scientific literacy. I have broken the significance of this SSI-based intervention into four main components. The first component outlines the importance of this doctoral dissertation research by expanding what is known about SSI-based interventions. The second and third components highlight the current gaps in empirical studies related to how individuals' ability to evaluate scientific information and NOS conceptualizations affect their informal reasoning, respectively. These discussions also include the significance of the empirical foci of this doctoral dissertation. The fourth component of this section address the importance of the

student interest aspect of this SSI-based curricular intervention. Finally, I connect the salient aspects of this doctoral dissertation (student interest, SSI-based curricula, NOS conceptualizations, evaluation of scientific information, and informal reasoning) together by discussing the need to promote scientific literacy.

The Need to Further Examine SSI Curricular Interventions

Sadler (2004a, p. 515) has acknowledged the need understand more about the affects of SSI-based learning environments. Although the body of literature studying SSI is growing, most studies have only assessed the need to implement SSI-based curricula. Only a few research designs have gathered empirical data on the affects of a SSI-based intervention. These studies include the work of Patronis, Potari, and Spiliotopoulou (1999), who studied the outcome of a several month long local environmental socio-scientific project on middle school students' informal reasoning. Zohar and Nemet (2002) assessed the effects of a 12-week socio-scientific genetic issues intervention on 9th graders' conceptual knowledge and argumentation skills. Jimenez-Aleixandre and Pereiro-Munoz (2002) implemented classroom debates about real life wetland environmental management socio-scientific issue over 16 sessions. Barab, et al. (2007), examined 4th graders responses to an aquatic habitat simulation, which was layered with a socio-scientific narrative. Keselman, Kaufman, Kramer, and Patel (2007) described a 4-week middle-school science intervention, which used HIV issues to develop students' critical reasoning. Khishfe and Lederman (2006) investigated of the effects of two approaches to infuse NOS conceptualizations into a 9th grade 6-week global warming unit. Walker and Zeidler (2007) reported the effects of high-school students' views of the NOS and argumentation skills after 7

consecutive classes, which promoted genetically modified food debates. Most recently, Zeidler, Sadler, Applebaum, and Callahan (2009) assessed changes in 11th and 12th graders reflective judgment in response to a year long SSI-based curriculum that utilized Kolsto's (2001a, p. 292) 8-topic minimum model. However, missing from these research reports are SSI-based curricular interventions for postsecondary learners.

This doctoral dissertation, on undergraduates in an introductory microbiology course, has differed in design from other SSI curricular interventions in several ways. For example, most studies that have implemented SSI-based instruction have assessed students' socio-scientific argumentation skills (how individuals make and justify claims and conclusions) in secondary schools. This dissertation has investigated college students' abilities to informally reason by studying how participants evaluated scientific information and developed NOS conceptualizations when researching SSI. Specifically, the data from undergraduates' research efforts and their analyses of experimental results were used to assess ways students' informal reasoning evolved.

Informal reasoning was defined in this study to align with the previous work of Means and Voss (1996, p. 140), Perkins (1985, p. 562), Sadler (2004a, p. 514), and Wu and Tsai (2007, p. 1164). Consequently, informal reasoning has been referred to as generating and/or evaluating evidence pertaining to claims or conclusions when information is debatable, complex, ill-structured, or open-ended. Unlike formal reasoning¹, a person may change how they informally reason as additional information becomes available and through discussions where individuals support

their perspectives (Means & Voss, 1996; Perkins, 1985). Sadler's (2004a, p. 515) review of SSI literature has recognized that educational researchers have examined participants' informal reasoning by their 1) ability to evaluate of information, 2) NOS conceptualizations, 3) conceptual knowledge, and 4) socio-scientific argumentation. This dissertation has been delimited to the first two of these themes.

Evaluation of Socio-scientific Information

National reform documents have promoted the development of science instructional techniques that facilitate learners' having pragmatic practice judging the relative truth of knowledge, yet at the same time understanding why it is rational to trust experts (AAAS, 1989; NRC, 1996b). The goal of this student interest SSI-based curricular and pedagogical intervention was to give undergraduates guided experiences at evaluating scientific information to make more informed decisions.

Researchers have suggested that SSI can be used to build learners' skills to evaluate alternative scientific perspectives (Kolsto, 2001a; Sadler, Chambers, & Zeidler, 2004; Zeidler, Sadler, Simmons, & Howes, 2005). However, there are data that have shown variations in the way individuals go about evaluating SSI when informally reasoning. For example, the study by Korpan et al. (1997) found that participants most frequently inquired about information regarding the research methodology and what factors may have influenced results. Korpan et al. (1997) have contended that students were less interested in what researchers found and how highly regarded these researchers were. Alternatively, Kolsto (2001b) found that students' tended to question the authority of the researcher rather than their

¹ Formal reasoning has historically been characterized by rules of logic and mathematics, which are

methodology. While a later study by Kolsto, et al., (2006) showed that participants focused on empirical and theoretical adequacy, the completeness of information, social aspects, and manipulative strategies employed by the author. These researchers also found that the participants' questions and the number of criteria the students' focused on differed considerably between participants (Kolsto, et al., 2006). Yet another study by Tytler, Duggan, and Gott (2001) reported that in a non-academic setting, non-professional scientists (members of society facing a community issue) demonstrated the tendency to rely most commonly upon informal proof such as common sense, circumstantial evidence, and personal experience when making public decisions (Tytler, Duggan, & Gott, 2001).

These studies have suggested there is a need to understand more about the factors that can affect a person's evaluation of scientific information when informally reasoning. For example, Tytler, Duggan, and Gott (2001) and Sadler, Chambers, and Zeidler (2004) have argued that the lack of familiarity with what participants considered as scientific data may account for their evaluations of SSI. While, Kolsto, et al., (2006, p. 649) have acknowledged that the sample population under study and the instructions given during an investigation affected their reported outcomes.

Resultantly, Sadler, Chambers, and Zeidler (2004) have noted the need to extend what is known about the ways learners' evaluate scientific information. They have asserted that this can be achieved by further designing and implementing curricula that challenge students to consider alternative views and dissect the rationale of their opinions (Sadler, Chambers, and Zeidler; 2004). This doctoral

fixed and unchanging (Means & Voss, 1996; Perkins, 1985)

dissertation has facilitated opportunities for students to consider alternative perspectives and reflect upon their rationalizations. For example, at the start of the semester students read a popular science article of their choice from a list of articles related to diet / nutrition, health / disease, their environment, and the language of life (DNA / genetics). These articles were based upon popular microbiology issues that have alternative perspectives. Undergraduates wrote a 1000-1200 word narrative that summarized the article and responded to questions that probed their ability to evaluate the information and their NOS conceptualizations. At the end of the semester, students reanalyzed their article and commented on how their initial responses had changed or remained the same.

Another example of ways students considered alternative points of view and dissected their rationalizations involved the group research project. Students worked in teams to create a research poster and PowerPoint presentation about personal issues that related to microbiology and affected their lives. This group project provided several opportunities for students to socially reflect upon their conceptual knowledge and beliefs about the topic, its importance to society, and alternative points of view. Consequently, this curricular intervention has met the criteria Sadler, Chambers, and Zeidler (2004, p. 405) have put forth to challenge students to consider alternative views and dissect prior rationalizations. Thus, findings reported in this doctoral dissertation have extended what is known about the ways learners evaluate scientific information.

NOS Conceptualizations

The NOS, also known as epistemology of science, or science as a way of knowing has been defined as values and assumptions inherent to scientific knowledge (Bell & Lederman, 2003, p. 353; Bell, Lederman, & Abd-El-Khalick, 2000, p. 564). The nature of scientific knowledge has been distinguished from other ways of knowing through its empirical standards, logical arguments, skepticism, and subjectivity to change as new evidence becomes available (NRC, 1996a). The scientific way of knowing has also been characterized by human endeavors such as 1) valuing peer review, 2) truthful reporting of methods and outcomes, and 3) recognizing the influence of society, culture, and personal beliefs (NRC, 1996a).

National reform documents have promoted science instruction that have provided students with skills that strengthen their understanding of the NOS (AAAS, 1989; NRC, 1996b). One principle behind developing students' awareness of the NOS has been to build a society that is more informed about science and technology issues (AAAS, 1989; NRC, 1996b). Researchers have suggested that the SSI-based framework can be used to encourage learners understanding of the NOS (Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002).

Although there have been some studies that have analyzed the connection between individuals' NOS conceptualizations (e.g., Bell & Lederman, 2003; Sadler, Chambers, & Zeidler, 2004; Khishfe & Lederman, 2006), differences have been reported in researchers' findings. For example, Bell and Lederman (2003) have pointed out that participants' views of the NOS did not significantly affect participants' decisions making. Specifically, Bell and Lederman (2003) found that individuals primarily reasoned from personal values, morals/ethics, and social

concerns, even if they had matured NOS conceptualizations. Bell and Lederman (2003) findings contrast the assumptions and data of others. For instance, Sadler, Chambers, and Zeidler (2004) and Zeidler, Walker, Ackett, and Simmons (2002) found that participants dichotomized their beliefs and conceptual knowledge of the NOS. These researchers also ascertained that many participants had difficulties identifying scientific evidence (Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002). Still others have asserted that there is an interaction between people's formal knowledge of the NOS and their beliefs, which influence how individuals learn and reason science information (Hogan, 2000; Smith & Wenk, 2006; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006; Yang, 2005).

Few studies have directly examined the effects of a SSI-based curricular intervention on learners' NOS conceptualizations. The investigation by Walker and Zeidler (2007), examining high-school students' views on the NOS and debating skills after seven consecutive classes, was one exception. The authors' interpretation of results suggested that although students did not use knowledge of the NOS when reasoning their positions to others. Given their disappointing results, Walker and Zeidler (2007) concluded that more research is needed to establish successful characteristics of SSI-based interventions that foster an individual's knowledge and use of the NOS when informally reasoning. Similarly, Zeidler, Sadler, Applebaum, and Callahan's (2009) SSI-based intervention resulted in findings that suggested high-school students' reasoning was limited by their epistemological knowledge of science. Resultantly, these authors have also acknowledged the need to explicitly examine NOS orientations under SSI-based frameworks.

The course examined in this doctoral dissertation facilitated students' NOS conceptual awareness by explicit and reflective SSI-based inquiry activities². Specifically, explicit discussions during lab and reflective journaling helped students to see how activities connected to their everyday life as well as developed their epistemological knowledge of science. For example, during the first lab Safety & Microscopy a discussion of why it is important to use aseptic techniques took place. Aseptic techniques have been used in hospitals as well as laboratory settings to prevent the spread of disease. However, there are also many perspectives that surround microbial resistance and how to prevent the spread of deadly diseases. During this lab, students began to learn more about this topic by testing the cleanliness of their hands and the lab counters before and after they had been washed. This was accomplished by having the undergraduates touch the surface of rich agar media, which cultured the microbes. Students then examined this microbial growth under a microscope the following lab session. During this lab, students also took notes about what they were testing and their results to be better prepared to design their own hand-washing experiment later in the semester. Time was also taken to discuss the limits of the conclusions that could be drawn from the assayed microbial growth. This discussion raised NOS conceptualizations such as the limit of the magnification power of the microscope, the skill scientists develop to interpret their data after looking at hundreds of samples, and the importance of scientific peer review.

² Khishfe and Abd-El-Khalick (2002, p. 555) have defined explicit teaching of the NOS as emphasizing student awareness of certain epistemological concepts in relationship to the science-based activities in which they are engaged. Khishfe and Abd-El-Khalick (2002, p. 555) have characterized

Over the course of the semester students were asked to informally reason their understanding of the NOS in several contextualized ways. For instance, undergraduates' lab write-ups served as a means of assessing how participants were applying their knowledge of the NOS to interpret their experimental results. The start and end of the semester article exercise was another example. Students were asked to reason 1) how they saw data being used to support the perspective(s), 2) how societal factors might have influenced the perspective(s), and 3) whether they believed the perspective(s) were accepted among the scientific community. These questions provided several contextualized insights into how students' understanding the scientific epistemology influenced their informal reasoning. Consequently, the findings from this student interest SSI-based curricular and pedagogical intervention have extended what is known about how SSI-based intervention affects on students' NOS conceptions in decision-making contexts.

Expanding the SSI Model to Include a Student Interest-Focus

Although science educators and researchers may strive for "learning with understanding for all" (Anderson, 2001) the Early Childhood Longitudinal Study (ECLS) assessments have shown non-mainstream students have substantially lower performances in science than mainstream learners (NSB, 2006a). Lee and Luykx (2007, p. 171) have characterized students who have social prestige, institutionalized privilege, and normative power as mainstream. Therefore, mainstream students in the United States have most often fallen into the classification of white, middle or upper class, and native speakers of Standard English. Conversely, non-mainstream students

reflective as providing students with opportunities to analyze various perspectives of the NOS by

have been found to have the characteristics of a range of proficiency levels in both their home language and English, immigration history, educational levels of parents, and family/community attitudes toward education. Non-mainstream students have frequently been African-American, Hispanic, and Native American students of low socioeconomic status (SES) who speak non-standard dialects of English (Lee & Luykx, 2007, p. 173).

One challenge that has complicated the reformation of science education has related to providing instruction that takes student diversity into account (Lee & Luykx, 2007; McNeil, 2000). Data have shown that science achievement gaps between mainstream and non-mainstream learners have been in part a product of culturally irrelevant science curricula. Studies on diverse student groups have indicated that science learning environments have commonly lacked cultural relevance and educational materials, such as textbooks, that represent information by acknowledging the diversity of student populations (Barba, 1993; Eide & Heikkinen, 1998; Ninnes, 2000). Atwater's (1994) work has indicated that the culture of Western science has been perceived as foreign to all students. However, Atwater (1994) has argued that non-mainstream children have additional challenges when the material fails to acknowledge or respect their cultural beliefs, values, ideas, and experiences. Science curricula that have incorporated materials related to students' cultural identities through experiences, examples, analogies, and values have been shown to improve science achievement and positive attitudes to science (Aikenhead, 1997; Matthews & Smith, 1994). In general, it has been acknowledged that there is a need

making connections between their activities and ones undertaken by scientists.

to develop pedagogical practices that more effectively promote “science for all” (Lee & Luykx, 2007).

Researchers supporting the recent SSI initiative have contended that SSI-based curricula can provide personal connections with science and develop their cultural beliefs, values, and ideas (Sadler, 2004a; Sadler & Zeidler, 2005; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). However, Sadler (2004, p. 525) has recognized that this claim lacks empirical support.

Currently, learning environments that have been acknowledged as SSI-based interventions have chosen the topics learners have examined. Seiler (2006) has defined teaching science with a student interest-focus as incorporating students existing interests into the learning activities. This doctoral dissertation is the first study that has examined the effects of a student interest SSI-based curricular intervention. Although Kolsto, et al. (2006) did use a methodological approach asking students to research the internet for a socio-scientific article of interest to them, students did not partake in any instruction specifically developing their evaluative or research skills. Consequently, Kolsto, et al. (2006) were not interested in stimulating participants’ interests in science. Rather, these authors were focused on the patterns of students’ arguments when informal reasoning SSI.

This undergraduate microbiology course provided opportunities for students’ to identify their existing interests. This aspect of the student interest SSI-based curricular and pedagogical intervention was to ensure all learners made connections with science beyond the classroom setting. Resultantly, this dissertation has extended

how the SSI-based framework can conceptually provide personal connections with science.

Promoting Scientific Literacy for a Scientifically Skilled Society

There has been a growing concern in higher education to ensure developmental opportunities for scientifically trained workers and scientifically literate citizens as a wide variety of jobs beyond science and engineering occupations have required the use of these skills (NSB, 2006d). Consequently, national and international organizations have promoted the development of successful higher educational learning environments that can effectively stimulate students' interest and knowledge about science (Association of American Colleges and Universities, 2002; National Research Council, 2003a, 2003b; National Science Board, 2004a, 2006a, 2006b, 2006c; Project Kaleidoscope, 2002; Rutherford & Ahlgren, 1989). These initiatives have led professional associations such as the American Association for the Advancement of Science (AAAS, 1989) and National Resource Council (NRC, 1996) to promote reformed approaches to teaching science.

This doctoral dissertation, on undergraduates' informal reasoning, has examined the effects of a SSI-based learning environment with these goals in mind. Although this curriculum generally focused on introducing ways microbes affects our world, it did so by connecting students' interests with accurate knowledge and interpretation of scientific content. For example, this course developed undergraduates' awareness of scientifically reliable sources and their ability to research several scientific perspectives. The hands-on labs also cultivated an understanding of scientific processes and epistemological concepts. These are also

fundamental objectives that have been recognized in the *National Science Education Standards* (NRC, 1996b, p. 22) for promoting scientific literacy.

Furthermore, the need to educate future teachers on how to effectively integrate NOS concepts with SSI in classrooms has been identified (Kolsto, et al., 2006; Sadler, Chambers, and Zeidler, 2004). Opportunities facilitating the transformation of popular press SSI into instructional exercises have been contended as a means to encourage this process (Sadler, Chambers, and Zeidler, 2004, p. 405). Yet, this is similar to the contentions promoting SSI-based interventions as a catalyst for fostering learners' interest towards science (e.g., Sadler, 2004a; Sadler & Zeidler, 2005; Zeidler, Sadler, Simmons, & Howes, 2005). These claims lack empirical support.

One of the tasks embedded within this undergraduate microbiology course was a group project, where students designed a learning exercise with a focus on "How I would teach this material." Students described an upper elementary to high-school grade (such as grades 4-10) their learning exercises / experiments targeted and explained how they addressed the Maryland Voluntary State Curriculum (Maryland State Department of Education, 1997) science teachers 5E model for science lessons³.

The examination of declared education majors' ability to integrate SSI and NOS concepts in classrooms was not a focus of the doctoral dissertation. However, this SSI-based intervention has served as a critical experience in the long-range mission of [Project Nexus](#). That is, the knowledge and skills these education majors

³ The Maryland Voluntary State Curriculum (Maryland State Department of Education, 1997) science teacher 5E model for science lessons includes: Engagement, Exploration, Explanation, Extension, and Evaluation

may have gained as a result of their exposure to this general microbes and society course will be investigated further through the [Project Nexus](#) initiative. Consequently, the data that have been reported in this doctoral dissertation are significant to [Project Nexus](#) researchers and may eventually contribute to what is known about future teachers' ability to effectively integrate SSI and NOS concepts into classrooms.

Purpose

This case-study used a qualitative approach to gain insights into the effectiveness of this SSI-based curricular and pedagogical intervention. Specifically, this doctoral dissertation was interested in whether the student interest aspect of this curriculum would motivate learners' interest in science. This investigation also assessed the effectiveness of this SSI-based intervention as well as the employed pedagogical practices on undergraduates' skills to insightfully reason scientific issues important to society. In particular, students' ability to informally reason was measured with respect to their NOS conceptualizations and skillfulness at evaluating scientific information.

Researcher's Positionality

My pursuit of this doctorate of philosophy degree was rooted in my passionate desire to enhance societal scientific literacy. The definition of scientific literacy I have referred to in this doctoral dissertation was taken from the *National Science Education Standards* (1996, p. 22). This definition has been defined as encompassing the knowledge and understanding of scientific concepts and processes required for persons to ask, find, or determine answers to questions they have about everyday experiences.

I have come to believe that there is informative power in viewing life through a scientific lens. Although idealistic, the scientific process of collecting and analyzing data seeks to impart unbiased decision-making by inferring logical and objective conclusions. Practically speaking, persistently revising evidence from observations or measurements with an open-mind has the potential to enrich one's understanding of life.

Yet, an aspect of the NOS is that our technological or intellectual perceptual apparatus will always be limited by observations, measurements, and human inferences (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002, p. 499).

Consequently, I have formed the perspective that the more aware we are of our environment in addition to the discovery⁴ and justification⁵ processes of science, the greater the objective power of our scientific lens.

Looking back at my own science education, I have recognized two very important components helping me “focus” my own magnifying objective. The first significant factor that has helped me form a deeper understanding of science has been the content knowledge many have devoted a lifetime to discover and disseminate. Countless hours of dedication, devotion, and continual scrutiny have advanced us into this technological century of physical, chemical, geological, astronomical, biological, and ecological exploration. My “view” of science content has been central to my ability to exchange ideas and scrutinize my comprehension. Having an understanding of fundamental scientific concepts has been essential in enabling my grasp of

⁴ Discovery is a contextual depiction of NOS, representing science as a rational, objective, social process of discovery and unproblematic decision-making (Abd-El-Khalick, 2003, p. 42).

⁵ Justification is the component of NOS that is value-laden, multidisciplinary, and ill defined characteristics that are constrained by missing knowledge (Abd-El-Khalick (2003, p. 42).

structural models that have explained physical phenomena in various experimental conditions.

However, as my years of studying science content increased along with my research experience, my awareness of the humanistic aspect of the NOS also grew. Years of reflection upon my own data in a yeast genetic lab studying the mitochondrial DNA escape phenomenon, fostered my appreciation for the social construct of a theory. Resultantly, I have come to believe our 21st century advancements, such as the prospect of human cloning (Abbott, 2002), has highlighted the need for people to also recognize the social aspects of science.

Reflecting upon my journey has also helped me to realize that my intrinsic motivation and interest to understand the power of scientific discovery has not been mainstream. For example, bachelor's degrees in the natural sciences (physical, life, environmental, and computer sciences, and mathematics) have averaged 12% of the graduating undergraduate population, without much fluctuation over the past 20 years (NSB, 2006b).

Given that the majority of students who have sought higher educational degrees have pursued interests outside the field of science, it is unknown how many people with non-science bachelor degrees feel about their ability to interpret scientific issues that affect society. Sadler (2004a, p. 528) found that most people who have recognized the need to evaluate scientific information have also admitted to feeling ill equipped to do so. Further, the NSB's (2006e) report has shown that people, especially those from disadvantaged backgrounds, were lacking knowledge of basic scientific facts and processes. However, the majority of the public has supported

science and technology advancements despite the fact that most people have felt ill informed about science. This has raised many concerns both within and outside the scientific community. For example, the NSB (2006e) committee has recognized that a lack of basic scientific facts and processes implicates how people have 1) evaluated various claims, 2) supported government research, 3) pursued science track careers, as well as 4) challenged miracle cures and other corrupt deceptions.

These are several reasons why I have sought out opportunities to develop science curricula that motivate others to become scientifically literate. My doctoral degree in science education has shown me that I am not alone. Many others have also recognized this need. For example, DeBoer (1991 preface xii) and Roberts (2007, p. 746) have pointed out that science education after the 1960s and 70s acknowledged the importance of emphasizing not only scientific content and skill development but also inquiry, conceptual understanding, as well as societal and technology concerns. Milton Pella (1967) and Norman Smith (1974) have been exemplified as instrumental in reforming the definition of scientific literacy to incorporate NOS issues such as science and society, ethics of science, science in the humanities, as well as science and technology (DeBoer, 1991, p. 175; Roberts, 2007, p. 737). These beliefs have been upheld through the 1980s by national organizations such as the National Science Teachers Association (NSTA). The NSTA has characterized scientifically literate citizens as having substantial content knowledge, epistemological conceptualizations, and an understanding of processes that define science (DeBoer, 1991, p. 177). These ideas continued to be supported currently (AAAS, 2006; Zeidler, 2003). One example is the SSI-based framework promoted by Zeidler (2003), Sadler (2004a), and others

(Kolsto, 2001a; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zeidler, Sadler, Simmons, & Howes, 2005). This SSI-based model has been devised to teach aspects of the NOS, enhance learners' ability to evaluate scientific information, as well as develop individuals' beliefs about science issues that affect their life (Kolsto, 2001a; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zeidler, Sadler, Simmons, & Howes, 2005).

The work that has led me to this investigation, originating in the summer of 2006. Supported by [Project Nexus](#) (Project Nexus, 2005) as well as by the College of Life Sciences and Chemistry, I was given an opportunity to help develop and operationalize a curriculum that sought to capture student interests by offering undergraduates the opportunity to influence their learning. This educational environment also promoted learning by giving students the chance to teach one another about their interests and their researched knowledge. These two goals were also in alignment with the [Project Nexus](#) vision (Project Nexus, 2005).

Beginning in the summer of 2006, I began my [Project Nexus](#) research apprenticeship under the guidance of Dr. Randy McGinnis and Dr. Gili Marbach-Ad. This learning experience advanced my knowledge about designing science educational research projects. Dr. McGinnis, a recognized exemplary undergraduate science methods instructor, was the Principle Investigator (PI) of [Project Nexus](#) (Project Nexus, 2005). Dr. Marbach-Ad was the director of the Teaching and Learning Center and senior research associate for [Project Nexus](#) (Project Nexus, 2005). Both Dr. McGinnis and Marbach-Ad spent hours working with me to devise research instruments that would meet the goals of the [Project Nexus](#) initiative.

As a member of the [Project Nexus](#) Research Team, I was also appointed as Dr. Spencer Benson's graduate research assistant. This experience developed my skills to design curricula appropriate for undergraduate learning. Dr. Benson was not only a joint faculty member to the College of Education and the College of Life Science and Chemistry, the director of the Center for Teaching Excellence, but he was also a Co-Principal Investigator of [Project Nexus](#). Dr. Benson spent countless hours working with me throughout my dissertation study to optimally reform this student interest SSI-based curriculum.

Thus, my training as both a biological scientist and as a science educator has culminated in this doctoral dissertation, examining the effects of a student interest SSI-based intervention. Recognizing that my desire to develop scientific curriculum is an interdisciplinary endeavor, I use an analytic approach that I believe may productively bridge both natural and social science domains. As a result, in [Chapter 4](#) I report my findings by qualitatively illustrating 4 participants' data. In [Chapter 5](#) I use specific quotes from the remaining 22 students and integrate descriptive statistics to exemplify general trends that emerged from my inductive analyses. Therefore, I acknowledge that in some social science researchers' eyes this report may not be seen sufficiently in alignment with the qualitative research paradigm. However, I believe my compromise of using some terms and counting features found typically in the quantitative paradigm may be pragmatically justified given the interdisciplinary audience my investigation seeks to inform. As Berg (2007, p. 362) notes, "When researchers write for their own disciplines, they write for a limited audience that is thoroughly familiar with the particular field of study and shares similar educational

backgrounds. In contrast, when the audience consists of different kinds of readers, special limitations must be set on the form the written report should take.”

Key Terms

Nature of Science (NOS): The NOS also known as epistemology of science, or science as a way of knowing, has been defined as the values and assumptions inherent to scientific knowledge. Bell and Lederman (2003, p. 353), among others have characterized these values and assumptions to include concepts such as empirically based (based on and/or derived from observations of the natural world), subjective (theory laden), tentative (subject to change), as well as being socially and culturally embedded (Bell, Lederman, & Abd-El-Khalick, 2000, p. 564; Lederman, 1992; Lederman, 2007).

Socio-scientific issues (SSI): SSI have been defined as social issues with conceptual or technological ties to science Sadler (2004a, p. 513). Examples of SSI include research on DNA/genetics, the health effects of diets/nutrition, medical treatments of diseases, and environmental concerns (Kolsto, et al., 2006; Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006; Zeidler, Sadler, Applebaum, & Callahan, 2009). In general, SSI are complex societal problems scientists have analyzed but are still subjected to human interpretations and ethical considerations.

Informal reasoning: Perkins (1985, p. 562) Mean and Voss (1996, p. 140) among other cognitive and developmental physiologists have defined informal reasoning as the process of considering a claim where the reasoner weighs and synthesizes the pro and cons to arrive at the best sound judgment. Informal reasoning assumes people’s positions change as additional information becomes available and they ponder causes,

consequences, positions, and alternatives. Sadler's (2004a, p. 515) review of SSI literature has shown how SSI have been used to measure a person's ability to informally reason by studying participants' 1) evaluation of scientific information, 2) NOS conceptualizations, 3) conceptual knowledge, and 4) socio-scientific argumentation.

Scientific literacy: DeBoer (1991, p. 174) has broadly defined scientific literacy as a functional understanding of science knowledge, which empowers an individual to answer questions about everyday life not just theoretical science.

Functional scientific literacy: Zeidler, Sadler, Simmons, and Howes, (2005) have defined functional scientific literacy as an individuals' conceptual and belief-based knowledge of scientific 1) epistemology, 2) discourse, 3) culture, and 4) cases where society has influenced and been influenced by science, which they apply in decision making contexts.

Student interest-focused curriculum: Seiler (2006, p. 338) has defined student interest-focused curricula as responsive to or emergent from student interests. This type of learning environment provides students with chances to influence their learning based upon questions, curiosities, passions, or circumstances that influence them.

Distal knowledge of the NOS: Hogan (2000, p. 57) has described knowledge formally taught about the methods and goals of professional science as distal knowledge of the NOS. An example of an individual's distal knowledge of the NOS would be distinguishing and/or articulating the differences between an observation and inference or a scientific law and theory.

Proximal knowledge of the NOS: Hogan (2000, p. 57) has defined students' proximal knowledge structures as beliefs, commitments, or personal theories about the NOS because they are associated with personal relevance and experience (knowledge structures nearest to the individual). An individual's beliefs about the NOS can be developed from personal experiences such as engaging in television, radio, and newspapers as well as learning from family, friends, formal education, and life experiences (Schommer-Aikins, 2002; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006).

Epistemological beliefs: Hofer and Pintrich (2002) as well as others have defined epistemological beliefs as an individual's beliefs about the nature and justification of knowledge, as well as beliefs about intelligence and learning (Maggioni, Riconscente, & Alexander, 2006). Epistemological beliefs have also been defined to include open-mindedness (Toplak & Stanovich, 2003; Zeidler, Walker, Ackett, & Simmons, 2002), motivation and persistence to learn (Buehl & Alexander, 2005; DeCorte, Op't-Eynde, & Verschaffel, 2002; Tolhurst, 2007; Tsai & Kuo, 2008), and self-confidence (DeCorte, Op't-Eynde, & Verschaffel, 2002; Paulsen & Feldman, 2005; Schommer-Aikins, Duell, & Hutter, 2005).

Explicit and reflective NOS teaching strategies: Khishfe and Abd-El-Khalick (2002, p. 555) have defined explicit teaching of the NOS as emphasizing student awareness of certain epistemological concepts in relationship to the science-based activities in which they are engaged. They have characterized the term reflective as providing students with opportunities to analyze various perspectives of the NOS by making connections between their activities and ones undertaken by scientists.

Limitations

Several limitations accompanied the construction of this doctoral dissertation:

1. It should not be assumed that the students in this study were representative of a population of potential future teachers or students entering non-science occupations. Rather, the data have described 26 non-science majors who were enrolled in this general microbes and society course in the spring of 2008. However, these results have still provided significant findings that can be transferred to other curricular interventions focused on improving science education. Specifically, the effects of this student interest SSI-based learning environment have provided valuable insights for researchers and educators interested in improving students' interest and literacy towards science.
2. This study took place over a 15-week period and only measured delimited aspects of informal reasoning. In particular, this doctoral dissertation focused on undergraduates' evaluation of scientific information and their NOS conceptualizations. Given the complexity involved in the mechanistic processes a person goes through when considering the pro and cons of scientific claims, the data from this study have offered limited insights into undergraduates' informal reasoning. For example, this doctoral dissertation has not examined how participants' conceptual understanding of the science content may have affected their ability to evaluate scientific information or their NOS conceptualizations. Future experiences may also strengthen the skills and knowledge participants gained through this general microbes and

3. Finally, my involvement as a curricular reformer and the limits of my own knowledge has undoubtedly biased my data analyses. Despite the fact that I was critical of my conclusions and sought external validity of my data analyses, it is impossible to escape my human nature. Specifically, this investigation has focused upon how people critically evaluate scientific information and their understanding of the NOS. A salient characteristic of scientific knowledge is that human perspectives, experiences, and understandings of the data limit interpretations. This is even more significant in social science research (Gall, Gall, & Borg, 2002). Therefore, even though I sought to reinforce my analyses through several triangulation techniques, such as member-checking and inter-rater reliability, the reported findings are still limited by the instruments, defined boundaries of the research, and interpreters' knowledge. However, in light of Guba and Lincoln's (1989) constructivist view, the fact that I did my best to critically reflect upon my own knowledge while seeking external validity, strengthens my data interpretations. That is, I sought to examine the effects this curricular and pedagogical intervention had on students, rather than positive changes in undergraduates' performance.

Assumptions

The major assumption of this doctoral dissertation was that the instruments examining undergraduates' ability to evaluate scientific information and their NOS

conceptualizations accurately assessed and represented their knowledge and belief-based insights.

CHAPTER 2: Literature Review

Overview

This chapter elaborates on many of the research studies introduced in [Chapter 1](#). I also introduce other research related to this doctoral dissertation that I reference in my methodology, findings, and discussion chapters ([Chapters 3, 4, 5, and 6](#)). Specifically, I have broken this literature review chapter into 5 sections, which have direct applications to the guiding research question. The first section reviews literature relevant to the socio-scientific perspective, supporting the use of this framework in science curricula. This section also considers what is known about motivating students to learn science through a student interest-focus. The second section evaluates research studies examining participants Nature of Science (NOS) conceptualizations within a socio-scientific issues (SSI) based context. The third section focuses on the research examining participants' evaluation of socio-scientific information. The fourth section discusses the empirical studies on SSI-based interventions. I have concluded [Chapter 2](#) by summarizing my review of the literature as well as foreshadowing upcoming chapters.

Learning Science through Socio-scientific Issues and a Student Interest Design

This section is divided into two parts. The first part focuses on the theoretical framework of this doctoral dissertation, a SSI perspective. Specifically, I reference Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) SSI-based framework as the original model from which this doctoral dissertation's student interest curricular and pedagogical intervention was built. This SSI-based model has been characterized by Zeidler, Sadler, Simmons, and Howes (2005, p. 361) as developing a learners'

conceptual and belief-based knowledge of scientific 1) epistemology, 2) discourse, 3) culture, as well as 4) cases where society has influenced and been influenced by science. Thus, the first subsections describe how Zeidler, Sadler, Simmons, and Howes (2005) have envisioned NOS, discourse, cultural, and case-based issues promoting students' scientific literacy. The second part of this section expands the Zeidler, Sadler, Simmons, and Howes (2005, p. 361) SSI-based framework, by showing how a student interest-focus can be used to further promote scientific literacy.

The Emergence of the Socio-scientific Perspective

DeBoer (1991) and Roberts (2007) have presented historical accounts of science education. They have noted a long list of science educators and researchers who have recognized the importance of defining scientific literacy by a person's conceptual knowledge of science as well as understanding of the technological, societal, ethical, and humanistic relations. The SSI-based initiative model has sought to promote this definition of scientific literacy (Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005).

The publication by McGinnis and Simmons (1999) has helped to show why the SSI-based framework replaced the earlier science, technology, and society (STS) pedagogical model. McGinnis and Simmons (1999) have shown that teachers who have agreed that the STS movement could promote opportunities to discuss important scientific, technological, and societal issues have favored safe non-ethical / non-value laden STS issues out of fear for losing their job or disapproval from the local community. McGinnis and Simmons (1999) have asserted that advocates promoting

the inclusion of STS issues in science curricula have failed to consider the implications to students' and teachers' beliefs and cultural values. Zeidler (2003) and Zeidler, Sadler, Simmons, and Howes (2005, p. 361) have argued that their SSI-based framework has taken these shortcomings of the STS movement into account.

Similar to the STS movement, Zeidler, Sadler, and others promoting this SSI-based initiative have defined this framework as social dilemmas with conceptual, procedural, and technological ties to science (Sadler, Chambers, & Zeidler, 2004, p. 387; Sadler & Donnelly, 2006, p. 1463; Sadler & Zeidler, 2005a, p. 112). However, advocates have contended that central foci of this model also include epistemological beliefs and ethics associated with scientific knowledge (Zeidler, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2008; Zeidler, Sadler, Simmons, & Howes, 2005). Specifically, Zeidler, Sadler, and others have defined this SSI-based framework as having 4 central factors (Zeidler, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2008; Zeidler, Sadler, Simmons, & Howes, 2005). These fundamental SSI-based elements have been characterized as 1) NOS issues, 2) classroom discourse issues, 3) case-based issues, and 4) cultural issues (Zeidler, Sadler, Simmons, & Howes, 2005, p. 361; Zeidler & Keefer, 2003, p. 12). The discussion that follows has described these primary aspects of this SSI-based model, respectively.

NOS issues

Zeidler, Sadler, Simmons, and Howes (2005, p. 362) and Zeidler and Keefer (2003, p.13) have claimed that NOS issues are important for students' pre-instructional views of SSI because they provide a structured focus on the ways scientists understand, select, and evaluate evidence. For instance, Abd-El-Khalick

(2003, p. 42) has acknowledged that the NOS has two historical contexts, discovery and justification. He has described the nature of scientific discovery as rational, objective, and an empirically based social process of interpreting data that are often deceptively misconstrued as unproblematic decision-making. Conversely, he has described the justification component of NOS as value-laden, multidisciplinary, ill-defined characteristics constrained by missing knowledge (Abd-El-Khalick, 2003, p. 42). Abd-El-Khalick (2003) and others have ascertained that in order to address students' scientific literacy, an understanding of how learners acquire and develop their epistemological concepts of science is essential (Hogan, 2000; Lederman, 2007; Sadler, Chambers, & Zeidler, 2004). One focus this doctoral dissertation was to examine how undergraduates' understanding of the nature of scientific discovery and justification affected their ability to informally reason scientific information. I have used the upcoming 'Research on the Relationship of NOS Conceptualizations and SSI' section of this chapter to support the need to examine learners' epistemological knowledge of science further.

Classroom discourse issues

Zeidler and Keefer (2003, p.13) have defined discourse issues as a means for learners to develop their 1) skills for framing positions, 2) awareness of fallacious reasoning, and 3) beliefs about science issues. Sadler and Donnelly (2006, p. 1464) have further extended discourse to include the development of a person's ability to informally reason. Specifically, Sadler and Donnelly (2006, p. 1464) have argued that social negotiation of claims and evidence is an informal reasoning process that reflects how people cognitively think about ill-structured problems. Although there

have been several studies, that have assessed informal reasoning and argumentation, these investigations have suggested that there are many outstanding questions about how learners' ability to evaluate scientific information may affect their decision-making process. I have discussed these questions more explicitly in the upcoming 'Research on Evaluating Scientific Information' section of this chapter.

Case-based issues

Zeidler, Sadler, Simmons, and Howes (2005, p. 362) among others have reasoned that case-based issues can be used to foster an awareness of how power and authority have influenced the scientific enterprises (Zeidler & Keefer, 2003). This includes knowledge of humanistic commitments to issue resolution (Zeidler, Sadler, Simmons, & Howes, 2005, p. 362). Keefer, Sadler, and Zeidler (2003) and Kolsto (2001a) have provided examples of how case-based issue frameworks can be used in science curricula. For instance, Keefer's (2003) chapter in *The Role of Moral Reasoning on Socio-scientific Issues and Discourse in Science Education* has shown how case-studies could enhance ethical instruction in science. Keefer's (2003) arguments for the use of case-studies have focused on 1) describing differences in experienced and novice responses, 2) comparing problem-based learning (PBL) and inquiry to case-studies, as well as 3) discussing benefits that result from integrating authentic real-world science into educational settings. Sadler and Zeidler's (2003) chapter in *The Role of Moral Reasoning on Socio-scientific Issues and Discourse in Science Education* have illustrated how 3 science case-studies, exemplifying scientific error or unethical science, could be used in an educational setting to promote learners functional understanding of science. Additionally, in a separate

review, Zeidler (2000) has discussed *Engineering Ethics: Balancing Cost, Schedule, and Risk—Lessons Learned from the Space Shuttle* by Pinkus, et al. (1997). He has used this study to further exemplify how case-studies could stimulate ethical decision-making.

Kolsto's (2001a, p. 292) eight-topic minimum model has more explicitly outlined how case-studies could be used to foster learners' knowledge of science and the scientific enterprise. Specifically, Kolsto (2001a) has characterized eight salient topics that he believes should be discussed when using case-studies to promote learners' scientific literacy. Consequently, Kolsto's (2001a) model has taken a more explicit approach to using case-studies than Keefer, Sadler, and Zeidler (2003).

The first of Kolsto's (2001a) topics has focused upon deciphering different estimations and evaluations of data to understand how experts have arrived at disagreements. Kolsto (2001a, p. 295) has asserted that this topic will foster students' understandings of the social review processes in science. Kolsto (2001a, p. 295) has also contended that this topic promotes trust in scientists' "ready-made-science"⁶ whenever learners realize there is disagreement about a particular science issue.

The second topic has delineated the importance of learners' understanding that societal influences such as religion and politics affect decisions of scientists as well as citizens. Kolsto (2001a) has claimed that this topic promotes students open-mindedness to the decision-making process. Kolsto (2001a, p. 298) has also argued that this topic builds learners connections to other knowledge domains outside of science.

The third topic has been exemplified to teach learners about the difference between descriptive (neutral and objective) and normative (a researcher's standard) statements. Kolsto (2001a, p. 299) has asserted that this topic develops students' skills for acquiring background information about an issue to more competently agree or disagree with the claims.

The fourth topic has been built upon the second. Kolsto (2001a) has used this topic to present the importance in uncovering how "science-in-the-making" claims may serve the interests of different parties. Kolsto (2001a, p. 300) has described how this topic could be used to support learners understanding that evaluations decrease the subjectivity of descriptive observations.

The fifth topic was also built on the second. For this topic, Kolsto (2001a) discussed how "ready-made-science" models are debatable when placed outside of their controlled environment, where the observations were originally made. In this case, students should learn to criticize expert reports and question the assumptions of relevance by seeking a wider range of knowledge before making a personal decision (Kolsto, 2001a, p. 301).

The sixth topic has extended the third by covering criteria for accepting data as evidence (Kolsto, 2001a, p. 302). This topic has also sought to teach an understanding of how different sorts of evidence (such as statistical and anecdotal) could influence interpretations of scientists' public statements. Kolsto (2001a, p. 302) has argued that an appreciation for different types of evidence and the role they play in SSI could result from this topic.

⁶ Kolsto, (2001a, p. 295) defined "ready-made-science" as textbook science, as opposed to frontier

The seventh topic has emphasized why scientists have suspend their beliefs when publicly interpreting scientific data until sufficient evidence has been accumulated to prevent misinterpretation. Kolsto (2001a, p. 303) has promoted this topic as a means of fostering appreciation for the validity of scientific information publicly available.

Kolsto (2001a) has focused the final topic on training students to become better at argumentation and critically assessing scientific information. Thus, Kolsto (2001a) contended that this topic seeks to make students conscious of the importance of evidence, relevance, sources, competence, consensus, and interests (Kolsto, 2001a, p. 306).

In general, Kolsto (2001a, p. 291) has claimed that this 8-topic minimum model has provided a SSI-based framework for the future teaching models. Unlike the discussion presented by Keefer, Sadler, and Zeidler (2003), Kolsto (2001a) has more explicitly guided instructors on how to use case-based issues in SSI-based interventions. The study by Zeidler, Sadler, Applebaum, & Callahan (2008) recently tested this 8-topic minimum model on 11th and 12th grade students (ages 16-18) enrolled in Anatomy and Physiology classes. The positive results from this study have been discussed in the ‘Research on SSI-based Curricular Interventions’ section of this chapter.

Cultural issues

Zeidler, Sadler, Simmons, and Howes (2005, p. 362) have promoted cultural issues to teach learners about mutual respect and tolerance for dissenting views.

science or “science-in-the-making”.

Zeidler, Sadler, Simmons, and Howes (2005, p. 362) have argued that issues provide learners with an understanding of how culture could affect any individual's beliefs and normative values (scientist or citizen). However, the role of culture in the SSI-based framework also needs to be further developed. Few studies have been classified as examining cultural issues within the SSI-based framework. McGinnis (2003) is an exception. In McGinnis's (2003) chapter examining SSI-based cultural issues, he discussed prospective science teachers' perceptions of using inclusion⁷ versus exclusion⁸ when teaching science. Thus, the McGinnis (2003) study has examined how prospective science teachers' cultural beliefs and normative values affected their ideas about including learning disabled students into mainstream classroom settings. The inclusion/exclusion controversy has been seen as a SSI. However, outside of this investigation, researchers have yet to examine how learners' cultures affect their knowledge and beliefs about SSI. In general, although authors have claimed that culture could influence students' decisions about SSI (Sadler & Zeidler, 2004; Zeidler & Keefer, 2003; Zeidler, Sadler, Simmons, & Howes, 2005), at large, the empirical data that have shown culture influencing one's reasoning is lacking.

Most researchers supporting SSI-based frameworks have contended that "one of the rationales supporting the development and implementation of socio-scientific curricula is the tendency for this material to truly engage students" (Sadler & Zeidler, 2005a, p. 130). However, outside the study by Kolsto, et al. (2006) who asked

⁷ Inclusion was defined as educational settings where learning-disabled students are taught within mainstream classroom environments.

⁸ Exclusion was defined as educational settings where learning-disabled students are taught outside of the mainstream classrooms.

students to research the Internet for a socio-scientific article of interest to them, no investigations have explicitly examined whether learners have formed a personal connection with the socio-scientific issue. Yet researchers have questioned if students' reasoning, emotional reactions and NOS conceptualizations have varied significantly with different SSI (Sadler & Zeidler, 2005a, 2005b; Zeidler & Schafer, 1984; Zeidler, Walker, Ackett, & Simmons, 2002). Consequently, another focus of this doctoral dissertation was to extend the culture aspect of SSI to include students' interests.

In summary, this 'Emergence of the Socio-scientific Perspective' subsection has outlined the SSI-based framework promoted by Zeidler (2003) and others to achieve scientific literacy (Zeidler, Sadler, Applebaum, & Callahan, 2008; Zeidler, Sadler, Simmons, & Howes, 2005). Specifically, I have summarized the 4 central factors, Zeidler, Sadler, and others have described as composing the SSI-based framework (Zeidler, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2008; Zeidler, Sadler, Simmons, & Howes, 2005). The primary aspects of this SSI-based framework discussed were 1) NOS issues, 2) classroom discourse issues, 3) case-based issues, and 4) cultural issues. The description of these issues also included questions that still need to be addressed. One such issue was the need to extend the cultural aspect of SSI to include students' interests. Resultantly, in the following subsection, I use the existing research related to motivating learners' interest in science to support the need to expand the current vision of the SSI-based framework to include a student interest focus.

Incorporating a Student Interest-Focus into the Socio-scientific Framework

Motivational constructs in science have been defined by several different terms. For example, Seiler (2006) has used student interests to designate students' motivational connection to science. Similarly, contextualized instruction has been defined as creating educational environments where real-world problems, which are meaningful to students, are used to stimulate learning (Rivet & Krajcik, 2008). Motivational constructs have also been defined as academic activities meaningful and worthwhile to learners Brophy (1987, p. 205). Whether one is using the term student interests, contextualized instruction, or motivational constructs, studies have provided evidence showing motivation is an integral aspect to the construction of knowledge (Koballa & Glynn, 2007; Palmer, 2005; Sadler, 2004). However, recent reviews of science education research have also acknowledged that there is a lack of empirical evidence supporting curricular strategies that have been found to stimulate students' interest (Koballa & Glynn, 2007; Palmer, 2005; Sadler, 2004).

The limited research that has been done to identify components that stimulate students learning science has suggested that several factors can improve achievement and interest (e.g., Baram-Tsabari, Sethi, Bry, & Yarden, 2006; Basu & Barton, 2007; Seiler, 2001, 2002, 2006). These factors include providing environments that relate science to students' identities through experiences, examples, analogies, and values (e.g., Aikenhead, 1997; Palmer, 2005; Rivet & Krajcik, 2008).

For example, Baram-Tsabari, et al. (2006) examined what interests attracted 4th thru 12th grade students to science. These authors used participants' self-generated questions as an indication of their interest in scientific topics. Baram-Tsabari, et al. (2006) found that the popularity of certain topics varied with age and gender. They

also argued that there is considerable promise in using student interest based questions to enhance the attractiveness and relevance of science to students' life. However, these authors did not delineate a specific curricular framework (such as SSI, STS, or inquiry-based models) that has incorporated students' interests. Rather, Baram-Tsabari, et al. (2006) proposed the use of "Ask-A-Scientist" websites to enhance science lessons. These authors have recommended that these databases be used to incorporate questions students have shown an interest in (Frequently Asked Questions [FAQs]).

Seiler (2006, p. 341) has shown that incorporating student interests into a curricular design can increase student engagement and motivation in science. She has defined student interest-focused curricula as responsive to or emergent from student interests. This type of learning environment provide opportunities for students to influence their learning based upon questions, curiosities, passions, or circumstances that influence them (Seiler, 2006, p. 338). Referencing her work with low-achieving, African American students in urban schools, Seiler's findings have shown that direct student input into a science curriculum can foster student interests (Seiler, 2001, 2002).

As with Seiler (2006), Basu and Barton (2005) also found that many students who displayed negative views of science, engaged in learning when provided with chances to relate topics to their life. Specifically, Basu and Barton (2005) investigated how urban, low-income students' experiential and content knowledge affected their interests in science. Using classroom observations, interviews, and students' work, these authors inductively coded and transcribed their data. Basu and Barton's (2005)

data interpretations have suggested that developing students' interest in science required opportunities where learners could relate their science experiences with their prior knowledge.

Contextualized instruction has also been defined with motivational connotations related to promoting students' interest in science. Specifically, Rivet and Krajcik (2008) characterized contextualized instruction as creating educational environments where real-world problems meaningful to students, are used to stimulate learning. Recently, Rivet and Krajcik (2008) showed that 8th grade students were more engaged in learning when they were able to connect the science concepts to their everyday experiences. Specifically, the authors suggested that 10-week contextualized instruction intervention promoted learners interest and knowledge of physics.

Researchers have shown how the SSI-based framework facilitates contextualized learning (e.g., Barab, et al., 2007; Keselman, Kaufman, Kramer, & Patel, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zohar & Nemet, 2002). In fact, Zeidler (2003) and others have argued that this is what distinguishes the SSI model from other ways of learning science (e.g., Barab, et al., 2007; Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009). However, investigations that have suggested SSI-based frameworks promote contextualized learning; have yet to empirically support student engagement or interest towards science.

In general, the limited research that has been done to identify components that stimulate students learning science has suggested providing environments that relate

science to students' identities can improve achievement and interest (e.g., Aikenhead, 1997; Matthews & Smith, 1994; Palmer, 2005). However, there are still many questions that can be asked about how to foster students' interest in science to answer questions that arise in their everyday lives. For instance, most of the research that has generated empirical data on educational settings engaging students to understand science have focused on primary and secondary learners (e.g., Basu & Barton, 2007; Palmer, 2005; Seiler, 2001, 2002, 2006). How could postsecondary learning environments be structured to stimulate students' interest while developing their knowledge of science?

Further, how effective are student interest based educational opportunities at fostering learners' functional understanding of science to answer their questions about everyday life? In addition to promoting skills to evaluate scientific information, the SSI initiative has also sought to make school science more relevant to people's lives by examining complex societal problems. However, Zeidler, Walker, Ackett, and Simmons (2002) and Sadler, Chambers, and Zeidler (2004) have shown that the use of SSI does not necessarily promote personal connections between students and the science content. Researchers have also found students' decisions about SSI can be effected by emotions, intuitions, and personal experiences (e.g., Bell & Lederman, 2003; Ekborg, 2008; Grace & Ratcliffe, 2002). For instance, Sadler, Chambers, and Zeidler's (2004) interpretation of data indicated that students' would make decisions based on how engaged they were with the scientific topic and not contemplation of the evidence. In other studies, personal experiences have been shown to dominate over reasoning from scientific knowledge (Patronis, Potari, & Spiliotopoulou, 1999;

Tytler, Duggan, & Gott, R, 2001). Therefore, Sadler (2004, p. 531) has argued that SSI-based curricula need to begin including approaches that help students integrate classroom science experiences with their personal lives. Currently, the research literature examining how meaningful personal connections can be integrated into SSI-based curricula to foster scientific literacy is missing (Sadler, 2004).

Research on the Relationship of NOS Conceptualizations and SSI

This section reviews studies that have been associated within the SSI-based framework and have sought to understand people's NOS conceptualizations. After a brief introduction, I discuss the relevant research chronologically. This section concludes by briefly summarizing the salient aspects of the reviewed literature in relationship to this doctoral dissertation.

The NOS, also the epistemology of science or science as a way of knowing, has been defined as values, assumptions, and processes inherent to scientific knowledge (Bell & Lederman, 2003, p. 353; Bell, Lederman, & Abd-El-Khalick, 2000, p. 564). These values, assumptions, and processes include science being a product of human imagination and creativity, a social process, empirically based, and limited by technology (Abd-El-Khalick, 2003, p. 42; Aikenhead & Ryan, 1992; Hogan, 2000). The NOS has been explicitly emphasized in recent reform movements as an essential component in achieving scientific literacy (AAAS, 1989, 1993; NRC, 1996). Educators and researchers who have advocated for the use of SSI-based interventions believe social, tentative, and empirical aspects of science are learned in this type of educational setting, which in turn promote more informed decisions (Sadler, 2004).

In general, the research that has looked at NOS conceptualizations using the SSI-based theoretical perspective has supported NOS conceptualizations influence on a person's informal reasoning. However, the degree and means by which an individual's scientific epistemological knowledge influences his/her decisions and understanding of science has been highly debated (e.g., Bell & Lederman, 2003; Hogan, 2000; Sadler, Chambers, & Zeidler, 2004). For example, Bell and Lederman (2003), among other science education researchers, have proposed that social/political issues, ethical considerations, and personal beliefs dominate over formal NOS conceptualizations when making decisions (Grace & Ratcliffe, 2002; Ratcliffe, 1997). Others have contended that students dichotomize personal beliefs and their formal knowledge about the epistemology of professional science when informally reasoning (Sadler, Chambers, & Zeidler, 2004; Walker & Zeidler, 2007). Still others have asserted that there is an interaction between one's formal knowledge of the NOS and a person's beliefs, which influences their learning and reasoning about science (Hogan, 2000; Smith & Wenk, 2006; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006; Yang, 2005). In the following subsections, I discuss research examining people's NOS conceptualizations about SSI in chronological order.

Zeidler and Schafer (1984)

Although, Zeidler and Schafer (1984) did not explicitly examine participants' NOS conceptualizations, their findings have been implicated by other researchers examining people's epistemological knowledge of science. Therefore, in this section I have included the significant aspects of the Zeidler and Schafer (1984) investigation

that have frequently been cited by researchers promoting and studying the effects of SSI-based interventions.

Zeidler and Schafer (1984) examined how learners' scientific knowledge, moral reasoning⁹ (an aspect of informal reasoning), attitudes, and past experiences have affected their decisions about environmental dilemmas. Zeidler and Schafer (1984) used several quantitative instruments¹⁰ to determine if 86 environmental science majors exhibited a higher level of moral reasoning than 105 non-science majors did. They also considered what mediating factors might have accounted for differences in their data. The authors recorded and transcribed pairs of participants discussing their responses to an Environmental Issues Test.

Zeidler and Schafer's (1984) interpretation of their data suggested that participants would frequently refer back to their personal experiences to support their points of view. This finding is an observation others have also found, suggesting that social interactions and personal interests are integrated in people's decisions about science issues (e.g., Bell & Lederman, 2003; Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002). Zeidler and Schafer (1984) also contended science majors' comprehension of ecology and scientific epistemology affected their higher reasoning skills.

Tytler, Duggan, and Gott (2001)

⁹ Informal reasoning, as defined by Sadler (2004a, p. 515), consists of four primary themes: 1) socio-scientific argumentation, 2) nature of science (NOS) conceptualizations, 3) the evaluation of information, and 4) the influence of conceptual understanding on informal reasoning.

¹⁰ The quantitative instruments used in this study included: 1) DIT = Defining Issues Test, a general measure of moral reasoning; 2) EIT = Environmental Issues Test, a measure of moral reasoning on environmental problems; 3) TEC = Test of Ecology Comprehension (TEC), a conceptual test of environmental understanding; 4) EAI = Ecology Attitudes Inventory (EAI), composed of three subtests, verbal commitment, actual commitment, and the affect related to the environment.

As with Zeidler and Schafer (1984), Tytler, Duggan, and Gott's (2001) case-study did not specifically focus on how participants' NOS conceptualizations affected their ability to informally reason. However, Tytler, Duggan, and Gott (2001) did report relationships between participants' informal reasoning and their epistemological conceptions of science. Therefore, I have included the significant findings from this case study in this 'Research on the Relationship of NOS Conceptualizations and SSI' section.

Specifically, Tytler, Duggan, and Gott (2001) investigated how scientists and public citizens dealt with a local environmental problem. These authors created an argumentation scheme¹¹ by examining documents and interviewing public members in the debate. Three significant findings emerged from their data: 1) how participants formally used scientific evidence based on data, 2) how participants used informal evidence (such as common sense, personal experience), and 3) how participants viewed general issues that were related to evidence (such as environmental or legal concerns). Tytler, Duggan, and Gott (2001) interpretation of their findings suggested that the community of non-scientists were unable to identify and use scientific data to strengthen their positions. Sadler, Chambers, and Zeidler's (2004) have used Tytler, Duggan, and Gott's (2001) findings to support their contention that a lack of NOS knowledge limits a person's informal reasoning.

Tytler, Duggan, and Gott (2001) have recognized that school science curricula should offer pragmatic opportunities for learners to question and manipulate different

¹¹ Scheme (singular), schemes (plural), has been defined by Piaget (1970) as operational activities that are repeatable and generalizable. Where schema (singular), schemata (plural), has been defined as figurative aspects of thought, where an individual attempts to represent reality (Piaget, 1970, p. 705).

types of real data. They have suggested that such chances could equip and empower public citizens to more effectively support or challenge SSI that affect their lives.

The learning environment in this doctoral dissertation provided pragmatic opportunities for learners to question and manipulate different sorts of real data. For example, the individual and group projects, required students to develop skills such as reading popular press scientific information in order to decipher fact from opinion and recognize how social factors have influenced scientific perspectives. The hands-on labs gave students chances to reflect on the limits of phenomenological data. The findings from these activities, discussed in [Chapters 4, 5, and 6](#), challenged students to reevaluate their understanding of reported data as well as their initial beliefs about SSI that have affected their life.

Zeidler, Walker, Ackett, and Simmons (2002)

The focus of the exploratory study by Zeidler, Walker, Ackett, and Simmons (2002) was on how high-school to collegiate students' NOS views affected their beliefs about animals used for scientific research. Zeidler, Walker, Ackett, and Simmons (2002) used inductive coding to analyze open-ended and interview questions. All authors validated the coded data. These authors investigated 82 students' (ranging in age from high-school to collegiate) responses to 4 questions taken from the Views of Nature of Science questionnaire (VNOS-B) (Lederman, 2002) and several questions that prompted their belief convictions on animal research in the name of science.

Zeidler, Walker, Ackett, and Simmons (2002) found students' NOS conceptualizations about scientific theories ranged from seeing theories as provable

and static definitions, to being modifiable by technological advancements. Many students also had trouble with conclusive, hypothetical, conjectured, and opinioned statements. For instance, the authors found that many participants had problems explaining how scientists could arrive at different conclusions when examining the same data. However, Zeidler, Walker, Ackett, and Simmons (2002) did find that participants had an understanding of the subjectiveness of opinions and the objectivity of scientific knowledge. That is, students expressed a general understanding that personal opinions are subjective in nature, but scientific knowledge arises from objective observations of physical phenomena.

With respect to how participants' NOS conceptualizations affected their beliefs, it was found that students' reactions varied. In particular, Zeidler, Walker, Ackett, and Simmons (2002) found that some students' reactions to using animals for scientific research resulted in ignoring or rejecting contrary ethical views of a classmate or conflicting information. Other participants tended to believe the data, yet lacked conceptual knowledge of the issue.

The results from Zeidler, Walker, Ackett, and Simmons's (2002) exploratory study have raised many questions about how students' NOS conceptualizations influenced their beliefs and informal reasoning. For example, Zeidler, Walker, Ackett, and Simmons (2002) have questioned if students' reasoning, emotional reactions, and NOS conceptualizations would have varied significantly with different SSI.

Given the range of NOS conceptions and variety of reactions, the authors have concluded further research is needed. One topic Zeidler, Walker, Ackett, and

Simmons (2002) identified how students' responses may have changed if a different socio-scientific issue was chosen. They have reasoned from their data that assessing a variety of SSI may provide more insights into how students' NOS concepts affected their beliefs and reasoning of SSI. Zeidler, Walker, Ackett, and Simmons (2002) have also speculated that different SSI could be more or less effective in stimulating student interest.

Bell and Lederman (2003)

Contrary to Zeidler, Walker, Ackett, and Simmons (2002) and basic assumptions of current science education reform efforts, Bell and Lederman (2003) have questioned the significance of NOS conceptualization on a person's informal reasoning. Bell and Lederman (2003) found that 21 university faculty decisions about different SSI were not based upon their understanding of the NOS. Rather, Bell and Lederman (2003) have argued that participants based their decisions primarily on personal values, morals/ethics, and social concerns.

Inductive coding was used to analyze the open-ended Decision-making Questionnaire (DMQ) and interviews. The DMQ questions were explicitly designed for this study. This questionnaire contained 4 SSI concerning 1) fetal tissue implantation, 2) global warming, 3) the relationship between diet and cancer, and 4) the relationship between cigarette smoking and cancer. Interviews served to validate data interpretations.

Bell and Lederman (2003) claimed the contextualized SSI-based setting and experience of participants have offered important insight into how people in positions to make substantial personal and public decisions informally reason. Bell and

Lederman (2003) found that regardless of their participants' NOS conceptualizations, the university faculty reached similar conclusions. They inferred that factors such as social/political issues, ethical considerations, and personal values, appeared to dominate over NOS conceptualizations when participants would informally reason. Bell and Lederman (2003) have also argued that their results have been supported by others' data (Fleming, 1986a, 1986b; Zeidler & Shafer, 1984). Yet, these authors offered no explanation as to why the science engineers in their study were assessed as having primitive NOS conceptualizations. Nor did Bell and Lederman (2003) examine participants' conceptual knowledge of the SSI. However, Bell and Lederman (2003) did acknowledge that their findings have warranted additional research on how much an individual's understanding of the NOS affects their decisions in real-world contexts.

This doctoral dissertation has examined how people's knowledge of the NOS developed in response to explicit and reflective¹² instruction. Instruction was also contextualized in real-world scenarios by using scientific issues that participants were emotionally connected to and have affected society. Consequently, the findings from this doctoral dissertation have offered significant insights into whether individuals' NOS conceptualizations affected their informal reasoning and beliefs about SSI.

Sadler, Chambers, and Zeidler (2004)

Sadler, Chambers, and Zeidler (2004) studied 84 high-school students. Their data aligned with the findings of Zeidler, Walker, Ackett, and Simmons (2002). In

¹² Khishfe and Abd-El-Khalick (2002, p. 555) have defined explicit and reflective teaching of the NOS as emphasizing epistemological concepts related to science and providing opportunities to make connections between an individual's activities and those undertaken by scientists.

particular, Sadler, Chambers, and Zeidler (2004) found that NOS conceptualizations influenced their participants' decisions about SSI.

Sadler, Chambers, and Zeidler (2004) examined students' responses to 5 questions after they read two alternative articles on the issue of global warming. Both articles had similar data and writing styles. Sadler, Chambers, and Zeidler (2004) also reported interviewing a subset of students to confirm their questionnaire interpretations. These 5 NOS and informal reasoning questions¹³ were used to create the article exercise instrument employed in this doctoral dissertation, see [Appendix B](#) and the instrumentation discussion in [Chapter 3](#). The authors inductively analyzed their qualitative data. They established credibility and trustworthiness by triangulating the questionnaires and interviews as well as establishing inter-rater reliability¹⁴ of data interpretations between the three investigators.

The authors claimed most students displayed a general understanding of the tentativeness of the NOS. Sadler, Chambers, and Zeidler (2004) also argued that the high-school students were comfortable with researchers producing vastly different conclusions. That is, high-school students recognized scientists have different ideological positions or produce different types of data. Similarly, students appreciated the social embeddedness of science, as most were able to identify societal factors such as economics, personal interests, social causes and effects.

¹³ The questions Sadler, Chambers, and Zeidler (2004) asked were 1) Are data used to support either position? If so, describe the data and how they are used? 2) Do societal factors (issues not directly related to science) influence either position? If so, describe how these factors influence each argument. If not, describe why these factors would not influence each argument. 3) Why do the two articles, which are both written by scientists discussing the same material, have such different conclusions? 4) Which article is more convincing? Please explain your response. 5) Which article has more scientific merit? Please explain your response.

However, Sadler, Chambers, and Zeidler (2004) also found that nearly half of their student sample lacked the ability to identify and describe data, which aligned with Zeidler, Walker, Ackett, and Simmons (2002). As with Zeidler, Walker, Ackett, and Simmons (2002), Sadler, Chambers, and Zeidler (2004) have also claimed their participants would dichotomize personal beliefs and scientific knowledge. This resulted in high-school students compartmentalizing scientific evidence when making personal decisions. Further, Sadler, Chambers, and Zeidler (2004) found that their participants would favor the article they perceived more persuasive but not necessarily the most meritorious. The authors also found that most students identified the more persuasive article as the one that aligned with their prior beliefs. Consequently, these authors have asserted that students' informal reasoning was biased.

These claims have both sustained and challenged the assertions made by Bell and Lederman (2003). On one hand Sadler, Chambers, and Zeidler (2004) argued that participants' NOS conceptualizations affected their ability to interpret the scientific information presented in the article. The authors also found that many participants did not integrate their knowledge of the NOS with their beliefs about global warming. It is unclear then, whether the high-school students' social/political, ethical, and personal values would dominate over their NOS conceptualizations when making decisions.

Given that the Sadler, Chambers, and Zeidler (2004) study was not examining changes in participants' NOS conceptualizations, the findings from this doctoral

¹⁴ Inter-rater reliability was defined as the consistency between two or more assessors in rating the

dissertation have offered important implications. In particular, the data from this student interest SSI-based curricular and pedagogical intervention have provided more insight into how NOS conceptualizations affect a person's informal reasoning.

Khishfe and Lederman (2006)

Few studies have directly examined the effects of a SSI-based intervention on participants NOS conceptualizations. The investigation by Khishfe and Lederman (2006) was the first with this explicit focus. Khishfe and Lederman (2006) researched the effects of two explicit¹⁵ approaches to infuse NOS conceptualizations into a 9th grade, 6-week global warming unit. Specifically, the authors examined how an explicit integrated instructional approach differed from an explicit non-integrated instructional approach, and how it affected 9th graders understandings of NOS. The integrated instructional approach was defined as teaching the NOS by embedding epistemological concepts within the science content. Conversely, the nonintegrated teaching approach had specific activities and lectures, which explicitly focused on participants' NOS conceptualizations.

There were 42 participants in total and the same teacher taught both classes. At the beginning of the study, participants in the two groups were administered a 5-item open-ended questionnaire. The first 4 questions were taken and slightly modified from the Nature of Science Survey used by Khishfe and Abd-El-Khalick (2002). The 5th question was specifically designed for Khishfe and Lederman's (2006) study. There were 5 participants from each group (integrated verses non-

same objects or responses.

¹⁵ Khishfe and Abd-El-Khalick (2002, p. 555) have defined explicit teaching of the NOS as emphasizing student awareness of certain epistemological concepts in relationship to the science-based activities in which they are engaged.

integrated instructional approaches) who were randomly selected and interviewed at the beginning of the study. At the conclusion of the study, all students were asked to complete the same open-ended questionnaire. Another 10 randomly selected participants were interviewed from the two groups at the conclusion of the 6-week unit. The 25–50 minute semi-structured interviews were used to validate participants' questionnaire responses. Khishfe and Lederman (2006) analyzed participants' interview transcripts and questionnaire responses separately and claimed inter-rater reliability of data analyses. The scoring rubric that was created by Khishfe and Lederman (2006) categorized students' NOS conceptualizations into naive, informed, or transitional.

The authors claimed that prior to instruction, the majority of participants in both groups held naive NOS conceptualizations. Khishfe and Lederman (2006) found that participants in both groups showed improvements in their views of the NOS. These researchers concluded that explicit NOS instruction improved students' views of scientific epistemology, regardless of how it was taught. However, the authors also acknowledged that their findings might have been affected by the nature of the real-world socio-scientific topic of the global warming unit. Khishfe and Lederman (2006) and others have recognized that explicit instruction about the NOS within real-world SSI may be a salient factor in helping learners to develop their knowledge of the epistemological aspects of science (Bell & Matkins, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2009). However, more research is needed to support this theory.

Khishfe and Lederman's (2006) findings have helped to inform the data analyses from this doctoral dissertation. For instance, it can be argued that the instructional approaches used in this student interest SSI-based curricular and pedagogical intervention were both integrated and non-integrated. In particular, NOS conceptualizations were integrated into the hands-on lab group discussions as we talked about undergraduates' experimental protocols and resultant data. There were also explicit non-integrated discussions about the NOS such as the PowerPoint presentation on the Maryland Voluntary State Curriculum 5-E Pedagogical Model (Maryland State Department of Education, 1997). [Chapter 5](#) has provided a more detailed illustration of this non-integrated pedagogical approach.

Walker and Zeidler (2007)

The study by Walker and Zeidler (2007), investigating 36 high-school students after a 7-week SSI-based learning exercise, is another example of investigative design explicitly interested in the effects of a SSI-based intervention on participants NOS conceptualizations. Walker and Zeidler (2007) used the Web Internet-based Science Environment (WISE) instructional framework to design a series of computer-based activities on genetically modified foods. Specifically, these learning activities asked high-school students questions about: 1) certainty of scientific claims and tentativeness of science; 2) validity and reliability of scientific claims; 3) objectivity and subjectivity; 4) role of government, corporations, media, and special interest groups in science; 5) and moral and ethical issues. At the end of the 6th week, students participated in a "policy-making" debate. Participants were then paired for semi-structured interviews.

Walker and Zeidler (2007) analyzed their data inductively. They also used Toulmin's (1958) model of argumentation to assess the students' debates. Walker and Zeidler (2007) found students expressed conceptual understanding for the tentative, creative, subjective, and social aspects of the NOS. However, students did not use their NOS conceptualizations during the "policy-making" debate. Instead, Walker and Zeidler (2007) found students attempted to reason with their factual-based content knowledge of the evidence. This disclosed students' misconceptions about the global warming issue. Similar to Tytler, Duggan, and Gott (2001), Walker and Zeidler (2007) have concluded that SSI-based interventions should offer opportunities for learners to apply their knowledge of the NOS in real-world decision-making contexts. Walker and Zeidler (2007) claimed that their SSI-based intervention failed to offer participants opportunities to apply their NOS knowledge. Walker and Zeidler (2007) believe this inhibited participants demonstrating their understanding of scientific epistemology. This student interest SSI-based instructional environment offered participants several opportunities to evaluate their beliefs and understanding of SSI that have directly affected their lives.

Summary

In summary, this section has reviewed several studies that have used SSI to understand people's NOS conceptualizations. The majority of the research that has looked at NOS conceptualizations using a SSI-based theoretical perspective has supported NOS conceptualizations influencing how a person informally reasons (e.g., Bell & Lederman, 2003; Sadler, Chambers, & Zeidler, 2004; Zeidler & Schafer, 1984; Zeidler). However, researchers have questioned the degree and means by

which an individual's scientific epistemological knowledge influences his/her decisions and understanding of science (e.g., Bell & Lederman, 2003; Sadler, Chambers, & Zeidler, 2004; Walker & Zeidler, 2007). For instance, Bell and Lederman (2003) interpreted their data to suggest social/political issues, ethical considerations, and personal beliefs dominate over formal NOS conceptualizations when people make decisions. While Sadler, Chambers, and Zeidler (2004) among others found that students dichotomize personal beliefs and their formal knowledge about the epistemology of professional science when informally reasoning (Walker & Zeidler, 2007). Still others have asserted that there is an interaction between one's formal knowledge of the NOS and a person's beliefs, which influences their learning and reasoning about science (e.g., Hogan, 2000; Smith & Wenk, 2006; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006; Yang, 2005). The data that I discuss in [Chapters 4, 5, and 6](#) support students' epistemological conceptualizations of science being an influential factor on how participants informally reasoned. Specifically, it was also found that undergraduates' formal knowledge of the NOS developed with their beliefs, which further influenced how students reasoned SSI perspective(s).

Research on Evaluating Socio-scientific Information

This section reviews studies that have been associated within the SSI-based framework and have sought to understand how people evaluate scientific information. As with the 'Research on the Relationship of NOS Conceptualizations and SSI' section, I begin my review of the relevant research by briefly introducing the need to further examine how people's evaluation of scientific information has affected their informal reasoning. I then summarize related studies in chronological order. I also

conclude this section by briefly summarizing the reported findings most relevant to the focus of this doctoral dissertation.

Researchers who have examined how individuals informally reason in the context of SSI, have suggested that participants often fail to comprehensively reflect and evaluate complex science issues affecting their life (Sadler, 2004, p. 528). Data interpretations have suggested many factors influence the way a person evaluates socio-scientific evidence. For example, Sadler, Chambers, and Zeidler (2004) and Tytler, Duggan, and Gott (2001) inferred from their results that most people were not able to discern what constitutes scientific data, which they believed affected their participants' evaluation of SSI. Other researchers have acknowledged that the criteria and context of the study can influence reported outcomes. For instance, Kolsto, et al. (2006, p. 649) contended that their results were in part a product of their explicit informal reasoning instructions.

Further, many studies that have discussed how people evaluate scientific information have included insights about how individuals' NOS conceptualizations could affect their conclusions and reasoning. For example, Tytler, Duggan, and Gott (2001) as well as Sadler, Chambers, and Zeidler (2004), previously discussed in the 'Research on the Relationship of NOS Conceptualizations and SSI' section of this chapter, also reported findings on how participants evaluated scientific information. For instance, Tytler, Duggan, and Gott (2001) showed non-professional scientists (members of society facing a community issue) relied most commonly on common sense, circumstantial evidence, and personal experience when making public decisions. Sadler, Chambers, and Zeidler (2004) contended that students favored

position statements that they could relate to, which resulted in biased decisions based upon personal relevance rather than contemplation of evidence.

Researchers have also acknowledged a need to extend what is known about how people evaluate scientific evidence. For example, Korpan, Bisanz, Bisanz, and Henderson (1997) examined the types of information requests 60 college students made as they evaluated four fictitious science news briefs. These researchers argued that their data have shown that students' requests for information varied between news briefs even though the format of each article was identical in design. Korpan, Bisanz, Bisanz, and Henderson (1997) also noted the tendency for participants to seek information concerning the methodology as opposed to factors such as the implications of the conclusions. Conversely, Kolsto (2001b) found participants mainly focused on the competence of the authoritative sources as well as critically evaluating the reported sources of information. Unlike the Korpan, Bisanz, Bisanz, and Henderson (1997) study, which indicated students rarely focused on what was found or who conducted the research, Kolsto (2001b) discovered students often questioned the authority of the researcher rather than the methodology. In the following subsections, I have further discussed reasons to extend empirically based research on how individuals evaluate scientific information. As with the 'Research on the Relationship of NOS Conceptualizations and SSI' section of this chapter, I chronologically summarize the research examining how individuals evaluate socio-scientific information.

Fleming (1986a, 1986b)

Although Fleming (1986a, 1986b) did not explicitly focus on learners' ability to evaluate scientific information, researchers promoting the SSI-based framework have historically cited these studies as significant. Therefore, I have summarized several salient findings reported by Fleming (1986a, 1986b).

Fleming (1986b) studied 38 students, who had recently completed introductory high-school chemistry and biology courses. Fleming (1986b) sought to examine how students used their science knowledge (which he calls nonsocial cognition) when analyzing SSI. Fleming's (1986a, 1986b) semi-structured interviews investigated students' reasoning on alternative nuclear power plants or genetic engineering issues.

Fleming's (1986a, 1986b) recorded and transcribed interviews indicated that few students actually incorporated scientific knowledge as they reasoned their perspectives. Participants tended to base their decisions on moral and personal beliefs rather than their conceptual knowledge acquired in their chemistry and biology courses. Fleming (1986b) inferred from his data that students lacked a strong conceptual understanding of science behind these SSI. Resultantly, Fleming (1986b) has argued that conceptual knowledge of science can inhibit how an individual reasons. Other researchers, such as Bell & Lederman (2003) have used Fleming's (1986a, 1986b) findings to suggest that a person's social knowledge and personal beliefs can influence how he/she informally reasons SSI (e.g., Bell & Lederman, 2003; Zeidler, Walker, Ackett, & Simmons, 2002; Zeidler & Schafer, 1984).

Korpan, Bisanz, Bisanz, and Henderson (1997)

As previously mentioned, Korpan, Bisanz, Bisanz, and Henderson (1997) examined the types of information requests from 60 college students as they evaluated four fictitious science news briefs. These researchers have claimed that one practical and important index for scientific literacy is the ability for people to effectively request information about scientific research reports in the media. As a result, these authors created scenarios that asked students to identify additional information they felt was needed to confirm the reports of 4 fictitious news briefs. All fictitious articles included information about 1) the scientists performing the research, 2) the issue, and 3) data supporting the researchers' claims. The authors coded students' responses using a 9-category taxonomy. The 9 major categories that Korpan, Bisanz, Bisanz, and Henderson (1997) used to characterize students' responses were social context, agent /theory, methods, data/statistics, related research, relevance, other, ambiguous/relevant, and off task.

Korpan, Bisanz, Bisanz, and Henderson (1997) interpreted their data to suggest students' requests for information varied between news briefs even though the format of each article was identical in design. Research methodology was the only consistent request of information by the students for all 4 articles. Outside of research methodology, students' requested information inconsistently between articles. Korpan, Bisanz, Bisanz, and Henderson (1997) found that each news brief elicited different informal reasoning patterns, which had been a finding reported by others (Sadler & Zeidler, 2005a). Korpan, Bisanz, Bisanz, and Henderson (1997) noted another interesting observation was the tendency for participants to seek information concerning the methodology as opposed to factors such as the

implications of the conclusions. In general, Korpan, Bisanz, Bisanz, and Henderson's (1997) interpretation of data indicated students focused more on how the research was conducted and factors' contributing to the results, rather than on what was found and who conducted the research. Additionally, Korpan, Bisanz, Bisanz, and Henderson (1997, p. 529) claimed that individuals evaluative processes and their understanding of science influence and are influenced by their experiential knowledge. However, these authors have also recognized the need for more empirical data on how people evaluate scientific evidence.

This doctoral dissertation intervention has provided an environment for students to evaluate scientific information about different SSI that have influenced their lives. Thus, the data from this student interest SSI-based intervention have extended what is known about the consistent and inconstant ways people evaluate different scientific issues that affect society.

Ratcliffe (1997)

Ratcliffe (1997) examined 15-year old boys' informal reasoning skills, knowledge, and values towards SSI that were included in science curriculum. Ratcliffe's (1997) investigation took place in a United Kingdom school. Data from participants in class discussions, interviews, and students' written work were examined.

Ratcliffe (1997) found several important characteristics that facilitated informed and thoughtful group decision-making about SSI. Specifically, Ratcliffe (1997) claimed that 1) considering alternative perspectives, 2) using relevant information, 3) identifying important criteria, 4) recognizing underlying concepts, 5) engaging with the issue, and 6) accepting other viewpoints with clarification were

significant factors that enhanced participants' reasoning. Ratcliffe (1997) also argued that conceptual knowledge of the SSI affected students' abilities to draw on evidence when informally reasoning.

Kolsto (2001b)

Kolsto's (2001b) study design was similar to Tytler, Duggan, and Gott (2001) in that he investigated a real local socio-scientific issue. Specifically, Kolsto (2001b) focused upon how 16-year old Norwegian students informally reasoned whether the local power transmission-lines were the cause of the increased number of childhood leukemia cases in the area.

Kolsto (2001b) used semi-structured interviews to analyze the salient factors participants focused on when deciding whether to trust knowledge claims, arguments, and opinions given to them prior to being interviewed. Each participant then took part in a semi-structured interview that took place after two informative science lessons introducing students to the local socio-scientific issue. Kolsto (2001b) inductively coded students' responses into four categories: 1) accepting knowledge claims, 2) the processes used in evaluating statements, 3) the processes used in evaluating sources of information, and 4) beliefs about the authoritative nature of the information.

Kolsto (2001b) interpreted his data to suggest students used a range of strategies in trying to evaluate the trustworthiness of arguments when deciding who to trust and what to believe. Kolsto (2001b) found participants mainly focused on the competence of authoritative sources as well as evaluating sources of information. Unlike the Korpan, Bisanz, Bisanz, and Henderson (1997) study, which indicated students rarely focused on what was found or who conducted the research, Kolsto

(2001b) discovered students often questioned the authority of the researcher rather than the methodology. Kolsto (2001b) also found that participants' evaluations were complex and multi-layered. However, Kolsto (2001b) concluded that students primarily used superficial contextual information rather than empirical evidence when reasoning.

Kolsto (2001b) further inferred from his conclusion that participants' reasoning were influenced by their personal experiences, social considerations, and beliefs. Kolsto (2001b) strengthened his contention by acknowledging the arguments of other science education researchers who have examined people's decision making processes (e.g., Bell & Lederman, 2003; Fleming, 1986a, 1986b; Sadler, Chambers, & Zeidler, 2004; Zeidler & Schafer, 1984). For example, Bell and Lederman (2003), Sadler, Chambers, and Zeidler (2004), Zeidler, Walker, Ackett, and Simmons (2002), among others have noted that factors such as social points of view, ethical considerations, and personal values can influence the processes by which an individual informally reasons (Fleming, 1986a, 1986b; Zeidler & Shafer, 1984).

Hogan (2002)

This study aligned with Ratcliffe's (1997) work by examining the affects of an existing curriculum on how students informally reasoned. Specifically, Hogan (2002) analyzed how 24, 8th grade, students applied their knowledge of ecology when arriving at environmental management decisions.

Hogan's (2002) data were derived from interview protocols and conceptual maps probing participants' knowledge of the invasive exotic plant *Hydrill*. In particular, students participated in two interviews and one group task. During the

first interview, participants' content knowledge was assessed by having the students construct an aquatic ecosystem concept map, where they traced the effects of perturbation. Students were also asked to work in groups of 3 to make an environmental management decision. Hogan (2002) concluded her study by interviewing students about their groups' environmental management decision. Results were scored by a point system that compared students' comments to environmental ecologists' management decisions.

A major finding from Hogan's (2002) study was that across groups, students touched upon all the themes environmental ecologists have considered important when making management decisions. However, the majority of discussions that took place within groups were narrowly focused upon a few salient issues. Hogan (2002) also recognized differences in groups' collective knowledge about aquatic ecology. In general, the groups that displayed high levels of prior knowledge offered the most thorough reasoning to defend their management decisions. Further, Hogan (2002) found that value judgments and concerns about uncertainty also were discussed among groups.

Hogan (2002) used her findings to argue the need to foster significant background knowledge and reasoning skills that build students' abilities to examine each other's assertions more critically. Resultantly, Hogan (2002) has acknowledged that opportunities to develop students' conceptual knowledge need to be integrated with experiences that ask learners to apply this information in pragmatic decision-making scenarios.

This doctoral dissertation examined a 15-week curricular model that provided several opportunities for students to work in groups and apply their conceptual knowledge of SSI. For instance, hands-on labs and the group project facilitated social interactions as undergraduates' informally reasoned socio-scientific information. Consequently, the findings from this study have provided important insights into how people's perceptions can change as they acquire additional information and socially discuss causes, consequences, positions, and alternatives perspectives.

Sadler and Zeidler (2005a, 2005b)

Sadler and Zeidler (2005b) used genetic engineering scenarios to consider how 30 undergraduates, 15 with extensive science course work and 15 with limited science course work, used their scientific knowledge of this socio-scientific issue when informally reasoning.

Sadler and Zeidler (2005b) took measurements of participants' genetic engineering conceptual knowledge using a Test of Basic Genetics Concepts (TBGC) instrument. The TBGC instrument had 20 multiple-choice items. Sadler and Zeidler (2005b) had explicitly developed this TBGC instrument for this study. The other aspect of this investigation asked undergraduates to participate in two individual semi-structured interviews. These interviews asked participants questions about 3 gene therapy and 3 cloning scenarios. Consequently, Sadler and Zeidler (2005b) employed a mixed-methodological approach to analyze the TBGC and interview data. Sadler and Zeidler's (2005b) analyses of participants interview responses resulted in a 1) deductive reasoning priori criteria of intra-scenario coherence¹⁶, 2) inter-scenario

¹⁶ Intra-scenario coherence was explained as the rationale supporting the stated position.

non-contradiction¹⁷, 3) counter position construction¹⁸, and 4) rebuttal construction¹⁹ coding scheme. Initially Sadler and Zeidler's (2005b) 4 inductive categories were used as a heuristic framework for coding the results from this doctoral dissertation. However, analytic induction proved to be more useful.

As with Bell and Lederman (2003) and others, Sadler and Zeidler (2005b) found that undergraduates' final interview responses indicated their reasoning was based upon personal experiences, social considerations, and personal beliefs (e.g., Fleming, 1986a, 1986b; Kolsto, 2001b; Sadler, Chambers, & Zeidler, 2004). This latter interview turned into a separate report (Sadler & Zeidler, 2005a). The coding of this latter interview had three main inductively emergent categories 1) rationalistic, 2) emotive, and 3) intuitive to classify students' responses. However, participants' responses often fell into more than one of these categories, which was depicted by a Venn diagram.

The findings from these papers have suggested differences in participants' conceptual knowledge of genetic engineering affected their informal reasoning (Sadler & Zeidler, 2005a, b). Students, with more advanced understandings of genetics, demonstrated fewer instances of reasoning flaws. These students were also more likely to incorporate content knowledge in their reasoning patterns, rather than participants with more naive understandings of genetics (Sadler & Zeidler, 2005b).

Another finding Sadler and Zeidler (2005a) inferred from their data were that different SSI could invoke different informal reasoning patterns. Similar to Korpan,

¹⁷ Inter-scenario non-contradiction was explained as the positions and rationales from each of the three related scenarios (i.e., three cloning scenarios and three gene therapy scenarios).

¹⁸ Counter position construction was explained as the ability to construct and explain a counter position.

Bisanz, Bisanz, and Henderson (1997), who found different news briefs influenced participants' informal reasoning, Sadler and Zeidler (2005b) found that the different gene therapy and cloning scenarios elicited distinct patterns of thought.

Kolsto, et al. (2006)

The study by Kolsto, et al. (2006) furthered Kolsto's (2001b) early work on the salient factors participants considered when evaluating scientific information. Kolsto, et al. (2006) investigated 89 science education students' abilities to assess the reliability of scientific claims about a socio-scientific issue of choice. In this investigation, students worked in groups of two to provide short evaluative summaries about the information and claims they came across while researching their science topic. Additionally, each student pair also commented on another groups' evaluation. Resultantly, the Kolsto, et al. (2006) study design had direct relevance to the student interest aspect of this doctoral dissertation's SSI-based intervention. In particular, this doctoral dissertation offered students the freedom to choose SSI of interest to them.

Kolsto, et al. (2006) analyzed data in two phases. During the first phase, the authors coded data on the content and sources of information participants focused on while researching their topic. The second phase focused on the principle points the students viewed as significant. Kolsto, et al.'s (2006) analyses of the data resulted in 4 categories participants identified as important. These categories were 1) empirical and theoretical adequacy²⁰, 2) completeness of presentation²¹, 3) social aspects of the

¹⁹ Rebuttal construction was explained as the participant's ability to construct a coherent rebuttal.

²⁰ The empirical and theoretical adequacy was defined as students' argumentation quality (their use of empirical data and research findings) to support their claims. This included participants' tendency to look for compatibility with a theory they understood and accepted. Scores are based upon: 1) quality

sources of claims²², and 4) manipulative use of language. As with Sadler and Zeidler's (2005b) data analyses, the 4 inductive categories from Kolsto, et al. (2006) were used initially as a heuristic framework for coding the results from this doctoral dissertation. However, analytic induction proved to be more useful.

Kolsto, et al. (2006) interpreted their data to suggest students' evaluations varied with respect to criteria and the quality. For example, while some groups carefully evaluated the authors' competencies or the correctness of scientific claims, other teams were more superficial in their critiques of the scientific information. Kolsto, et al.'s (2006) data also revealed the tendency for students to comment that arguments needed more details to enable critical examinations; however few students demonstrated an effort to crosscheck their sources. When focusing on social aspects, the students noted the potential for institutions to influence scientific interpretations. Participants also felt that varying sources different points of view were useful in assessing their socio-scientific issue more completely. In addition, many students acknowledged an expert's prestige and the importance of a peer reviewed consensus in science.

Kolsto, et al. (2006) concluded that in general, participants' demonstrated varying degrees of scientific literacy. With respect to Kolsto's (2001b) early work on the salient factors participants considered when evaluating scientific information,

of references 2) consistency of argumentation 3) face validity of argumentation 4) compatibility with subject knowledge.

²¹ The completeness of presentation was defined as students' comments about the lack of arguments and references in the examined articles. Scores were based upon: 1) completeness of references 2) completeness of an argument 3) one-sidedness in the presentation.

²² The social aspects of claims encompassed many social NOS concepts such as qualifications or competence of those conducting the study, the experts' honesty, and role of funding. Scores were

Kolsto, et al. (2006) found that participants considered a broader range of factors. However, these authors also noted that their results could have been influenced by their explicit informal reasoning instructions.

Sadler and Donnelly (2006)

Sadler and Donnelly (2006) investigated the role content knowledge and morality played in the quality of 56 high-school students' arguments. Although Sadler and Donnelly (2006) did not directly assess how participants evaluated SSI, their findings included several relevant implications. For example, Sadler and Donnelly (2006) acknowledged that argumentation is the discursive practice associated with evaluating evidence, assessing alternatives, establishing the validity of claims, and addressing counter-positions. Further, Sadler (2004a) has connected socio-scientific argumentation and conceptual knowledge with evaluating scientific information under the informal reasoning umbrella. Resultantly, the significant findings reported by Sadler and Donnelly (2006) have been included in this 'Research on Evaluating Socio-scientific Information' section. Additionally, Sadler and Donnelly's (2006) significant findings have also been discussed in [Chapters 4](#) and [6](#).

Sadler and Donnelly (2006) analyzed participants by using a mixed-methodological approach. Specifically, as with Sadler and Zeidler (2005a, b) study, participants' conceptual knowledge of the socio-scientific issue was assessed by the Test of Basic Genetics Concepts (TBGC) instrument²³. Sadler and Donnelly (2006)

based upon: 1) possible underlying interest 2) personal value-related qualities 3) author(s)' or experts' competence 4) level of professional recognition 5) level of expert agreement.

²³ The Test of Basic Genetics Concepts (TBGC) instrument came from Sadler and Zeidler's (2005b) study.

analyzed participants' moral reasoning by the Defining Issues Test (DIT)²⁴. Sadler and Donnelly (2006) measured argumentation skills during an interview, where participants were asked to respond to Sadler and Zeidler's (2005a, b) three alternative genetic engineering scenarios. Sadler and Donnelly (2006) coded their interview data by generalizing high-school students' argumentation quality, ability to acknowledge multiple perspectives, and skillfulness at forming a counter-position.

Unlike others' findings Sadler and Donnelly's (2006) multiple regression analyses revealed no statistically significant relationship among content knowledge and argumentation quality²⁵ (e.g., Jimenez-Alexandre & Pereiro-Munoz, 2002; Sadler & Zeidler, 2005b; Tytler, Duggan, & Gott, 2001). The authors concluded that increased content knowledge did not necessarily enhance students' ability to reason.

Sadler and Donnelly (2006) proposed a "Threshold Model of Content Knowledge Transfer" to explain why their findings have failed to align with previous investigations. In this model, Sadler and Donnelly (2006) described two knowledge thresholds; around which participants' discursive ability to evaluate evidence, assess alternative perspectives, and form counter-positions is believed to increase. Sadler and Donnelly's (2006) findings and "Threshold Model of Content Knowledge Transfer" have further complicated the theoretical mechanism by which people informally reason.

Sadler and Fowler (2006)

Sadler and Fowler's (2006) study was an investigation that further supported Sadler and Donnelly's (2006) findings and the "Threshold Model of Content

²⁴ The Defining Issues Test (DIT) came from Rest (1979).

Knowledge Transfer.” In this study, Sadler and Fowler (2006) examined high-school students, non-science college majors, and science college majors with variable knowledge about genetic engineering. Sadler and Fowler (2006) were interested in how participants used their scientific content knowledge to justify their claims. Specifically, Sadler and Fowler (2006) examined how 45 students utilized their knowledge of genetic engineering when supporting their position. As with Sadler and Donnelly (2006) and Sadler and Zeidler (2005a, b), Sadler and Fowler (2006) used a mixed methodological approach to understand how participants’ conceptual knowledge implicated their ability to informally reason their perspective. Resultantly, Sadler and Fowler (2006) also used Sadler and Zeidler’s (2005a, b) TBGC to assess participants’ conceptual knowledge of genetics. These authors also used Sadler and Zeidler’s (2005a, b) three genetic engineering scenarios to assess participants’ justification of their claims. A five-point rubric measured the number of justifications participants offered as well as their justification quality.

Sadler and Fowler’s (2006) multivariate analysis of variance indicated that college science majors outperformed the other groups in terms of argumentation ability. Sadler and Fowler (2006) also found that the justification level between non-science majors and high-school students did not reveal any significant differences. The science majors demonstrated more advanced argumentative skills by using their conceptual knowledge of genetics in their claims. However, all three groups appeared to focus on similar socially complex genetic engineering issues. Resultantly,

²⁵ Argumentation as defined by Sadler (2004a, p. 515), contribute to a person’s informal reasoning.

these authors have argued that their results support Sadler and Donnelly's (2006) Threshold Model of Content Knowledge Transfer.

Although Sadler and Fowler (2006), as well as Sadler and Donnelly's (2006) research, have raised several important issues with respect to how an individual informally reasons scientific information, these studies have also introduced questions. For instance, neither Sadler and Fowler (2006) nor Sadler and Donnelly (2006) examined how prior experiences may have affected participants' reasoning or their conceptual knowledge of genetic engineering issues. Further, this model has not addressed the findings by Jimenez-Aleixandre and Pereiro-Munoz (2002) and Zohar and Nemet (2002) who implemented a SSI curricular intervention and showed improvement in participants' uses of conceptual knowledge. Rather, Sadler and Donnelly (2006) have argued that students would need to acquire a substantial body of contextual understanding before learners could effectively apply their knowledge when informally reasoning. Sadler and Donnelly (2006) have argued that this level of conceptual instruction may not be possible in typical high-school settings. However, Jimenez-Aleixandre and Pereiro-Munoz (2002) showed that a 2 month, 16-session, real-life environmental socio-scientific issue could promote high-school students' use of relevant conceptual knowledge. Jimenez-Aleixandre and Pereiro-Munoz (2002) found that participants demonstrated the ability to integrate their conceptual knowledge when synthesizing and evaluating potential solutions. Similarly, Zohar and Nemet's (2002) assessment of a 12-week socio-scientific genetic issues intervention on 9th graders conceptual understandings of genetics reported significant

knowledge gains. Zohar and Nemet (2002) also found participants demonstrated the ability to integrate their conceptual knowledge when reasoning their position.

Nonetheless, Sadler and Fowler (2006) have contended that their findings are significant and should be considered. They also have claimed that their data have challenged the notion that social/political issues, ethical considerations, and personal values, dominate over NOS conceptions when making decisions (Bell & Lederman, 2003; Sadler & Zeidler, 2005a; Ratcliffe, 1997). Explicitly, Sadler and Fowler (2006) have argued that if social/political issues, ethical considerations, and personal values dominated how people arrive at decisions then their conceptual knowledge of science would not significantly influence this process.

Wu and Tsai (2007)

Wu and Tsai (2007) examined the effects of using a nuclear energy issue on 10th graders' ability to informally reason. Wu and Tsai (2007) used a mixed methodological approach to analyze 71 students' ability to support their decisions about the real local socio-scientific issue. Consequently, this investigation resembled others' research designs that have focused on local SSI (e.g., Jimenez-Aleixandre & Pereiro-Munoz, 2002; Kolsto, 2001b; Tytler, Duggan, & Gott, 2001). Additionally, Wu and Tsai's (2007) study was similar studies interested in analyzing participants' ability to support their position through socio-scientific argumentation (e.g., Sadler & Donnelly, 2006; Sadler & Fowler, 2006; Sadler & Zeidler, 2005a, b).

Inductive coding and statistical measures were used to analyze the data. Wu and Tsai's (2007) interpretation of the data suggested students could reason from multiple perspectives and demonstrated evidence-based decisions. However, less than

40% of the students showed the ability to refute counter-arguments. In addition, Wu and Tsai (2007) contended that students' knowledge of the scientific issue was an important factor in how they reasoned their position.

Science, Technology, and Society (STS) Studies

Aside from these investigations, which have been identified under the SSI-based umbrella, there are also investigations that have been frequently cited by researchers who have examined the uses and limits of this framework. Specifically, Science, Technology, and Society (STS) investigations are frequently compared to SSI-based research. As a result, I discuss a few relevant STS studies that have been repeatedly referred to in studies evaluating how participants' informally reason scientific information.

Kortland (1996)

Kortland (1996) placed his case-study, about how 8th graders reasoned issues related to recycling and reducing house hold waste, under the STS framework. Kortland (1996) examined 27 students' pre and post responses to a questionnaire as well as how their classroom interactions changed in response to his STS curricular intervention. Kortland's (1996) curricular intervention focused on students' decisions and ability to formulate arguments as they learned about the science and societal issues related to household waste. Kortland's (1996) experimental learning environment grouped students together to respond to a series of questions about recycling issues. At the completion of this group interaction, students engaged in a classroom forum discussion. Kortland (1996) transcribed and coded the data from classroom discussions along with pre and post responses to the questionnaire.

Kortland (1996) interpreted his results to suggest that students showed an increased ability to more clearly articulate their knowledge and make valid claims about the waste issue. However, Kortland's (1996) intervention did not prompt students to consider alternative perspectives nor did students consider a wider range of negative environmental impacts. Rather, participants used their initial limited range of knowledge about environmental issues surrounding packaging household waste.

In general, Kortland (1996) was disappointed in the effectiveness of his intervention. Resultantly, he has challenged science educators to find ways to help students utilize their knowledge about science when making decisions about societal issues. This doctoral dissertation has offered valuable insight into a student interest SSI-based curricular design that was successful in fostering students' ability to make more informed decisions about science issues that affect society. Specifically, this student interest SSI-based curriculum developed undergraduates' skills at finding, interpreting, and discussing alternative perspectives. Additionally, it was found that this SSI-based intervention promoted learners re-evaluation of their initial beliefs related to science issues that affect their life.

McGinnis and Simmons (1999)

McGinnis and Simmons (1999) examined 5 teachers' evaluation, beliefs, and implementation of STS curriculum units. In this 2-year case-study, McGinnis and Simmons (1999) pointed to several reasons as to why the STS framework has not been successful in reforming science curricula. Resultantly, the findings from the

McGinnis and Simmons's (1999) investigation have contributed to the significance and theoretical framework of this doctoral dissertation SSI-based investigation.

The first year of their case-study established the explanatory framework for interpreting data. The data from the first year came from two practicing teachers who took part in a 3-week workshop. The second year validated the researcher's first year inferential assertions by repeating a similar investigative protocol. The second year's data came from three different teachers. The three science educators from the second year did not participate in the same 3-week workshop, but rather a 5-credit quarter long academic course. However, the authors claim both curricula were identical, as the same science educator taught both courses.

In general, McGinnis and Simmons (1999) selected their five participants to represent a variety of teaching experiences, geographic locations, job securities, communal statuses, and beliefs about teaching STS issues in science classrooms. Participants were asked to evaluate the uses and limits of implementing STS issues in classroom settings. Specifically, participants studied science content, laboratory exercises, and field-trips that related to environmental STS issues.

McGinnis and Simmons (1999) analyzed their data with two foci. First, the authors concentrated on the beliefs their participants had towards teaching STS. Second, the authors focused on how participants used STS issues in classrooms and if the teachers believed their local community would support curricula with alternative STS issues.

The researchers' interpretations of their data showed that there were a range of beliefs among the five participants depending upon teaching experience, job

security, and communal status. It was found that many of the teachers claimed STS issues could help move students beyond classroom knowledge towards making connections to the world. However, most teachers also feared losing their job if they were to include STS curricular activities that made students confront their values and moral, especially if the topic had perspectives that challenged the local school culture. Those teachers who saw themselves as outsiders to the local community felt a higher degree of risk in incorporating alternative STS issues in their curricula. McGinnis and Simmons (1999) concluded that teachers failed to fully embrace the potential of the STS movement by favoring STS issues that lacked alternative scientific perspectives with ethical implications to society.

Consequently, McGinnis and Simmons's (1999) study has exemplified many reasons why the STS movement has failed to be widely implemented in science curricula. For instance, McGinnis and Simmons (1999) have contended that advocates who have promoted the inclusion of STS issues in science curricula need to acknowledge the implications related to students' and teachers' beliefs and cultural values. The SSI model Zeidler (2003) and others have argued for has been promoted as taking this shortcoming into account (Zeidler, Sadler, Applebaum, & Callahan, 2008; Zeidler, Sadler, Simmons, & Howes, 2005, p. 361). Resultantly, this student interest SSI-based intervention has included time for students to reflect and develop their beliefs and values. For example, built into the start and end of the semester article exercise, journals, research projects, and hands-on labs were tasks that asked students to consider different perspectives and to reassess their initial beliefs. Consequently, this learning environment challenged undergraduates, many of whom

were prospective teachers, to examine their existing knowledge and beliefs about several SSI that have affected their lives.

Fang-Ying (2004)

Fang-Ying (2004) examined how 90 students in the 10th grade applied their knowledge of theory and evidence to evaluate underground water use in Taiwan. Similar to other studies (e.g., Kolsto, 2001b; Tytler, Duggan, & Gott, 2001; Wu & Tsai, 2007), Fang-Ying (2004) used a real local socio-scientific issue to study how students evaluated information when making decisions. Additionally, as with McGinnis and Simmons (1999), Fang-Ying (2004) examined the effects of a STS intervention. Fang-Ying's (2004) 3-week STS curriculum presented 10th graders with discussion topics about the formation of underground water and possible disasters that could arise due to excessive water usage. At the end of the 3 weeks, students participated in a class debate where they considered a hypothetical excessive underground water scenario.

Fang-Ying (2004, p. 1351) claimed the main purpose of this 3-week intervention was to enhance students' background knowledge of the issues to foster a contextualized knowledge base for further learning. Similar to Hogan (2002), Fang-Ying (2004) used concept-maps to measure students' conceptual knowledge. Fang-Ying (2004) also included an open-ended questionnaire at the end of the 3 weeks. The purpose of this questionnaire was to examine students' final opinions and informal reasoning skills. This questionnaire was similar in design to Wu and Tsai

(2007) and Sadler, Chambers, and Zeidler's (2004)²⁶. Fang-Ying (2004) scored students' performances during a final debate according to the strength of their information and responses to other students. All qualitative data underwent inter-rater reliability.

Fang-Ying (2004) claimed students progressed in knowledge of basic scientific information. However, students rarely referenced theory and evidence correctly in their reasoning. The author also noted that "boys displayed a better ability to use theories while girls performed better in referring to scientific information when making judgments" (Fang-Ying, 2004, p. 1359). Furthermore, Fang-Ying (2004, p. 1357) reported that students who were uncertain about their socio-scientific position after the 3 weeks wanted more information. Similar to Kortland (1996), Fang-Ying (2004) asserted that learning environments should be explicitly focused on helping students utilize their knowledge about science when making decisions about societal issues.

This doctoral dissertation has investigated the effects of pragmatic experiences that offered students several opportunities to learn about SSI participants recognized as relevant to their lives. Part of this curriculum was to foster an understanding of how to evaluate scientific information and reflect upon one's initial beliefs to make sounder judgments. Thus, the findings from this doctoral dissertation discussed in [Chapters 4, 5, and 6](#) have several important empirically based insights to offer the educational research community.

²⁶ The questionnaire used by Fang-Ying (2004) consisted of four questions: 1) What do you think caused the previous ground subsidence in the town? Why? 2) Do you think the residents' resistance was reasonable? Why? 3) Do you believe the claim made by the water company that they had done

Summary

In summary, this section has reviewed several studies that have sought to understand how people evaluate scientific information. Researchers that have empirically assessed how participants informally reason SSI have most commonly found that participants have failed to comprehensively reflect and evaluate science issues that affect their lives (Sadler, 2004, p. 528). Studies have also indicated that conceptual knowledge has played a role in how people evaluate socio-scientific information. For example, Sadler and Zeidler (2005a, b) found that participants' conceptual knowledge of genetic engineering affected how they informally reasoned. Specifically, Sadler and Zeidler (2005b) found that participants with more advanced understandings of genetics demonstrated fewer instances of reasoning flaws. These students were also more likely to incorporate content knowledge in their reasoning patterns rather than participants with more naive understandings of genetics (Sadler & Zeidler, 2005b). Resultantly, Sadler and Donnelly (2006), as well as Sadler and Fowler (2006), have proposed a "Threshold Model of Content Knowledge Transfer" to explain differences in participants' discursive ability to evaluate evidence, assess alternative perspectives, and form counter-positions is believed to increase.

The data discussions in [Chapters 4, 5, and 6](#) show how effective this student interest-SSI based curricular and pedagogical intervention was at developing undergraduates' ability to evaluate scientific information. It was also found that having the opportunity to explore SSI and influence one's educational environment were important factors in promoting undergraduates skills and interest towards

careful investigation before the decision of well drilling was made? Why? What could they do to

evaluating scientific information. Further, it was found that the undergraduate participants in this study reevaluated their initial beliefs, which resulted in the majority of students forming new perspectives. However, it is not known how students' conceptual understanding of microbiology may have influenced the reported findings. Therefore, although the data from this doctoral dissertation have provided several important insights, it should be noted that there are other complex variables that may have influenced the data that need to be further investigated.

Research on SSI-based Curricular Interventions

This section reviews studies that have been identified as SSI-based curricular interventions. As with the 'Research on the Relationship of NOS Conceptualizations and SSI' and 'Research on Evaluating Socio-scientific Information' sections, I discuss relevant research chronologically after a brief introduction. Additionally, I conclude my review of SSI-based curricular interventions by summarizing the relevance of these studies to this doctoral dissertation.

Unlike the literature, documenting the need to include societal, ethical, epistemological, conceptual, and technological orientations to foster the public's scientific literacy, the design, implementation, and examination of SSI-based curricular frameworks is a relatively new area of research (Sadler, 2004; Zeidler, Sadler, Applebaum, & Callahan, 2009). Zeidler and Sadler (2008) and others have claimed that there are several distinguishing characteristics to a SSI-based learning model with respect to other science teaching approaches. These distinguishing aspects have been identified as examining alternative scientific and societal

make you believe? 4) Are you sure about your answers? Why?

viewpoints related to real-world issues. Yet, students' examination of these issues should be done in a way that facilitates social and personal reflection upon an individual's science content and informal (belief-based) knowledge domains (Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009)

Those studies that have been identified as SSI interventions have mainly examined primary and secondary student learners and have varied in scope and effectiveness (e.g., Jimenez-Aleixandre & Pereiro-Munoz, 2002; Patronis, Potari, & Spiliotopoulou, 1999; Walker & Zeidler, 2007). This section has reviewed those SSI-based interventions that have been reported in the literature. Two of these studies have already been discussed in the 'Research on the Relationship of NOS Conceptualizations and SSI' section of this Chapter. Specifically, Khishfe and Lederman (2006) researched the effects of two explicit approaches to infuse NOS conceptualizations into a 9th grade, 6-week global warming unit. Walker and Zeidler (2007) investigated high-school students' debate skills and NOS conceptualizations on genetically modified foods after a 7-week SSI-based learning exercise. Additionally, the STS studies in the 'Research on Evaluating Socio-scientific Information' section were also curricular interventions. For example, Kortland (1996) assessed 8th graders decision-making abilities after classroom discussions and learning activities centered on recycling issues. McGinnis and Simmons's (1999) case-study examined the effects of a STS intervention designed to promote practicing teachers' implementation of scientific issues that have several perspectives and societal implications. Finally, Fang-Ying (2004) investigated how 10th graders used theory and evidence during a 13-week STS curricular intervention focused on a local

underground water issue. I have summarized the remaining SSI-based interventions in the following subsections chronologically.

Patronis, Potari, and Spiliotopoulou (1999)

Patronis, Potari, and Spiliotopoulou (1999) examined the effects of a curricular intervention on 14-year-old students' informal reasoning through argumentation. Specifically, Patronis, Potari, and Spiliotopoulou (1999) intervention focused on the effects of building a new road in the area. Consequently, this investigation resembled others' research designs that have focused on local SSI (e.g., Jimenez-Aleixandre & Pereiro-Munoz, 2002; Fang-Ying, 2004; Wu & Tsai, 2007). This study was also unique, as the implementation of the intervention took place in a math, not science, learning environment. Patronis, Potari, and Spiliotopoulou (1999) argued that this curricular intervention was an interdisciplinary approach to teach participants that science and mathematics are not value free.

Patronis, Potari, and Spiliotopoulou's (1999) intervention was a sequence, where students first reflected upon their opinions individually, then over several months worked in groups and as a class to create a final road design proposal for the city council. The ethnographic design of this study involved the teacher as a member of the research group and researchers as participant observers. The authors transcribed and analyzed field notes as well as classroom videotapes and audiotapes. The systematic qualitative, semi-quantitative, and quantitative approach Patronis, Potari, and Spiliotopoulou (1999, p. 749) used for analyzing students arguments was similar to Wu and Tsai's methodical framework (2007, p. 1170).

Patronis, Potari, and Spiliotopoulou (1999) interpreted their data to suggest students arguments were based on intuitive ideas; only in a few cases did students attempt to use school knowledge of math and science. However, the authors also noted that the nature of the problem was open-ended. Given that there was no formula or ideal methodological approach to designing a new road, the students' justifications of their proposals could not be judged on the basis of their being scientifically right or wrong (Patronis, Potari, & Spiliotopoulou, 1999, p. 752). Rather, Patronis, Potari, and Spiliotopoulou (1999) recognized that participants had to convince each other that their proposal was the optimal solution. Consequently, the authors were encouraged that students' arguments referred to personal experiences that were economic, ecological, and humanistic in nature.

Jimenez-Aleixandre and Pereiro-Munoz (2002)

Similar to Kolsto (2001b), Tytler, Duggan, and Gott (2001), and others, Jimenez-Aleixandre and Pereiro-Munoz (2002) examined a real local socio-scientific issue (Patronis, Potari, & Spiliotopoulou, 1999; Fang-Ying, 2004; Wu & Tsai, 2007). Specifically, Aleixandre and Pereiro-Munoz (2002) investigated classroom argumentation in the context of a real life wetland environmental management socio-scientific issue. These researchers focused on how 38, 11th grade, students would use relevant conceptual knowledge as they evaluated different sources of information. Over 2 months, 16 sessions, students analyzed different dimensions (such as landscape values, plant or animal communities, and the projected drainpipes) and produced a report about the predicted impact of the proposed project. Jimenez-Aleixandre and Pereiro-Munoz (2002) transcribed and analyzed their data from audio

and video recordings of the learning sessions, small group discussions, field notes, and collective reports using Toulmin's (1958) and Walton's (1996) models of argumentation.

Jimenez-Aleixandre and Pereiro-Munoz's (2002) findings suggested that this type of learning environment promoted students' application of their conceptual knowledge in a real-world context. That is, the authors have argued that participants were not just passive 'knowledge consumers', but developed their scientific literacy skills in a situation they could encounter in life. Jimenez-Aleixandre and Pereiro-Munoz (2002) findings have also supported other's claim that conceptual knowledge and personal value judgments influence how individuals informally reason scientific information (Fleming, 1986a; Sadler, Chambers, & Zeidler, 2004; Sadler & Zeidler, 2005a, b; Zeidler, Walker, Ackett, & Simmons, 2002; Zeidler & Schafer, 1984).

Zohar and Nemet (2002)

As with Jimenez-Aleixandre and Pereiro-Munoz (2002), Zohar and Nemet (2002) assessed the effects of a SSI-based curricular intervention on how students used their conceptual knowledge when constructing arguments. In this study, 9th graders were divided into experimental (N = 99) and comparison (N = 87) groups. Similar to Sadler and Zeidler (2005a, b) and others, Zohar and Nemet (2002) used genetic engineering to examine how participants' conceptual knowledge of this socio-scientific issue affected their informal reasoning (Sadler & Fowler, 2006; Sadler & Donnelly, 2006). Specifically, students in the experimental group learned concepts through a Genetic Revolution unit where students in the comparison group learned concepts by a conventional method (through a book, with the same genetic

information as the experimental unit). The Genetic Revolution - Discussions of Moral Dilemmas unit (or Genetic Revolution for short) was part of a 'Thinking in Science Classrooms' project, where learning activities were designed to foster higher-order thinking skills and scientific argumentation (Zohar, 1996; Zohar, Weinberger, & Tamir, 1994). Both groups studied genetic concepts for 12 lessons.

Zohar and Nemet (2002) reported no significant differences between groups in pretest questionnaires prior to a 12-week socio-scientific genetic issues intervention. Measurements of genetic content knowledge came from a pre and post-test. Specifically, a General Test of Genetics Knowledge (composed of 20 multiple-choice items) as well as written responses from dilemmas related to genetics and everyday life, assessed participants' conceptual knowledge. The analytic inductive categories used by Zohar and Nemet (2002) to analyze the extent to which students considered biological knowledge, were unique to this study. However, Zohar and Nemet's (2002) argumentation categories of single, simple, and more complex justifications were based on Resnick, Salmon, Zeitz, Wathen, and Holowchak (1993) and Pontecorvo and Girardet (1993). In all cases, Zohar and Nemet (2002) claimed the coded data had an inter-rater reliability of at least 85%.

Zohar and Nemet's (2002) found several significant differences between groups. In particular, the authors contend that prior to instruction; most students were able to formulate simple arguments, counterarguments, and rebuttals that they used. Resultantly, Zohar and Nemet (2002) have suggested that argumentation skills were present initially but not fully mature. The authors' post analysis of students' discourse, indicating improvements in quality and transferability of participants'

reasoning skills, was greatest in the experimental group. Specifically, they noted that the frequency of students who did not consider biological knowledge was higher in the comparison group than the experimental group (30.4% versus 11.3%, respectively). Likewise, Zohar and Nemet (2002) also found that the frequency of students who correctly considered specific biological knowledge was higher in the experimental group than the comparison group (53.2% vs. 8.9%, respectively). Zohar and Nemet (2002) reached the conclusion that an explicitly instructive SSI-based curricular intervention can positively affect students' conceptual understandings as well as informal reasoning skills.

Barab, et al. (2007)

Barab, et al. (2007) examined 4th graders responses to an aquatic habitat simulation with a layered socio-scientific narrative. In particular, 28 students who were labeled as gifted were observed over 2 weeks. During this time, participants 1) completed a pretest and posttest examination, 2) were subjected to videotaping during class, and 3) were interviewed. Qualitative data were transcribed and coded into 3 main categories: narrative²⁷, inscription²⁸, and inquiry²⁹. The authors also claimed their data interpretations underwent inter-rater reliability validation as well as member-checking³⁰.

²⁷ Narrative referred to whether students' activities during the computer lab sessions demonstrated evidence that subjects were actually engaged in the aquatic habitat simulation (Taiga) narrative.

²⁸ Inscription measured students' involvement in reading and creating graphs, deconstructing graphs, as well as examining representations of scientific process such as erosion.

²⁹ Inquiry was described as a process where students' developed an informed response by making hypotheses, collecting evidence, formulating explanations, challenging prior understandings, and communicating knowledge to others.

³⁰ Gall, Gall, and Borg, (2002, p. 465) have defined member-checking as the process where participants review selected sections of their raw data and confirm their data have been accurately reported. Participants also validate the researcher's interpretations of data for accuracy and completeness (Gall, Gall, & Borg, 2002, p. 465).

In general, the authors found that participants showed statistically significant gains in insightfully completing work, engagement, and skillfully reasoning their perspective. Barab, et al. (2007) also claimed that their aquatic habitat simulation socio-scientific narrative fostered learners' perceptual, conceptual, and ethical understandings of science.

The authors used their findings to further characterize the SSI-based framework. Specifically, Barab, et al. (2007) identified 4 possible elements that can impact the implementation of SSI-based interventions: external resources, teacher facilitation, social negotiation, and prior experience. The authors have claimed that these 4 components are essential to structurally coherent SSI-based learning curricula. However, Barab, et al. (2007) also acknowledged the need to further evolve the 4 elements they believe to be foundational to SSI-based frameworks by implementing and examining the affects of other interventions. This student interest SSI-based curricular and pedagogical intervention has extended the research by Barab, et al. (2007). That is this doctoral dissertation's SSI-based framework not only included these 4 elements, but also examined these 4 fundamental components in a postsecondary general microbiology curriculum.

Keselman, Kaufman, Kramer, and Patel (2007)

Keselman, Kaufman, Kramer, and Patel (2007) described a 4-week middle-school science intervention where the topic of HIV was used to develop students' critical reasoning. Two 7th grade classes from an inner city school serving primarily low socioeconomic status African American and Hispanic students participated in this SSI-based intervention. There were two central activities to this intervention,

critical reasoning and science writing endeavors. One class implemented both critical reasoning and writing activities (CR&W), while the other class only engaged in critical reasoning activities (CR). In total, there were 61 participants, 22 students were from the CR&W class and 24 students were from the CR group. Additionally, 15 participants from an 8th grade class, which never experienced this 7th grade curriculum, served as a comparison group. In particular, these 8th graders were used to see if one year of adolescent development alone could produce improvement equal to that demonstrated by participants of this SSI-based intervention.

Keselman, Kaufman, Kramer, and Patel's (2007) SSI-based intervention included teacher-led lectures, student-led small-group presentations, and critical reasoning activities for both groups. In addition, CR&W participants worked in groups of three to four to complete writing activities based on a realistic scenario³¹. The CR students spent this time engaged in additional reasoning activities that focused on the global AIDS epidemics. All 46 CR&W and CR participants completed the Center for Disease Control (CDC) Secondary School Risk Survey (DuRant et al., 1992) at the start and end of the 4-week intervention. This pre/post questionnaire consisted of 17 yes/no/not sure questions about HIV/AIDS. Participants were also asked to respond to the HIV/AIDS Conceptual Understanding Test prior to and at the end of the 4-week intervention. This instrument, consisting of 6 essay questions, was developed on the basis of a semi-structured interview protocol from a prior study by Keselman, Kaufman, and Patel (2004). The purpose of the HIV/AIDS Conceptual Understanding Test was to assess students' understanding of the

biological concepts (such as viruses, infection, and the immune system). The 8th graders, who served as a comparison group, only took the CDC Secondary School Risk Survey and HIV/AIDS Conceptual Understanding Test once. Students' understanding of the nature of HIV, the mechanism of HIV infection, and disease progression was coded into one of three conceptual models: naive³², intermediate³³, and advanced³⁴.

Keselman, Kaufman, and Patel's (2004) results suggested that both CR&W and CR groups improved their factual knowledge of HIV and understanding of HIV biology between pre- and posttest. However, the authors found greater improvements in the CR&W groups' biological understanding. Keselman, Kaufman, and Patel (2004) also claimed that the CR group did not demonstrate the same level of reasoning growth on the HIV/AIDS Conceptual Understanding Test as the CR&W participants. Although it should be noted that the HIV/AIDS Conceptual Understanding Test strongly resembled the writing tasks participants from the CR&W group completed, which may have affected reported outcomes. In general, Keselman, Kaufman, Kramer, and Patel (2007) claimed that this SSI-based intervention strengthened participants' conceptual understanding of HIV, by providing opportunities for students to reason social and scientific issues related to HIV.

Wong, Hodson, Kwan, and Yung (2008)

³¹ This scenario described a young woman who was seeking more information about her risk of contracting HIV from her boyfriend (Keselman, Kaufman, & Patel, 2004, p. 851).

³² The naive model was defined as intuitive everyday concepts of health and disease.

³³ The intermediate model necessitated understanding of HIV on a systemic level.

³⁴ The advanced model required subjects to have a basic understanding of HIV-relevant biological structures and processes on the cellular level.

Zeidler, Sadler, Simmons, and Howes (2005) and others have argued that there is an important distinction between the STS movement of years past and the SSI-based framework (Zeidler, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2009). Specifically, Zeidler, Sadler, Simmons, and Howes (2005) have argued that STS educational frameworks have not addressed the epistemological growth of learners. However, proponents of the SSI-based movement have contended that their progressive framework has considered how science-based issues are related to learners' epistemological beliefs (Zeidler, Sadler, Simmons & Howes, 2005). Additionally, researchers have noted that a salient feature of any SSI-based intervention provides individuals with opportunities to applying their conceptual and belief based knowledge in decision-making scenarios (Kortland, 1996; Walker & Zeilder, 2007). Given these definitive parameters, it is questionable whether the recent study by Wong, Hodson, Kwan, and Yung (2008) would be classified as a SSI-based intervention. However, given that the focus of Wong, Hodson, Kwan, and Yung's (2008) investigation was similar to a focal point of this doctoral dissertation, I have included the significant findings of their study in this 'Research on SSI-based Curricular Interventions' section.

Wong, Hodson, Kwan, and Yung (2008) created and assessed the effects of a 4-hour instructional experience about the severe acute respiratory syndrome (SARS) socio-scientific issue. Similar to one of the sub-research questions in this doctoral dissertation, the authors were interested in understanding the affects of their intervention on postsecondary learners' NOS conceptualizations. The authors also

described their instructional intervention as having explicit discussions about NOS conceptualizations.

Specifically, Wong, Hodson, Kwan, and Yung (2008) examined 57 student-teachers' pre and post responses to a modified version of the Views of Nature of Science Questionnaire (VNOS-C) by Lederman, Abd-El-Khalick, Bell, Schwartz (2002). Additionally, Wong, Hodson, Kwan, and Yung (2008) interviewed 38 of these participants to confirm their data analyses. These researchers focused on NOS conceptualizations related to 1) the inseparable links between science and society, culture, and politics, 2) how science and technology influence each other, and 3) the processes of authentic scientific inquiry including the subjectivity of human interpretations (Wong, Hodson, Kwan, & Yung, 2008). Consequently, it can be argued that this investigation examined alternative scientific and societal viewpoints related to a real-world issue.

However, within the 4-hour treatment it is not clear how well students socially or individually reflected upon their conceptual knowledge and epistemological beliefs about the NOS. For instance, Wong, Hodson, Kwan, and Yung (2008) have inferred from their data that several participants demonstrated a more sophisticated understanding of the NOS. However, these researchers also found that when asked to reflect upon their VNOS-C responses many participants' interview responses contradicted their initial answers. This could have suggested that participants were still synthesizing their understanding and beliefs about the NOS. Additionally, after participants viewed the 2-hour interactive video session, they spent 2 hours in a 'reflective workshop'. This workshop was initially designed to provide learners with

opportunities to reflect upon their understanding of the NOS. However, Wong, Hodson, Kwan, and Yung (2008) found that this self-directed group work did not result in positive findings. Rather, the authors reported that participants found this activity to be confusing, which resulted in only a few demonstrations of reflection upon NOS conceptualizations. Further, this investigation did not ask participants to use their understanding of the epistemology of science in a decision-making context.

Given the description and focus of this intervention, it is not clear whether the Wong, Hodson, Kwan, and Yung (2008) study would be viewed under the SSI-based framework. That is, despite the authors' use of the SARS socio-scientific issue that potentially exposed learners to a number of discrepant scientific, social, and/or moral viewpoints, it remains unclear how this 4-hour intervention may have fostered participants' reflection upon their epistemological beliefs. Zeidler, Sadler, Simmons, and Howes (2005) and others have acknowledged this is an important characteristic of this progressive SSI-based framework (Zeidler, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2009). Additionally, researchers have noted that a salient feature of successful SSI-based interventions include opportunities for learners to practice applying their knowledge through the use of decision making contexts (Kortland, 1996; Walker & Zeidler, 2007). Given that participants in the Wong, Hodson, Kwan, and Yung (2008) investigation were not asked to apply their understanding of the NOS in a decision-making context, could be used against this intervention being placed within the SSI-based framework. The authors' examination of postsecondary learners' scientific epistemological conceptualizations in a case-study, has direct relevance to the findings reported in Chapters [5](#) and [6](#) of this doctoral dissertation.

Zeidler, Sadler, Applebaum, and Callahan (2009)

Zeidler, Sadler, Applebaum, and Callahan (2009) assessed changes in 23, 11th and 12th grade, students' reflective judgment in response to a year long SSI-based curriculum that utilized Kolsto's (2001a, p. 292) 8-topic minimum model. Specifically, 10 students from 2 honors and 2 regular Anatomy and Physiology classes were randomly selected to participate in this investigation. Of the initial 40 participants, only 23 completed both pre and post-test interviews. One of the honors and regular Anatomy and Physiology classes served as comparison groups, where learners were taught mainly by an anatomy and physiology textbook. Both the experimental and comparison groups received explicit NOS instruction and the same instructor taught all 4 classes. However, the experimental group was subjected to a SSI-based intervention based upon Kolsto's (2001a) 8-topic minimum model³⁵.

Zeidler, Sadler, Applebaum, and Callahan (2009) used the Prototypic Reflective Judgment Interview (PRJI; King & Kitchner, 1994; 2004) to measure learners' reflective judgment. The PRJI required an interviewer to present participants with an ill-structured problem. After the participant read the brief scenario, the interviewer asked seven standard questions that encouraged the participant to describe his/her position on the issue as well as a justification for that position. The PRJI scenarios used in this project were related to chemical additives in food, religion and science, and genetic determination of alcoholism. Initially, interview responses (to all seven main questions) for each of the three scenarios were

³⁵ This 8 topic minimum model included: 1) science-in-the-making and the role of consensus in science; 2) science as one of several social domains; 3) descriptive and normative statements; 4) demands

qualitatively analyzed for correspondence with the seven developmental stages postulated by the Reflective Judgment Model. Three raters, who were familiar with the PRJI protocols, randomly selected three transcripts to independently code. All data were blindly coded and raters sought validation of their assessments by collaborative comparisons. Comparisons of pre and posttest qualitative data indicated changes in a single student's reflective judgment over the course of the school year.

Zeidler, Sadler, Applebaum, and Callahan (2009) found that students who participated in the SSI-based intervention showed evidence of epistemological development. This epistemological development was not found among the comparison group of students. The authors also claimed that participants, who experienced the SSI-driven curriculum, learned more basic anatomy and physiology concepts than their peers in the comparison group. Zeidler, Sadler, Applebaum, and Callahan (2009) also felt that their data supported the importance of using personally relevant SSI. However, their assessment of motivational factors that engaged learners was not explicitly examined. Zeidler, Sadler, Applebaum, and Callahan (2009) have also acknowledged that more work needs to be done that directly examine NOS orientations under an SSI framework. That is the authors have recognized that although parallels exist between more advanced stages of reflective judgment and more sophisticated views of NOS, there were also findings that needed to be investigated further. For instance, the authors recognized that participants' knowledge of the tentative NOS might not be conceptualized the same way by quasi-reflective and reflective thinkers. Consequently, the findings discussed in [Chapters 4,](#)

for underpinning evidence; 5) scientific models as context-bound; 6) scientific evidence; 7) suspension

5, and 6 have offered several important empirical insights, to extend what is known about learners' NOS conceptualizations in response to a SSI-based intervention.

Summary

In summary, designing and examining SSI-based curricular frameworks is a relatively new area of research (Sadler, 2004; Zeidler, Sadler, Applebaum, & Callahan, 2009). Zeidler and Sadler (2008) and others have claimed that there are several distinguishing characteristics to a SSI learning model with respect to other science teaching approaches. These distinguishing aspects have included examining alternative scientific and societal points of view related to real-world issues. Further, students' examination of these issues should be done in a way that facilitates social and personal reflection upon an individual's science content and informal (belief-based) knowledge domains (Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009).

Those studies that have been identified as SSI interventions have mainly examined primary and secondary student learning and have varied in scope and effectiveness (e.g., Jimenez-Aleixandre & Pereiro-Munoz, 2002; Patronis, Potari, & Spiliotopoulou, 1999; Walker & Zeidler, 2007). For instance, Jimenez-Aleixandre and Pereiro-Munoz (2002) showed that a 2 month, 16-session, real-life environmental socio-scientific issue could promote students' use of relevant conceptual knowledge. Their results suggested that students developed skills to analyze different dimensions of data and demonstrated integration of their conceptual knowledge to synthesize and evaluate potential solutions. However, Walker and Zeidler (2007) reported that

of belief; and 8) scrutinizing science-related knowledge claims.

participants, at the end of a 7-week SSI-based learning exercise, incorrectly used factual-based knowledge in their reasoning. These authors found that although students possessed an understanding of the tentative and social aspects of scientific discovery, they justified their claims by using factual-based knowledge. This resulted in high-school students disclosing their lack of conceptual understanding (Walker & Zeidler, 2007). Both studies used Toulmin's (1958) model of argumentation to assess students' arguments and warrants. However, Walker and Zeidler (2007) used the Web-based Science Environment (WISE)³⁶ to develop students' Nature of Science (NOS) conceptualizations by designing internet-based activities centered on the socio-scientific issue of genetically modified foods. Jimenez-Aleixandre and Pereiro-Munoz's (2002) SSI-based intervention was a real-life environmental issue that provided authentic problem solving activities performed by experts in the field.

These findings have suggested that further research is needed to identify those most salient characteristics of successful SSI-based curricular designs. Jimenez-Aleixandre and Pereiro-Munoz (2002) have claimed that the real-world context of their learning activity was a cornerstone for developing students' scientific literacy. However, neither Jimenez-Aleixandre and Pereiro-Munoz's (2002) nor Walker and Zeidler (2007) measured learners motivational interest. Rather, Walker and Zeidler (2007) acknowledged that their socio-scientific issues approach lacked opportunities for students to apply their NOS conceptualizations in a decision-making context. Consequently, it can be argued that the complexities of SSI-based interventions have not fully assessed the variables that contribute to the differing success of SSI-based

³⁶ WISE educational activities were designed to include alternative perspectives of scientific

interventions. Given the diversity and early stages of SSI-based curricular models, more research is needed to understand what components are most central and effective in developing students' scientific literacy.

Other studies that have investigated SSI-based interventions, discussed in detail in this section, included Barab, et al. (2007) who examined 4th graders responses to an aquatic habitat simulation with a layered socio-scientific narrative. Keselman, Kaufman, Kramer, and Patel (2007) described a 4-week middle-school science intervention where the topic of HIV was used to develop students' critical reasoning. Khishfe and Lederman (2006) investigated the effects of two approaches to infuse NOS conceptualizations into a 9th grade, 6-week global warming unit. Patronis, Potari, and Spiliotopoulou (1999) studied the outcome of a several month long local environmental socio-scientific project on middle school students' informal reasoning. Zohar and Nemet (2002) assessed the effects of a twelve-week socio-scientific genetic issues intervention on 9th graders' conceptual knowledge and argumentation skills. Most recently, Zeidler, Sadler, Applebaum, and Callahan (2009) assessed changes in 11th and 12th graders reflective judgment in response to a year long SSI-based curriculum that utilized Kolsto's (2001a, p. 292) 8-topic minimum model. However, missing from this research has been SSI-based curricular interventions for postsecondary learners.

The study by Wong, Hodson, Kwan, and Yung (2008) could arguably be one exception. As mentioned earlier, Wong, Hodson, Kwan, and Yung (2008) were interested in understanding the affects of their 4-hour instructional experience about

phenomena (Linn, Clark, & Slotta, 2003; Walker & Zeidler, 2007).

SARS on student-teachers' understanding of the NOS. Although it can be argued that this intervention included alternative scientific and societal points of view related to a real-world issue, it was not clear if participants reflected upon their conceptual knowledge and/or epistemological beliefs about the NOS. Additionally, this investigation did not ask participants to use their understanding of the NOS in a decision-making context. Zeidler, Sadler, Simmons, and Howes (2005), as well as others, have acknowledged these are important characteristics of this progressive SSI-based framework (e.g., Kortland, 1996; Walker & Zeidler, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009). Therefore, it can also be argued that the explicit NOS intervention used by Wong, Hodson, Kwan, and Yung (2008) was more similar to the comparison groups in the Zeidler, Sadler, Applebaum, and Callahan (2009) study, which did not receive the SSI-based treatment.

In general, it can be argued that research on SSI-based interventions is relatively new. Empirical research has suggested that a SSI-based framework can support learners' functional scientific literacy. However, the characterization of the most salient features of SSI-based interventions has yet to be fully described. Further, there is a gap in the literature with respect to SSI-based interventions assessing post secondary learners. Therefore, this doctoral dissertation has significantly extended the empirically based knowledge of designing and implementing SSI-based interventions.

Summary

In the first section of this chapter, I have elaborated on many of the research studies used to introduce the theoretical SSI-based framework in [Chapter 1](#).

Specifically, I referenced Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) SSI-based framework. Resultantly, in the first subsection I described how Zeidler, Sadler, Simmons, and Howes (2005) have envisioned NOS, discourse, cultural, and case-based issues promoting students' scientific literacy. In the second part of this section I concentrated on expanding the Zeidler, Sadler, Simmons, and Howes (2005, p. 361) SSI-based framework, by showing how a student interest-focus can be used to further promote scientific literacy.

After my review of literature, related to the theoretical framework of this doctoral dissertation, I summarized studies with direct relevance to the guiding research question. Specifically, in the second section of this chapter I evaluated research examining participants' NOS conceptualizations within a SSI-based context. I used the third section of this chapter to focus on literature related to how participants' evaluate scientific information. In the fourth section, I reviewed empirical studies that have examined the effects of SSI-based interventions.

In general, my review of relevant literature discussed in [Chapter 2](#) has suggested there is a need to know more about student interest SSI-based curricular and pedagogical interventions. Throughout my literature review, I also identified several studies that have directly influenced my methodological approach, which are outlined in [Chapter 3](#). For example, in the 'Research on the Relationship of NOS Conceptualizations and SSI' section I discussed the Sadler, Chambers, and Zeidler (2004) investigative instrument, which I referenced as being the basis of the article exercise used in this doctoral dissertation.

Additionally, the research findings that I report in [Chapters 4](#) and [5](#) and summarize in [Chapter 6](#) are also connected to the studies reviewed throughout [Chapter 2](#). For instance, in the ‘Research on Evaluating Socio-scientific Information’ section I discussed how both Kortland’s (1996) and Fang-Ying’s (2004) interpretations of their data left these authors contemplating how to more effectively develop learners’ skills to make more informed decisions about scientific issues that affect society. In both cases I connected Kortland’s (1996) and Fang-Ying’s (2004) conclusive remarks to the findings reported in this doctoral dissertation. In particular, I alluded to empirical data that have suggested this student interest SSI-based curricular and pedagogical curriculum developed undergraduates’ skills at finding, interpreting, and discussing alternative perspectives. I also discussed how undergraduates reevaluated their initial beliefs about science issues affecting society. These data are reported in [Chapters 4](#), [5](#), and [6](#). Further, I have referred to reported findings that confined my inferential claims. For example, in my discussion of the significant findings reported by Sadler and Donnelly (2006), I referenced a limit of this doctoral dissertation in not examining participants’ content knowledge. I explicitly acknowledge this limitation in [Chapters 4](#) and [6](#). Consequently, the studies reviewed throughout this chapter have also served to foreshadow the discussions and reported findings in [Chapters 3](#), [4](#), [5](#), and [6](#).

CHAPTER 3: Design & Methodology

Overview

This chapter begins with an explanation of the conceptual framework model that guided this study. The model serves to visualize how this investigation has contributed to the current body of literature and introduces the analytical framework. The next section delineates the research setting by describing the lecture and laboratory components of this investigative case-study, examining a student interest-socio-scientific issues (SSI) based circular and pedagogical intervention. The discussion of this innovative learning environment also includes those changes that were made from the 2007 pilot study. A depiction of the undergraduate participants ensues. This section is followed by a discussion of the pedagogical practices that were used to engage students' interest in science and develop their skills to informally reason scientific information. Next, the instrumentation is discussed, outlining the assessment tools and the construct(s) (student interest, evaluation of scientific information, and/or NOS conceptualizations) they measured. The procedural framework then explains the data gathering and analyses procedures used in this investigation to address the main research question. At the end of the analyses procedures, a summary table can be found that illustrates how each instrument was used to analyze students' interests, evaluation of scientific information, and NOS conceptualizations. This is followed by discussions of issues related to ethics and trustworthiness. This chapter concludes by summarizing the discussion in this chapter as well as foreshadowing of [Chapters 4](#), [5](#), and [6](#).

Conceptual Framework Model

The theoretical framework of this case-study falls under the socio-scientific issues (SSI) science education initiative. The research studies that were examined in [Chapter 2](#) on student interest, the evaluation of socio-scientific information, and NOS conceptualizations are used to explain the methodological framework in this section.

SSI Conceptual Framework Model

The literature in [Chapter 2](#) has argued for the socio-scientific perspective as a useful instructional framework for science education. The research articles presented in [Chapter 2](#) have discussed several reasons for including social dilemmas in curriculums to teach people science. Some of these reasons were contingent upon data that has suggested participants do not frequently engage in comprehensive reflection and evaluation of scientific information about today's scientific advancements (Sadler, 2004, p. 528). For example, Sadler, Chambers, and Zeidler (2004) found that almost half of their student sample could not identify and describe data. They also showed, as with Zeidler, Walker, Ackett, and Simmons (2002) that students tended to dichotomize personal beliefs and scientific knowledge as well as compartmentalize scientific evidence when making personal decisions. Tytler, Duggan, and Gott's (2001) interpreted their data to show participants were unable to draw on content knowledge to strengthen their positions. Thus, the research has emphasized several reasons for why science learning environments should include real-world SSI.

The literature review in [Chapter 2](#) has also highlighted some SSI based curricular frameworks that have been successful in linking science to students' lives. For instance, Jimenez-Aleixandre and Pereiro-Munoz (2002) showed that a 16-week

real life environmental socio-scientific issue intervention promoted 11th-grade students use of relevant conceptual knowledge. Their results have suggested that students developed skills to analyze different dimensions of data and demonstrated integration of their conceptual knowledge beyond the surface level. Zohar and Nemet's (2002) data, which assessed the effects of a 12-week socio-scientific genetic issues intervention on 9th-grade students, revealed several positive outcomes for those students who took part in the SSI-curricular treatment with respect to the control group. For example, students more frequently and correctly referred to their biological knowledge as well as indicated transferability of their knowledge to other everyday life contexts. Thus, both Jimenez-Aleixandre and Pereiro-Munoz (2002) as well as Zohar and Nemet (2002) have concluded that an explicit SSI curricular intervention can positively affect students' conceptual understandings as well as informal reasoning skills.

However, the literature discussed in [Chapter 2](#) has also reinforced the need to further test and design SSI based curricular interventions. For instance, Tytler, Duggan, and Gott (2001) showed a sample of public citizens was unable to draw on content knowledge to strengthen their positions. These authors concluded that schools should provide students chances to question and manipulate different sorts of real data to become more functionally literate in science. Walker and Zeidler (2007) indicated that high-school students; at the end of a 7-week, socio-scientific issue based learning exercise, incorrectly used factual-based knowledge in their reasoning. As a result, Walker and Zeidler (2007) deduced that SSI based curricular interventions should include opportunities for learners to informally reason their

perspective(s). Kortland (1996), examining another SSI-based intervention, asked 8th-graders questions about recycling issues. This study showed students' failed to consider alternative perspectives, which was correlated to participants' narrow perceptions of the positive benefits recycling. Disappointed in the learning results from his experimental learning environment, Kortland (1996, p. 688) has claimed learning environments should be created to explicitly focus on fostering decision-making judgments about alternative perspectives related to science issues affecting society.

Additionally, there are some studies that have required further analyses. For instance, Sadler and Fowler's (2006) investigation needed more data on opportunities participants may have had to practice justifying their perspectives on an alternative science issue while developing their contextual understanding. The Walker and Zeidler (2007), Kortland (1996), as well as Sadler and Fowler (2006), investigations are just a few of examples that were discussed in [Chapter 2](#), which have supported the need to further investigate and develop SSI based learning environments.

Zeidler (2003) and Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) model of a SSI based framework is one view of how social dilemmas tie to science. Kolsto's (2001a) eight topic minimum model would be another. [Figure 1](#) depicts Zeidler (2003) and Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) functional scientific literacy framework.

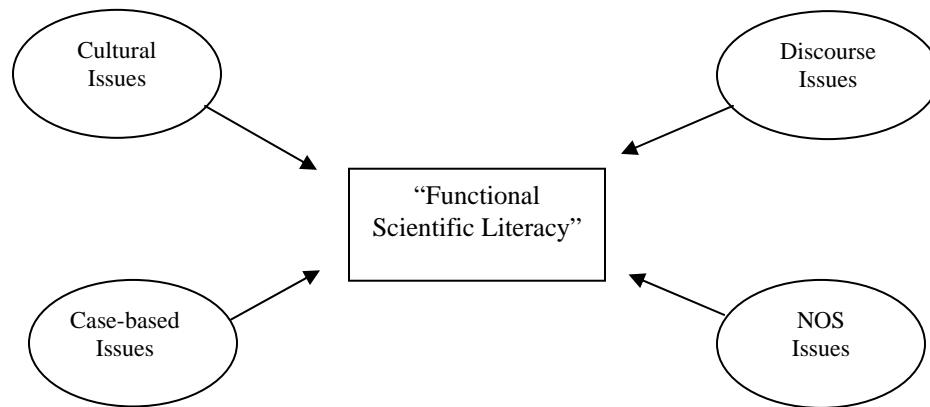


Figure 1. This figure is a simple illustration of Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes’s (2005, p. 361) model of a SSI based framework to achieve functional scientific literacy.

Functional science literacy in this model has been characterized by an understanding of 1) Nature of Science (NOS) issues, 2) classroom discourse issues, 3) case-based issues, and 4) cultural issues (Zeidler, Sadler, Simmons, & Howes, 2005, p. 361; Zeidler & Keefer, 2003, p. 12). Specifically, NOS issues have been described as important for students pre-instructional views of SSI because they foster an understanding of the ways scientists select, evaluate, and reason evidence. Classroom discourse issues are believed to play a role in the development of skills to frame positions, become aware of fallacious reasoning, and consider how belief convictions influence emotions towards science issues. Case-based issues have been advocated as a way to promote awareness of how power and authority are part of the scientific enterprises while learning about commitment to issue resolution. Finally, cultural issues have been suggested to promote students respect and tolerance of dissenting

views, while realizing the impact culture has on their beliefs and normative values (Zeidler, Sadler, Simmons, & Howes, 2005, p. 362; Zeidler & Keefer, 2003, p.13).

Extension of the SSI Conceptual Framework Model

This dissertation both fits and extends Zeidler (2003) and Zeidler, Sadler, Simmons, and Howes’s (2005, p. 361) model of a SSI based framework in several ways. [Figure 2](#) illustrates how this study falls within and expands this functional scientific literacy framework.

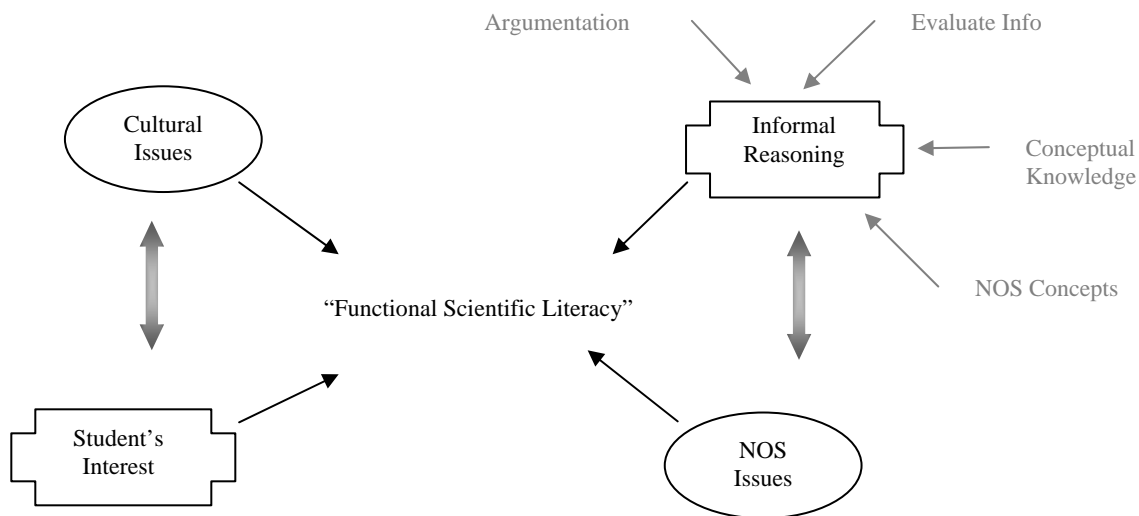


Figure 2. This figure modifies Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes’s (2005, p. 361) model to show how this dissertation study’s conceptual framework fits within the SSI initiative.

This study falls within Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes’s (2005, p. 361) model framework by facilitating a curriculum that promotes NOS conceptualizations and informal reasoning skills through case-based issues that are relevant to students culturally influenced lives. Recall that both Sadler

(2004a) and Sadler and Donnelly (2006, p. 1464) have connected informal reasoning to discourse issues. Sadler (2004a, p. 515) has also defined informal reasoning as 1) evaluation of information, 2) NOS conceptualizations, 3) conceptual knowledge and 4) argumentation. This investigation did not examine students' argumentation skills; rather this investigation was interested in the first two components of informal reasoning as defined by Sadler (2004a, p. 515). Consequently, this model has replaced Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) discourse issues component with Sadler's (2004a, p. 515) more general definition of informal reasoning.

Case-based issues have been shown to facilitate participants' integration of science into real world contexts (Keefer, 2003). In most studies that have examined Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) functional scientific literacy framework, the investigators or instructor have determined the case-based subject matter participants were asked to examine. Kolsto, et al. (2006) is the one example where students were allowed to assess an article about a socio-scientific issue of choice. The focus of this curricular and pedagogical intervention was similar to Kolsto, et al. (2006), as students identified a topic they found engaging and related it to microbes. Therefore, students' interests replaced case-based issues in the Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) model.

Cultural issues have been suggested to impact beliefs and normative values (Zeidler, Sadler, Simmons, & Howes, 2005, p. 362). It has been argued that a person's belief about his/her own scientific knowledge is not necessarily reflected by

one's ability to articulate science content or concepts formally learned (Hammer & Elby, 2002; Hogan, 2000; Sinatra, Southerland, McConaughy, & Demastes, 2003). It has also been shown that people's beliefs about science can influence their functional understanding of science knowledge to answer questions about everyday life (Toplak & Stanovich, 2003; Zeidler, 1997; Zeidler, Walker, Ackett, & Simmons, 2002). Similarly, McGinnis (2003) has reported that moral considerations can dominate one's decision-making. Resultantly, it has been acknowledged that evaluations of participants' scientific literacy should not only include students' declarative formal understanding of science³⁷, but also their open mindedness and ability to reflect upon their scientific knowledge beliefs and morals (Hand, Lawrence, & Yore, 1999; Hogan, 2000; McGinnis, 2003).

The role culture plays in an individual's functional scientific literacy needs to be further investigated in the SSI model. McGinnis (2003) is one of the few studies that examined how culture influences participants' decision-making. Focusing on the socio-scientific issue of inclusion verses exclusion in science classrooms, McGinnis (2003) found that participants did not reflect upon many of the moral issues related to inclusive classrooms.

McGinnis also recognized that culture is a multifaceted construct that can be viewed either at the macro or micro level, but consistently influences one's actions and beliefs. Students' interests may also be viewed in the context of the "pupil's voice in education" (Baram-Tsabari & Yarden, 2007). In this case, student interest has

³⁷ Declarative formal understanding includes aspects such as a students' ability to evaluate evidence and conclusions based upon their conceptual understanding of content and the epistemology of professional science (Hogan, 2000).

been associated with pragmatic as well as moral development of students by recognizing opportunities to learn about one's life develops functional skills in addition to ethics and values (Baram-Tsabari & Yarden, 2007; Davie, 1996). Therefore, personal interests are one way to further envision cultural issues.

Seiler (2006, 338) has defined student interest-focused curriculums as responsive to or emergent from student interests. This type of learning environment has been suggested to provide opportunities for students to influence their learning based upon questions, curiosities, passions, or circumstances that affect them. Researchers examining SSI have questioned if students' reasoning, emotional reactions, and NOS conceptualizations vary significantly with different social issues (Sadler & Zeidler, 2005a, 2005b; Zeidler & Schafer, 1984; Zeidler, Walker, Ackett, & Simmons, 2002). Consequently, one focus of this study was to expand the way culture has been previously envisioned in the Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) SSI model to include students' interests.

Simplification of the Extended SSI Conceptual Framework Model

However, the explanation of how this dissertation's conceptual framework falls within Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes's (2005, p. 361) functional scientifically literate model has also suggested that [Figure 2](#) can be further simplified. Using Sadler and Donnelly's (2006, p. 1464) connection of discourse issues to informal reasoning and Sadler's (2004a, p. 515) critical review of informal reasoning research connecting informal reasoning to NOS, argumentation,

conceptual knowledge, and the evaluation of information, both discourse issues and NOS issues can be combined under informal reasoning.

Furthermore, Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes (2005, p. 361) have perceived cultural issues as influencing beliefs and normative values. Considering that, a student's interest towards a science issue has included personal relevance, emotions, and values (Wade, 2001) and that Kolsto, et al. (2006) have shown how case-based investigations can include chances for students to pick socio-scientific articles relevant to their interest, case-based issues and cultural issues have been combined under students' interests. [Figure 3](#) illustrates this simplified model.

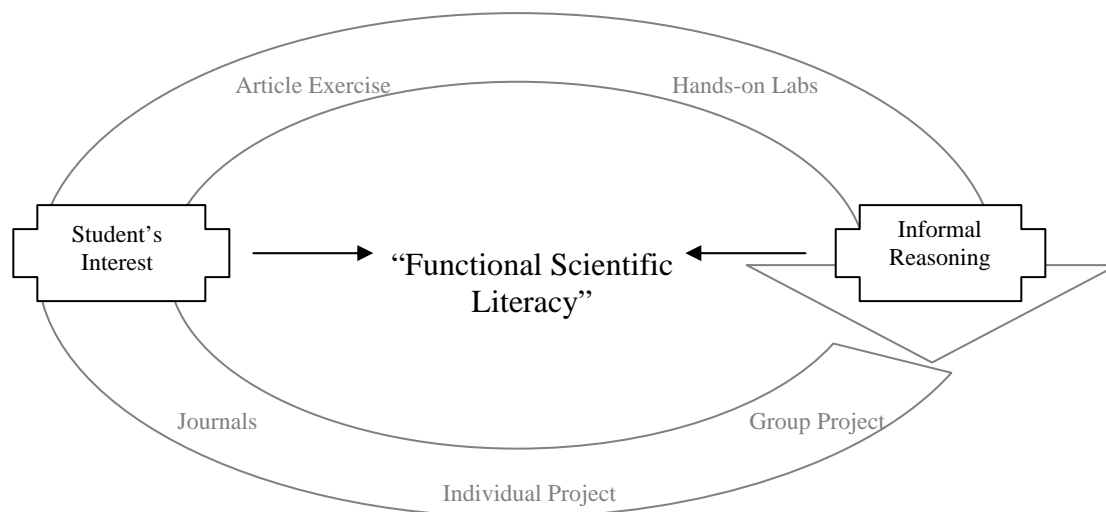


Figure 3. This figure shows how Zeidler (2003, p. 12) and Zeidler, Sadler, Simmons, and Howes’s (2005, p. 361) model can be extended and simplified to fit this dissertation’s student interest SSI-based curricular and pedagogical intervention.

In [Figure 3](#), informal reasoning integrates discourse, conceptual knowledge, evaluation of scientific information, and NOS issues. However, in this investigation only participants’ evaluations of scientific information and NOS conceptualizations were measured. Similarly, students’ interests have incorporated both cultural issues and case-based issues. In the presented theoretical framework, students’ interests are rooted in cultural issues, which can be used as case based issues to develop learners’ informal reasoning. It was found that when given the opportunity to influence their learning, participants sought to know more about how their cultural environment, perspectives, and/or lineage influenced their beliefs about microbiology issues affecting their lives. The topics chosen by students were used as socio-scientific cases. Over the course of 15 weeks students recognized how their knowledge of the issue and NOS conceptualizations resulted in more informed perspectives.

This illustration also shows the curricular activities that affected students' functional scientific literacy. Over the course of 15 weeks students researched, analyzed, and summarized alternative scientific issues written for the popular press and then reflected upon their personal beliefs regarding this information. The start and end of the semester article exercises, individual and group projects, and journals provided students with these opportunities. Additionally, several authors have reinforced the need for school science curricula to promote practice in questioning and manipulating different sorts of real data in a variety of ways to better equip students to make the most sound judgments possible regarding alternative science issues (e. g. Jimenez-Aleixandre & Pereiro-Munoz, 2002; Tytler, Duggan, & Gott, 2001; Walker & Zeidler , 2007). Over the semester, students had many hands-on laboratory experiences. This gave students a feel for some of the techniques scientists use to view life beyond the naked eye as well as to be able to analyze real data. The laboratory write-ups also asked students to reflect upon their knowledge and beliefs in relationship to the data they examined.

Description of the Context

Lecture and Laboratory Structure

The setting of this case-study was a transformative undergraduate microbiology course at a major research-extensive Mid-Atlantic university. This 4-credit course had two 75-minute lecture sessions and two 60-minute laboratory sessions. The microbiology curriculum covered general ways microbes affect the world around us. Specifically, the course helped students develop an understanding of: the unity of life, evolution, disease, antibiotic resistance, and the roles microbes

play in providing food and recycling waste, as well as how societal influences are interconnected. This course transformation was first introduced in the spring of 2007 as part of [Project Nexus](#), an NSF supported endeavor, aimed to recruit and train future upper elementary/middle school science teachers (Marbach-Ad, et al., 2008; Project Nexus, 2005). However, the transformation of this course, to focus on the goals of [Project Nexus](#), began in the summer 2006.

In the summer of 2006, I began my apprenticeship to learn about designing science educational research under the guidance of Dr. McGinnis, Marbach-Ad, and Benson as a member of the [Project Nexus](#) Research Team. At the time of this study, Dr. McGinnis was a recognized exemplary undergraduate science methods instructor, and he was also the Principal Investigator (PI) of [Project Nexus](#) (Project Nexus, 2005). Dr. Marbach-Ad was the director of the Teaching and Learning Center and senior research associate for [Project Nexus](#) (Project Nexus, 2005). Dr. Benson was not only a joint faculty to the College of Education and the College of Life Science and Chemistry, the director of the Center for Teaching Excellence, but was also a Co-Principal Investigator of [Project Nexus](#).

In the spring of 2007, I was given the opportunity to act as Dr. Benson's teaching assistant and enact the summer / fall 2006 lab pilot. Though regular meeting with the [Project Nexus](#) Research Team and Dr. Spencer I furthered my understanding of desirable pedagogical practices. For example, the [Project Nexus](#) Research Team taught me about the values of keeping a reflective journal while Dr Benson would help me revise weekly lesson plans based upon the needs of the students. These types of practices helped me become more aware of students' needs and reevaluate better

ways to promote positive learning experiences. Over the summer and through the fall of 2007, my science education knowledge continued to grow through my [Project Nexus](#) (Project Nexus, 2005) role in analyzing data and the ongoing process of improving the spring's 2008 curriculum. As a result of the institutionalization of the project at this research-extensive Mid-Atlantic university I was offered the opportunity to maintain my graduate teaching assistantship role that involved my support of Dr. Benson in course design and in teaching the two laboratory sections.

This course took place in a lecture hall and microbiology laboratory. The Enterprise Learning Management System (ELMS) and Knowledge, Exchange, Exhibition, Presentation toolkit (KEEP) were used as a way of electronically housing course materials and encouraging communication (Blackboard Inc., 2006; Carnegie Foundation, 2002). These online frameworks enabled student-teacher and student-student communication to occur outside the course. Additionally, the electronic learning environment allowed instructors to better prepare for lecture and laboratories by viewing students' questions before the course.

Although there is overlap in the content and learning goals of lecture and lab, these two components of the course also have differing dynamics. For example, both lecture and lab focused on developing students' informal reasoning through asking questions about the physical world, deciphering fact from opinion in popular press media, recognizing factors that influence social perspectives, as well as encouraging social and independent reflection upon one's knowledge and beliefs. However, the lecture had a focus upon an award winning twelve-part video series Unseen Life on Earth (Oregon Public Broadcasting, January, 2000). This video used animations and

engaging case studies to capture benefits and disease causing aspects of microorganisms. This video series included interviews, allowing students to meet the scientists carrying out investigations in laboratories and natural environments across the globe. The video clips were broken up by student centered lectures, where students often drove the direction of content topics by raising questions in groups or individually.

The weekly laboratory sessions also offered students opportunities to influence their learning but used research projects, wet labs, and student journals. In addition to the differences in learning activities, there were also differences in the teaching practices of the lecture and lab instructors. Since I was conducting this investigation, and had a greater influence on students learning in the laboratory setting, the pedagogical component of this study focused upon the teaching practices specific to the lab component of this course.

Laboratory Structure

The laboratory structure focused on giving students explicit feedback to develop their skills for critically evaluating scientific information. This educational setting also made apparent ways the learning tasks connected to everyday life. For example, during the first lab, Safety and Microscopy, a discussion of why it is important to use aseptic techniques took place. Aseptic techniques are used in hospitals as well as laboratory settings to prevent the spread of disease. However, there are also many perspectives that surround microbial resistance and how to prevent the spread of deadly diseases. During this lab, students began to learn more about this topic by testing the cleanliness of their hands and the lab counters before

and after they had been washed. This was accomplished by having the undergraduates touch the surface of rich agar media, which cultured the microbes. Students then examined their microbial growth under a microscope in the following lab session. Seeing bacterial growth both before and after cleaning, facilitated several opportunities to discuss microbial resistance in an everyday context. During this lab, students also took notes about what they were testing and their results, to be better prepared for their own hand-washing experiment later in the semester. Time was also made to discuss the limits of the conclusions that could be drawn from the assayed microbial growth. This part of the discussion raised students' awareness for the limit of the magnification power of the microscope, the skill scientists develop to interpret their data after looking at hundreds of samples, and the importance of scientific peer review.

Consequently, the laboratory exercises were one example of the SSI-based scaffold that encompassed popular science issues. At the beginning of the semester students learned about basic experimental tools, such as how to plate bacterial cultures, by following lab instructions that walked them through the essential steps of the procedure. These lab instructions required students to conceptualize appropriate controls and record their results in a way that demonstrated conceptual understanding. These early introductory labs were sequenced to help students grasp the role of microbes in more complex labs such as understanding the uses and limits of DNA microarray technology. The later labs also added the task of synthesizing and investigating a testable question.

Students' research projects were another example of how this SSI-based lab scaffold sought to stimulate a functional understanding of science. For instance, in the first week of class students were asked to journal³⁸ about an area of scientific interest they had, which related to microbial biology. The students' identified interest could be generalized into one of four microbial biology categories: genetics, health/disease, diet/nutrition, or environment. Over the next several weeks, students began to investigate this interest, which evolved into their individual research project. This individual project provided the lab instructor with opportunities to work with students to 1) learn how to ask scientific research questions; 2) understand the differences between opinion, theoretical, and factual statements; 3) find reliable sources of scientific information; and 4) establish some contextual knowledge base on their topic of choice. Students' individual research projects also served as the basis for teams, where undergraduates further explored alternative views of their popular socio-scientific issue resulting in a group research project.

There were several additional aspects to this group project. For example, students were given a chance to teach their peers about the importance of their topics and the different scientific perspectives at the end of the semester through group PowerPoint presentations. Thus, this group project furthered students' knowledge of the issue, informal reasoning skills, and reflection upon previous beliefs. Another aspect to the group project involved students designing a learning activity (or experiment) for a selected age (5-10). This aspect of the transformed curriculum also aligned with the [Project Nexus](#) initiative. By asking students to develop learning

³⁸ Students' journals were reflective records of their personal beliefs and experiences.

activities / experiments education majors not only get practice with planning science activities they also learned about the Maryland voluntary state curriculum 5-E model (Maryland State Department of Education, 1997). However, non-education majors also recognized the benefit from such opportunities by further developing their conceptual understanding of the scientific process, communicative skills, knowledge of microbial biology, and in some cases parenting skills.

Tod: “Even though I am still not planning on making science my career, this course has added greatly to my understanding of the world around me, and this is something I can carry with me for the rest of my life. When my kids ask me how they got chicken pox or why the milk went bad, I will be happy to have my microbial answer at hand.”

Implemented Changes in the Lecture and Laboratory Structure for Spring 2008

The laboratory syllabus can be found in [Appendix A](#). The piloting of this curriculum, in the spring 2007, showed positive changes in facilitating student learning. Consequently, most of the student activities carried over to spring 2008. However, there were some modifications to the 2008 curriculum. These changes included fewer journaling exercises. Students made several comments over the course of the 2007 semester that the number of journals became tedious and lost their novelty. Consequently, students’ journals were no longer required after each lab. Instead journals were used to promote reflection upon students’ beliefs and knowledge at the start and end of the semester. Additionally, more wet labs replaced computer labs and one lab required students to visit the [Marian Koshland Science Museum](#) in Washington D.C.

The start and end of the semester writing activities were also a spring 2008 addition to assess the effects of this curricular and pedagogical intervention on students’ informal reasoning. The open-ended questionnaire associated with the start

and end of the semester exercise was based on Sadler, Chambers, and Zeidler's (2004) study. However, Sadler, Chambers, and Zeidler (2004) had students respond to two fictitious articles on global warming. This investigation had students select from a variety of readings that had alternative socio-scientific perspectives and were related to microbial biology. These topics were also purposefully linked to the four general microbial biology categories students researched for their KEEP projects over the semester (genetics, health and disease, diet and nutrition, and environment). At the start and end of the semester students were asked to read (or re-read) their article. They then summarized the same article and elaborated on the Sadler, Chambers, and Zeidler's (2004) open-ended questions. Resultantly, modifications were made to Sadler, Chambers, and Zeidler's (2004) original open-ended questions to fit the selection and protocol of this exercise. For example, Sadler, Chambers, and Zeidler's (2004) question 4 asked "which article is more convincing? Please explain your response." For this study, there was only one article with two alternative scientific perspectives, thus the question became "what is/are the conclusion(s) of the article, how accepted are they among the scientific community?" [Appendix B](#) contains the end of the semester article exercise, including the articles students summarized.

The other three instruments added since the spring of 2007 were a lab quiz and two anonymous surveys. These instruments were administered to students through ELMS (Blackboard Inc., 2006) and can be found in [Appendix B](#). The lab quiz was developed from students journals during the 2007 pilot study. Because the 2008 curriculum had reevaluated the use of students' journals to enhance the quality of reflection, several questions that provided great insights to students NOS

conceptualizations and evaluation of scientific information were not asked through this instrument. Therefore, a lab quiz was created to provide data with respect to whether undergraduates viewed the scientific process as being linear or circular, how scientific knowledge is different from other ways of knowing, and the relationships/connections of science and human endeavors.

The two anonymous surveys assessed students study techniques and the effectiveness of the instructional pedagogy mid-semester and at the end of the semester, respectively. These instruments contained open-ended and Likert Scale questions. The focus of these surveys was to assess students' preparation for class exams and how they perceived their learning experiences. The mid-semester evaluation was developed during the study as a result of the feedback students were making informally outside of lecture about the time, effort, and contextual understanding they had of the material. They felt the tests were not fair assessments of their knowledge. The end of the semester evaluation was to assess students' final perception of the curriculum and their resultant learning gains.

Participants

Student profiles ranged from freshman to senior status, with a variety of science experiences and ethnic backgrounds. At the start of the semester there were 32 students enrolled (the maximum enrollment with only one teaching assistant). Within the first week, 5 students dropped and 1 student dropped at the university's drop-a-class deadline resulting in 26 students successfully finishing out the semester. All 26 participants agreed to participate in this investigation, as documented by signed Institutional Review Board (IRB) consent forms. Resultantly, there were 15

freshman, 9 sophomores, 1 junior, and 1 senior. For this study, no student claimed science as their major. There were however, 11 education majors (1 special ed, 5 pre-K, and 5 elementary) and 15 non-education majors (2 accounting, 2 business, 2 communication, 1 English, 1 history, 1 journalism, 4 government and policy, 4 undecided). Of the 26 participants, only 5 White European Americans claimed to be confident and excited about science. The ethnicity of students included 5 Asian American, 4 African American, and 17 White European Americans. Additionally, when students were asked to journal about the role their culture played in their life, 11 students discussed their religious background (including Catholicism, Judaism, and Greek Orthodox). One student did not identify with any culture. The remaining 14 students elaborated on their family heritage. There were also more females than males, 17 to 9 respectively.

Pedagogy

This section focuses on the teaching practices that I used over the course of the semester. I have use this section of [Chapter 3](#) to generally introduce these pedagogical practices. Then throughout my findings discussions in [Chapters 4](#) and [5](#) I give specific examples of ways my pedagogy may have influenced results. I have chosen to break down the main components of the teaching practices I used over the semester to encourage learning into four categories.

- 1) Finding out students' interest(s) or fears towards science
- 2) Exciting students to learn about aspects of microbiology
- 3) Providing opportunities to reflect upon academic feedback and personal growth

4) Balancing professional and personal interactions with students

Finding-out Students' Interest(s) or Fears towards Science

At the start of the semester, I established a more personal relationship with students several ways. The KEEP journal not only served to gather data on undergraduates' diversity³⁹ and interest toward microbiology, but also was critical in helping me to understand each student on a more individual level. For example, students' journals not only revealed their interests in microbiology but also gave me insights into their life.

"I am a freshman here at the University of Maryland College Park. My major is Early Childhood Education, but I want to also take classes that involve Pre-Law. I have always had a passion for teaching younger children. Growing up with my 3 other siblings, I always loved the role of helping them with their homework... I also want to be a paralegal for Family Court, so I can work with children who have been abused. I want to help children turn their lives around... My main interest in this class...has to deal with weight and genetics. I have always been told that me being overweight is normal because it runs in my family. I come from a family that is known for diabetes, high blood pressure, overweight, heart attacks and strokes for generations... I really want to find out how it is possible that this can be passed on through genetics... I hope to come out of this class with a better understanding of genes and weight and the relationship between them."

I would also walk from lecture to lab with different groups of students striking up conversations about questions they had about lab, lecture, or their extra curricular activities. I recorded students' questions, comments, and interests in my weekly journals. This helped me personalize the way I would introduce labs or relate content discussed in lecture or lab so that concepts were more connected with students' lives. For example, I learned that one student worked as a cook at Planet Fun (a children's video arcade and with amusement rides). This student expressed an interest in understanding more about the relationship between microbes and food. In my

introduction to the Yogurt Lab, I asked this student to share some of his food preparation practices. I used this student's experiences with food in the Planet Fun kitchen to begin my discussion of the pasteurization process used to extend the shelf-life of foods by killing harmful microbes. This was the first important take home concept of the Yogurt Lab, which also included the use of microbes to change the physical and chemical properties of foods to inhibiting other harmful microbial contamination. I also created a help thread for lab in Enterprise Learning Management System (ELMS) discussion board feature. Students used this space to share questions or concerns they had with respect to laboratory concepts or learning tasks in this space. These pedagogical practices gave me an opportunity to understand the needs and interest of this diverse group of learners.

Exciting Students to Learn About Aspects of Microbiology

At the start of the semester, I took several opportunities to excite students about the research projects and hands-on lab scaffold. For instance, the first day of lecture Dr. Benson gave me an opportunity to share with the students the objective behind the transformed laboratory curriculum. This not only gave me an opportunity to ask students to participate in this doctoral study, but also gave me a chance to express the significance of the learning activities students would have in this course. The first lab introduced students to the ELMS learning environment and KEEP; this gave me time to share some of the significance behind projects students from the 2007 pilot chose to research. The first hands-on lab was Safety and Microscopy. My

³⁹ Diversity in this study, relative to Lee and Luykx's (2007) broad definition, has been defined by the limits of the data collected on the participants. Specifically, diversity in this study has been defined as issues of undergraduates' ethnicity, culture, prior science experiences, and gender.

introduction to this lab not only included a discussion of why it is important to use aseptic techniques, but also focused on the unique lab scaffold, which would provide them with chances to design and test their own experimental protocols later in the semester.

I also recognized the different levels of comfort students had with learning science. For example, some students recognized that “I have always found science to be easier than other subjects because I find it the most interesting. After I took AP Biology in 11th grade, I realized that I loved learning new science information.” Others acknowledged, “I’m just not too knowledgeable I guess with biology like some other people in the class are. I always feel like I’m so behind or unknowing of what everyone else is saying in class... it kind of makes me feel like I missed an entire lecture because they know so much and I know so little...” My own pedagogical practice not only sought to challenge those who were excited about science but also encourage those who were less confident and skilled with reading, interpreting, and discussing scientific information. For example, I found my walks to lab and from lecture were often opportunities students used to discuss questions they had about assignments or exams. I recorded several instances in my practitioner journal where I tried to re-explain a science concept in ways that might have been more relevant to students’ experiences. I encouraged study groups and specifically tried to pair those students with more background knowledge with those who did not come from strong primary and secondary science education programs. I worked hard to help all undergraduates feel comfortable about directly seeking Dr. Benson’s advice. Finally, I spent time giving students feedback on their individual and group

KEEP research projects. I helped students who had little experience with researching scientific articles begin to develop skills to find reliable sources of information, while challenging those more skilled students to develop their knowledge of the issue(s).

Providing Opportunities to Reflect Upon Academic Feedback and Personal Growth

Throughout the semester, the activities built into the transformed laboratory curriculum offered students chances to reflect upon their understanding of science and their own personal beliefs. For example, the KEEP journal explicitly asked “In looking back at my initial scientific interest I realize...I have learned_____ about my initial scientific interest...I still have questions about...My initial opinion about this topic was...After understanding more about... I find myself (agreeing or disagreeing) with my initial beliefs because...” The article exercise asked “After carefully rereading the article you chose address the following points... including if your initial response has changed or remained the same.” However, I also encouraged students to reflect upon their ability to evaluate scientific information through my ELMS and KEEP interactions. For instance, after each lab, students posted their lab write-ups in ELMS. I gave each student feedback not only on their misconceptions but also praised their developed skills, understanding, and level of effort. Similarly, for the individual KEEP research project I offered each student insights on the weaknesses and strengths of their final poster.

Balancing Professional and Personal Interactions with Students

One of the challenges I faced each week was how to balancing the personal relationship I established with students over the semester and my role as instructor. I reflected upon my own personality and interest in my life long ambition to seek and

share the priceless gift of wisdom. I believe that one of the reasons I loved teaching this transformed curriculum was because it offered undergraduates a chance to develop life long skills of scientific literacy in a context that had personal relevance to each students' life. I also believe that my passion and interest in seeing this diverse group of students succeed came out in several ways. Talking to students on a personal level about their interests was one way. I believe that this formed a bond between me and students that necessitated trust, sensitivity, and care while balancing professionalism. Often times I found myself reflecting in my practitioner journal and discussing with Dr. Benson aspects of my personal and professional interactions. For example, I had noticed a few weeks into the course that one student was going through personal issues. I had seen this student very upset both inside and outside of class. This undergraduate approached me and shared that she suffers from an anxiety disorder and depression. She told me she had been doing well with the medication she was on, but recently switched medication, which she believed triggered a severe relapse. When she asked to speak with me, I was grateful for her comfort in discussing such a personal issue. However, I also acknowledged that her issue was beyond my professional obligation and skills. Recorded the following recommendations in my practitioner journal as well as informed Dr. Benson of the incidence.

- 1) First, I asked her what I could do to help her keep from falling behind. I offered to meet with her on the following Thursday March 13th to help her with her first KEEP draft.

2) I also asked her what kind of support she had and if she was seeking help. She told me she had found a support group on campus and had been going to counseling. I asked if she would bring me some documentation of her Dr.'s appointments so that I could excuse her absences from lab. She had missed last Thursday's lab and left a bit early on Tuesday March 4th because she was very upset. She had also not been engaging with the material since I noted her distress.

3) I asked her if she had scheduled an appointment to meet with her advisor, she had not so I also recommended she talk to her advisor and tell her advisor the situation.

I found that several students felt my interest in their learning was sincere yet I also made it clear that my level of expectation of them academically needed to be objective. My feedback to students over the course of the semester documents the standard of achievement I expected of students. I show examples of these pedagogical interactions in [Chapters 4](#) and [5](#).

Instrumentation

This section describes the origin of each instrument and the construct(s) (student interest, evaluation of scientific information, and/or NOS conceptualizations) it measured. The validity and reliability of the resulting data follows this discussion in the data gathering and analysis procedures section. All instruments have been illustrated in [Appendix B](#).

Start and End of the Semester Article Exercise

The start and end of the semester article exercise was used to gather data on undergraduates' 1) response to a student interest focused activity, 2) ability to evaluate scientific information, and 3) ability to evaluate scientific information. The open-ended questionnaire associated with this exercise was based on Sadler, Chambers, and Zeidler's (2004) instrument that was published in the respected and peer-reviewed *International Journal of Science Education*. Sadler, Chambers, and Zeidler (2004) looked at eighty-four high-school students' responses to five questions after they read two factitious articles, constructed specifically for the study. These two articles were on the topic of global warming and offered opposing positions on the socio-scientific issue. Participants then responded to 5 questions, the first 3 were designed to elicit their NOS conceptualizations and the last 2 focused on socio-scientific decision-making skills. The authors inductively analyzed the qualitative data. They established credibility and trustworthiness by triangulating the questionnaires and interviews as well as establishing inter-rater reliability between the three investigators.

The questions used in the Sadler, Chambers, and Zeidler (2004) study improved upon the work of Zeidler, Walker, Ackett, and Simmons (2002), who examined 41 pairs (82 students) responses to questions that were based off of Bell, Lederman, and Abd-El-Khalick's (2000) Nature of Science Questionnaire. The questions from the Sadler, Chambers, and Zeidler (2004) study were chosen over other instruments, such as the Nature of Science Questionnaire for several reasons. First, I had previous experience with using questions from the Nature of Science Questionnaire in two other studies I conducted at the University of Maryland (Schalk,

McGinnis, McCaleb, 2007; Schalk, et al., 2008). The data suggested that these questions resulted in responses that were difficult to analyze without further interviews. I chose not to conduct interviews to decrease any confusion or anxiety about the instructor relationship I had established with the participants, which could have resulted from the desire to be truthful yet not jeopardize their grade. Second, other investigations (Kolsto, 2001b; Kolsto, 2006; Korpan, Bisanz, Bisanz, & Henderson, 1997; Sadler and Zeidler, 2005a) examining participants' NOS conceptualizations or ability to evaluate SSI either conducted interviews or used protocols that were not relevant or useful for this dissertation study's curricular framework.

This investigation sought to understand the effects of a student interest-SSI-based curricular and pedagogical intervention. Consequently, rather than ask students to respond to factious articles on global warming, students selected from a variety of readings that had alternative socio-scientific perspectives and were related to microbial biology. These topics were directly linked to the four microbial biology areas students chose to examine over the semester. These articles also discussed alternative perspectives. Students summarized an article and elaborated on questions that originated from the Sadler, Chambers, and Zeidler (2004) investigation. Further, this exercise helped students to begin developing their individual KEEP research poster by offering several ideas and references. At the end of the semester, students were asked to re-read their article and initial response. They then summarized the same article and elaborated once again on the Sadler, Chambers, and Zeidler's (2004) open-ended questions, allowing data on students' NOS conceptualizations and

evaluation of scientific information to be compared. However, because this instrument asked students to read one article, modifications were made to Sadler, Chambers, and Zeidler's (2004) original open-ended questions. For example, Sadler, Chambers, and Zeidler's (2004) question 4 asked "which article is more convincing? Please explain your response." For this study there was only one article with two alternative scientific perspectives, thus the question became "what is/are the conclusion(s) of the article, how accepted are they among the scientific community?"

Students' KEEP Journal

The KEEP journal was to gather data on undergraduates' 1) diversity⁴⁰, 2) interest toward microbiology, 3) NOS conceptualizations, and 4) ability to evaluate scientific information. Students used this major research-intensive Mid-Atlantic university's version of the KEEP toolkit⁴¹ as a medium of expression (Carnegie Foundation, 2002). Students made two journal entries at the start and end of the semester. The first journal entry served to systematically document participants' personal information such as culture, future career aspirations, previous science experiences, and interest in how microbial science relates to their life. The final journal entry gave undergraduates a chance to reflect upon their initial scientific interest by asking them to discuss what they had learned, questions they still had, and if their initial opinion about this topic had changed.

⁴⁰ Diversity in this study, relative to Lee and Luykx's (2007) broad definition, has been defined by the limits of the data collected on the participants. Specifically, diversity in this study has been defined as issues of undergraduates' ethnicity, culture, prior science experiences, and gender.

⁴¹ Knowledge Exchange Exhibition Presentation (KEEP) toolkit is a Carnegie Foundation electronic learning tool which serves to mine data as well as facilitate the exchange and presentation of knowledge (Carnegie Foundation, 2002).

The usefulness of this instrument was realized during the spring 2007 pilot study. It was found that all 24 participants, from the spring 2007, were able to express their interests, beliefs, and understandings of scientific information in a way that quizzes and surveys were not able to capture. Analyses of the spring 2007 data also suggested that asking undergraduates to make fewer journal entries over the course of the semester would also provide richer insights. Students' feedback from the spring 2007 indicated that weekly journals became a tedious task that they lost interest in mid-way through the semester. Consequently, the use of the KEEP journal instrument was limited to two reflections upon the growth they had over the course of the semester.

Individual KEEP Research Poster

The individual KEEP research poster was also to gather data on undergraduates' 1) diversity, 2) interest toward microbiology, 3) NOS conceptualizations, and 4) ability to evaluate scientific information. The students' individual research posters also came from the spring 2007 pilot study. The spring piloting data from this individual instrument suggested that this exercise was very useful in exposing students to topics that interested them while building their knowledge base for the follow-up group project. Few modifications were made to this instrument. The most notable change was minimal edits to refine the instructional wording to align better with the final group project.

The overarching focus of this individual project was to expose students to the importance of understanding different scientific perspectives before forming opinions. The notion of this instrument being a research poster in KEEP, rather than a

research paper, came from Dr. Benson's previous successes with using KEEP in this course for group based research projects.

Other aspects of the individual project included giving students time to research a topic with personal relevance to their life while getting instructional feedback that challenged them to expand their knowledge and reflect upon their beliefs. This feedback came through their individual project draft and final poster. Students were asked to submit a draft of their topic and at least two references to ensure students had narrowed their topic focus and were able to find reliable references discussing the different perspectives on their socio-scientific issue. I offered students help if they expressed difficulties in finding a topic or reliable resources by working one-on-one with students. I provided them with some initial electronic resources containing information relevant to their expressed interest. However, students were asked to find their own references for their final report. In addition, the individual project was used to put undergraduates together for their group project, which served to further students' understandings and reflections in a more social setting.

[Group KEEP Research Poster](#)

The group KEEP research poster was to gather data on undergraduates' 1) interest toward microbiology, 2) NOS conceptualizations, and 3) ability to evaluate scientific information. The group research poster was another instrument that needed few modifications from the spring 2007 pilot study. The most notable change from the spring 2007 was slight rewording of the instructions for clarity. This instrument was an extension of students' individual projects. Consequently, this group project

had the added component of giving students the opportunity to teach their peers about their topic through a Power Point presentation as well as a learning activity / experiment designed for an identified 5 -10 grade. These instructional components of the group project offered both education majors and non-education majors' practice at socially discussing the alternative perspectives of the socio-scientific issue as well as practically applying their knowledge to teach others.

Anonymous Mid-Semester Evaluation on Students' Study Techniques

The anonymous mid-semester evaluation on students' study techniques was to gather data on undergraduates' diversity and perceived ability to evaluate scientific information. The instrument was not piloted, but designed as a result of the instructional feedback I received several weeks into the study after meeting with members of my dissertation committee (namely, Dr. Mawhinney and Dr. Benson). The rationale behind this evaluation was to address the feedback students were making informally outside of lecture about the time, effort, and contextual understanding they had of the material, yet feeling as though the tests were not fair assessments of their knowledge. Consequently, this instrument was the result of this case-study's progression.

This instrument was made available to students through ELMS (Blackboard Inc., 2006). This survey provided students a chance to express their study techniques, the amount of time they were putting into exam preparation, and how the course could be modified to better facilitate learning. This instrument consisted of 10 Likert Scale questions and 8 short answer responses.

Anonymous End of the Semester Evaluation

The anonymous end of the semester evaluation was used to gather data on undergraduates' 1) diversity, 2) interest toward microbiology, 3) NOS conceptualizations, and 4) ability to evaluate scientific information. The instrument evaluating students' laboratory experiences was adapted from a spring 2007 bonus journal and questions from Dr. Benson's end of the semester evaluation. This instrument was made available to students through ELMS (Blackboard Inc., 2006). The evaluation provided students a chance to express their 1) confidence in finding, reading, and discussing scientific information, 2) beliefs about the engagement and usefulness of the various learning activities (individual and group KEEP research projects as well as hands-on labs), and 3) thoughts about if they would recommend this educational experience to others. This instrument consisted of 10 Likert Scale questions and 16 short answer responses.

Student Laboratory Experiments

The students' lab write-ups were to gather data on undergraduates' 1) interest toward microbiology, 2) NOS conceptualizations, and 3) ability to evaluate scientific information. Most of the labs were piloted in the spring of 2007. These lab activities were created to foster undergraduates' authentic ideas, practical awareness of how the lab related to their everyday life, and conceptual understanding of the science content. For example, the Hand-Washing labs required students to 1) define a testable question, 2) outline their experimental protocol, 3) describe their controls, 4) devise a method of data collection and analysis and, 5) discuss whether their testable question was answered.

The changes made from the 2007 pilot study included fewer computer labs and a trip to the [Marian Koshland Science Museum](#) in Washington D.C. Specifically, in 2007 two computer labs were designed to teach students about DNA and protein sequencing by accessing the National Center for Biotechnology Information (NCBI) database. Students from the 2007 pilot study did not demonstrate the desired interest or conceptual knowledge intended; therefore these labs were replaced by a DNA microarray lab (Campbell, 2006) and a yogurt lab. The DNA microarray lab had not been used in prior years but the yogurt lab had. For more details on the labs carried out in this study see [Appendix A](#), which contains the laboratory syllabus.

Student Laboratory Quiz

The students' lab quiz gathered data on undergraduates' ability to evaluate scientific information and NOS conceptualizations. The lab quiz questions were derived from the 2007 journals that were omitted in 2008 to narrow the focus of the students' journaling. The original journal questions were slightly reworded for clarity by Dr. Benson. These three questions were open-ended and asked students about 1) whether they viewed the scientific process as being linear or circular, 2) how scientific knowledge is different from other ways of knowing, and 3) the connections between science and human endeavors.

Practitioner Researcher Self-reflective Journal Outline Instrument

The practitioner researcher self-reflective journal outline instrument came from the 2007 spring pilot study. As a member of the [Project Nexus](#) (PN) research team, I kept a journal on my teaching practices. The original journal outline I was given came from the [Project Nexus](#) Team which included my reflection upon active

learning, linkage to pre-collegiate science teaching, recruitment to teaching, teaching for all, data management and analysis, and “traditional” instruction. For this dissertation, I took into account the advice of my dissertation committee and modified the journal to keep track of:

- 1) The general lab description for that week
- 2) How the activities related to SSI, NOS conceptualizations, evaluation of scientific information, and students’ interest
- 3) My instructional preparation with Dr. Benson
- 4) The microbiology content covered
- 5) My interactions with students in ELMS, lecture, and lab

I also recorded other important observations or comments that I felt could be useful in data analyses such as the topic covered in lecture and student-to-student interactions.

Data Gathering and Analysis Procedures

This section describes the methodology used in gathering and analyzing data to address the guiding question of this dissertation: “How does a socio-scientific issues (SSI) curricular and pedagogical intervention, including a student interest-focus, affect undergraduates’ ability to informally reason?” Consequently, the following discussion is broken into collection of data and analytical procedures subsections. At the end of the analyses procedures is summary table that illustrates how each instrument was used to measure the specific components of the guiding research question (students’ interests, evaluation of scientific information, and NOS

conceptualizations). This table also precedes a foreshadowing of the upcoming findings [Chapters 4](#) and [5](#).

Data Gathering

Convenience sampling was used for this case-study (Gall, Gall, & Borg, 2002, p. 175). All undergraduates who participated in this study were selected based upon the fact they had enrolled in this course in the spring of 2008. All participants freely and willingly participated in this study, as witnessed by the signed IRB consent form⁴², see [Appendix C](#). All participants also agreed to let their data be written in this dissertation and other educational reports, providing their identities are protected. Consequently, all data have been coded to mask the identity of the participants.

Additionally, a few students were selected in the spring semester of 2009 to validate accurate reporting of their data as well as comment on my interpretations of their responses. These participants were asked to sign a new IRB consent form⁴³, see [Appendix C](#). This IRB form allowed me to interview these students and record their comments as a way of validating the interview and my data analyses.

Data were collected electronically through this major research-extensive Mid-Atlantic university's Enterprise Learning Management System (ELMS) and the Knowledge, Exchange, Exhibition, Presentation (KEEP) toolkit (Blackboard Inc., 2006; Carnegie Foundation, 2002). A large percentage of data for this investigation came from academic products used in assessing students final grades such as the 1) Individual KEEP project, 2) Group KEEP project, 3) KEEP journals, 4) students'

⁴² The IRB consent form was accepted on January 9th, 2008 by the University of Maryland's Institutional Review Board. The IRB used in this study was given an application number of 07-0686.

⁴³ The IRB consent form was accepted on January 9th, 2008 by the University of Maryland's Institutional Review Board. The IRB used in this study was given an application number of 07-0686.

laboratory write-ups, 5) end of the semester lab quiz, and 8) a start and end of the semester article exercise. Consequently, assignments students chose not to complete had to be honored to respect subject participation as described in the original IRB consent form, see [Appendix C](#). That is students were not pursued to complete an assignment for the sake of this dissertation's data collection. Those students who were asked to validate their data and my interpretations were contacted by email once. Several times in this electronic letter it was reinforced that students were being asked to voluntarily be interviewed. During the interview, I began by asking each student to sign the new IRB consent form, see [Appendix C](#). This gave me an opportunity to clarify that if at any time subjects could decide not to participate and/or have their data be reported. Further, the IRB renewal application made it clear that had participants not respond to the voluntary request, no further pursuit was to be made to pressure students into complying. All participants selected freely and willingly participated in the interview and allowed for their voices to be recorded, as witnessed by their signing of the new IRB consent form.

The anonymous surveys administered in ELMS were chosen over interviews to decrease any anxiety that could have been associated with interviews, especially considering I did not want to jeopardize the truthfulness of students' responses given that I had a practitioner researcher role in this study. Additionally, I was also a participant of this study through analyses of my pedagogical practices self-reflective journals.

Analysis Procedures

All instruments yielded qualitative data and the two anonymous evaluations also incorporated Likert Scale questions. Analyses of this case-study's data were accomplished through analytic induction. Analytic induction has been defined as a process by which the research searches through the data bit by bit and identifying underlying themes or patterns (Gall, Gall, & Borg, 2002, p. 21, 618). Detailed explanations and examples of the resulting coded data can be found in [Chapters 4](#) and [5](#), where the findings are reported. Descriptive statistics have also been used to clarify resulting trends.

The proposed design of this dissertation originally included several deductive approaches to analyze the data. Analytic deduction involves the identification of themes prior to data collection and then searching through the data for representative instances (Gall, Gall, & Borg, 2002, p. 21). However, the deductive methods proposed were contingent upon the use of Sadler, Chambers, and Zeidler's (2004) article instrument. The changes made to this instrument, under the guidance of Dr. Benson, resulted in data that could not be deductively subjected to Sadler, Chambers, and Zeidler's (2004) coding scheme. Additionally, statistical tests were proposed to measure differences in education vs. non-education major populations. Due to the reduced focus of the original proposal, no statistical tests were needed. Thus, descriptive statistics were used when explaining general trends among the participants.

Analytic Induction

With respect to analytic induction, both interpretational and structural methods were used to identify themes or patterns inherent in the data.

Interpretational analysis has been defined as the process of examining case-study data closely to find constructs, themes, and patterns that can be used to describe and explain the phenomena being studied (Gall, Gall, & Borg, 2002, p. 453). Structural analysis also identifies patterns to describe and explain the phenomena under investigation but does so with little if any inference (Gall, Gall, & Borg, 2002, p. 457). These methods of data analyses could also be considered as latent and manifest, respectively. Latent content analysis is the process by which the researcher extends an interpretive reading of symbolism to the data (Berg, 2007, p. 308). Manifest content analysis is limited to counting specific words, thus examining the surface level of the data (Berg, 2007, p. 308).

For example, students' journals were interpretationally (latently) coded into one of three categories (career, family history, or personal) with respect to their expressed interest(s) in microbiology. Career was related with students proclaimed future occupations. Family history was associated a student's desire to become more educated about their own life and life style because some family member has died or been diagnosed with a disease. Personal referred to students' desire for self-improvement but was not associated with a relative's death or illness. Students' journals were also structurally (manifestedly) analyzed with respect to their ethnic backgrounds and academic major. Specific examples of interpretational and structural analyses coding have been provided on pages 173- 175.

Although the examples I have provided on these pages are used to illustrate clearly how I analyzed data (interpretationally and structurally) there were times when students' responses did not fit neatly within my inductive category scheme. In

some cases undergraduates' answers: 1) were not thoroughly explained, 2) fell into more than one category, and/or 3) were uncharacteristic of subjects prior comments. For example, in Hugh's first journal he states that he had "interest in what scientists know about everything. I'm very curious." His general statement did not fall neatly within my inductive categories of career, family history, or personal. In such instances, I used several techniques to code data (latently). One strategy I used was to consider the surrounding comments he made in this journal entry, such as "I love having conversations about the role of endogenous retroviruses... I have always found science to be exciting because it's meritocratic to a degree which most disciplines are not." Given that Hugh had also discussed his Government and Politics major and was forward about his debate interests in political affairs in sentences prior, I viewed such comments as supporting an underlying career related interest. To strengthen my judgments I used my practitioner researcher journals. In many instances, I had memos supporting my analyses. In Hugh's case, I noted a conversation we had about how he was using his acquired knowledge from this course in collegiate debates. Recognizing his career aspirations in government, he had joined the university's debate team. Since I treated each participant as a case, I also used students' final journal reflections and research project focus to decipher underlying meanings. In Hugh's final journal, he stated that "I've learned a lot about the fundamentals of microbiology, enough to be able to read scholarly journals or articles and understand what's going on. This seems minor, but I think it will seriously affect my base level of information to enable me to engage with my field of study." For his individual and group projects, he chose popular political topics being

disputed among government officials, such as doctors' use of antimicrobials on fatally ill patients and censorship of potentially dangerous scientific research. Further, for some undergraduates I was able to confirm my data analyses through member-checking.

As with my interpretational analyses, I noted difficulties in my manifest coding scheme as well. In these cases, undergraduates often failed to respond to the specific question. For instance, when asked to describe their ethnicity a few students failed to respond to this question. On such occasions, I had to rely solely on my recorded practitioner journal notes or biographical data from the class roster.

I conducted both interpretational and structural analyses by compiling the data stored in the ELMS and KEEP databases into NVivo (version 7). I created document folders for students' journals, individual KEEP project, group KEEP project, article exercise, lab write-up data, lab quiz, anonymous mid-semester and end of the semester evaluations, as well as one for my practitioner self-reflective journals. I categorized all data into cases. One case was a student's portfolio of work over the semester. Each student case was also linked to my practitioner journals if I recorded instances of interaction with that participant in lecture, lab, or through ELMS. Free nodes and memos were used to note trends in the data as I began my analyses. Tree nodes were later created to categorize the resulting interpretational schemes into the three main research components of this dissertation, namely students' interests, evaluation of scientific information, and NOS conceptualizations. Branches were created within each of the three main tree nodes as I dissected and identified underlying emergent themes. A specific theme (such as the NOS discovery,

processes, and justification) and the instrument the data came from defined these branches. This analysis procedure enabled me to visualize how the instrumental data supported my interpretation of the data. Once I had completed my analytical analyses I then went into the literature and made memos where my tree node branches reinforced or challenged the existing theoretical models.

Several procedures were used to test the internal validity (or credibility) of the causal inferences about the effects of this student interest SSI-based curricular intervention on students' evaluation of scientific information and NOS conceptualizations. Pattern matching was one approach used to strengthen the findings reported. Pattern matching is the process by which data from the case-study corresponds to predictions drawn from theoretical propositions (Yin, 2003, p. 119). For this investigation, after the data were coded inductively (as described earlier), I searched the literature to compare my findings to findings reported by others in the literature. My data tended to either :1) support theoretical models that had not been tested, 2) challenge other empirically based reports, and/or 3) reinforce reported outcomes. For example, in [Chapter 6](#) on page 257 I discuss how advocates for the use of SSI-based interventions have contended that NOS conceptualizations are learned in this type of educational setting, which in turn can promote more informed reasoning about scientific issues in an everyday context (Sadler, 2004a). However, several reported findings have yet to support this claim (Khishfe & Lederman, 2006; Walker & Zeidler, 2007; Wong, 2008). One specific example I discuss is the study by Walker and Zeidler (2007) who found that high-school students' failed to draw upon their conceptual knowledge of the NOS when supporting their claims. I then

discuss how my findings from [Chapter 5](#) illustrate how the 26 participants in this investigation did develop and utilize their acquired knowledge of the NOS when reasoning.

Altheide and Johnson (1994) have emphasized multivocality being a factor that strengthens the validity of case-study research. Multivocality refers to settings where participants do not speak with a unified voice but express diverse views and interests (Altheide & Johnson, 1994). Consequently, I have used multiple electronic data-collection methods (anonymous surveys, quizzes, discussion board posts, assignment submissions, as well as KEEP projects and journals) and data sources (mid and end of the semester evaluations, research projects, article exercises, journals, a lab quiz, and lab write-ups) to demonstrate the diverse interests and views students expressed over the semester.

Additionally, my interpretations of the data were also subject to validation by Dr. Benson during the data collection period. I sought confirmation of my use of descriptive statistics over other statistical measures such as Analysis of Variance (ANOVA) with Dr. Haring, an associate professor in the College of Education's Measurements, Statistics, and Evaluation Department. Over the summer and fall of 2008 I also sought verification of my data analyses with objective graduate associates and faculty in the College of Education's Curriculum and Instruction Department (namely Dr. Elby, Hammer, Hughes, Imig, and Levin). Thus, part of the strength data interpretation comes from my triangulation of data, as defined by Gall, Gall, and Borg, (2002). Finally, in the spring of 2009 I used member-checking to further validate my claims. Gall, Gall, and Borg, (2002, p. 465) have defined member-

checking as the process where participants review selected sections of their raw data and confirm their data have accurately reported. Participants also validate the researcher’s interpretations of data for accuracy and completeness (Gall, Gall, & Borg, 2002, p. 465).

Gall, Gall, and Borg, (2002, p. 465) have acknowledged that case-study triangulation includes the use of multiple data-collection methods, data sources, and analysts to strengthen the interpretive validity of the research’s claims. [Table 1](#) illustrates how instrumental data were triangulated by multiple data-collection methods and data sources as well as summarizes how each instrument addressed the guiding research question. Although, this table has excluded my practitioner researcher self-reflective journal. This journal was used to strengthen interpretation of my data for all instruments. Discussions of the ways my pedagogical practices may have affected the outcomes reported have also been threaded throughout the findings [Chapters 4](#) and [5](#). Consequently, this table highlights only those instruments used to collect data on the undergraduate participants.

Table 1. *Integration of the Guiding Research Question with Data Analyses*

Connection to The Guiding Research Question	Article Exercise	Journals	KEEP Projects	Mid-Evaluation	End-Evaluation	Lab Experiments	Lab Quiz
Student Interest							
What stimulates students' interest(s) in science	X	X	X		X	X	
Relationship between interest and learning	X	x	X	x	x	X	X
Relationship between SSI and interest	X	X	X		x		
Evaluation of Scientific Information							
Experiences influence informal reasoning of SSI	X	X	x		x	X	x
Evaluating evidence / conclusions	X	x	X		x	X	x
Asking scientific questions			X		x	X	x

Higher-ordered epistemological thinking	X					X	X
NOS Conceptualizations							
Differentiating facts, theories and opinions	X		X				X
Societal factors influence on scientific discovery	X		X				X
How scientists ask & experimentally test questions						X	X
Viewing a lack of data, as a weakness for a claim	X					X	X
Informally reasoning using NOS conceptualizations	X		X			X	
NOS conceptualizations affect social beliefs		X			x		

X = students' interests, evaluation of scientific information, or NOS conceptualizations data

x = supporting data from students' beliefs or perceptions

This table serves to simplify my data analyses as well as foreshadow the discussion in my findings [Chapters 4](#) and [5](#). For example, in [Chapter 4](#) I have discussed data relevant to popular SSI diverse learners are drawn to as they develop skills to evaluate scientific information. [Table 1](#) indicates that the Article Exercise, Journals, KEEP Projects, End-Evaluation, and Lab Experiments were used to measure students' interest(s) to learn about microbiology. The lighter lowercase x are used to indicate supporting data from students' beliefs or perceptions. For instance, the Article Exercise, KEEP Projects, Lab Experiments, and Lab Quiz were used to measure undergraduates learning relative to their expressed interests; while students beliefs expressed in the Journals, Mid-Evaluation, and End-Evaluation supported the data analyses.

[Chapter 5](#) has focused on findings that relate undergraduates' epistemological views about science with respect to their ability to informal reasoning. Although there was some overlap in how participants evaluated scientific information and conceptualized science as a way of knowing when informally reasoning, these chapters have distinct connections to the predictions of researchers' theoretical propositions.

Specifically, [Chapter 4](#) includes findings on what microbiology topics stimulated students interest in science and why. These data are connected to theoretical literature that has suggested there is a need to know more about educational opportunities that motivate students to learn science (e.g., Koballa & Glynn, 2007; Osborne, Simon, & Collins, 2003; Sadler, 2004). The findings from this chapter have also focus on the theory that leaning environments relating science to students' identities through experiences, examples, analogies, and values can improve achievement and interest (e.g., Palmer, 2005; Seiler, 2001, 2002, 2006; Rivet & Krajcik, 2008). The data in [Chapter 4](#) are further linked to theoretical predictions that the SSI framework offers an engaging learning forum (e.g., Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Walker, Ackett, & Simmons, 2002).

With respect to undergraduates' ability to evaluate scientific information, the data from [Chapters 4](#) and [5](#) are connected to research suggesting personal experiences influence a person's informal reasoning of SSI (e.g., Bell & Lederman, 2003; Sadler, Barab, & Scott, 2006; Zeidler, & Sadler, 2008). However, [Chapter 4](#) explicitly focus on the effects of the student interest SSI-based curriculum on students' personal development (e.g., Sadler, Barab, & Scott, 2006; Sadler, & Zeidler, 2004; Zeidler, & Sadler, 2008). [Chapter 5](#) concentrates on the debate among science education researchers about how much epistemological conceptualizations of science influence a person's social beliefs (e.g., Bell & Lederman, 2003; Grace & Ratcliffe, 2002; Tytler, Duggan, & Gott, 2001). Both [Chapters 4](#) and [5](#) are additionally connected to researchers' supposition about students' knowledge of science being enhanced by

having skills to evaluate evidence/conclusions and ask scientific questions (e.g., Korpan, Bisanz, Bisanz, & Henderson, 1997; Roberts, 1995, 2007; Sandoval, 2003). Further, the findings from this doctoral dissertation have suggested that undergraduates developed higher-ordered epistemological syntheses and evaluation of scientific information. This has been connected to the recent theoretical implications about making science more meaningful to students to facilitate higher stages of reflective judgment (e.g., Zeidler, Sadler, Applebaum, & Callahan, 2009).

[Chapter 5](#) extends the discussion of evaluating scientific information by more critically examining of the NOS discovery, processes, and justification. With respect to the nature of scientific discovery, specifically the ability to differentiate facts, theories and opinions, the findings from this dissertation have been associated with other empirical investigations and theoretical perspectives (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Zeidler, Walker, Ackett, & Simmons, 2002; Sadler, Chambers, & Zeidler, 2004). Similarly, results from the 26 participating undergraduates' understanding of the societal factors influence on scientific discovery have been connected to earlier research (Zeidler, Walker, Ackett, & Simmons, 2002; Sadler, Chambers, & Zeidler, 2004). The data that are reported on the nature of scientific processes, such as understanding of how scientists ask and experimentally test questions as well as viewing lack of data as a weakness in a claim, are linked to the conjectures of others (e.g., Sandoval, 2003; Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002). Finally, undergraduates' developed awareness of how social beliefs and NOS conceptualizations affect scientific

justifications are tied to the theoretical inferences of educational researchers (e.g., Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005).

The discussion in [Chapter 6](#) combines the emerging insights that have come out of both [Chapter 4](#) and [5](#). As a result, [Chapter 6](#) more completely emphasizes the implications of this doctoral dissertation to future science education research.

Ethical Considerations and Trustworthiness

The issues related to ethics of the research and researchers have also played a significant part in this investigation. For example, before any data were collected, the proposed framework of this study was submitted to the University of Maryland's IRB. The IRB application, found in [Appendix C](#) was approved on January 9th, 2008 and given a protocol number of 07-0686. This was not only required by the University of Maryland for research involving human subjects but also helped to ensure that I was aware of my responsibility to protect students participating in this study. Consequently, at the start of the semester, I announced my practitioner researcher role in this investigation and informed students not only of the importance of their participation in this study but also of potential risks. All undergraduates freely and willingly participated in this study, yet were aware that at anytime they could withdraw from being subjected to investigation without any negative penalty. Not only were students asked to sign an Institutional Review Board consent form (see [Appendix C](#)), but I also made it a point to reaffirm their consent by asking each student throughout the semester if their academic products could be used as examples for educational conferences, papers, or future undergraduates who enrolled in this

course. All participants agreed to the use of their data for educational purposes that would benefit future students' educational experiences.

However, given the open relationship of trust I established with the students' over the course of the semester, their disclosure of personal information in their journals, and my practitioner researcher role, I reflected heavily upon my obligations related to ethics and trustworthiness. Consequently, several fail-safes ensured student confidentiality. First, pseudonyms were used in place of students' names to protect all participants' identities. Second, no person beyond the research team had access to student information such as name, social security number, and any other personal identification information. Further, participants had the right to refuse to respond to any instrumental related task or question. Given that a large percentage of data came from academic products, I honored those assignments students chose not to complete and did not pursue students to ensure 100% participation. However, I also recorded in my practitioner journal that several students approached me after missing a deadline with legitimate excuses and were given additional time with an assignment (Dr. Benson adhered to the policy of 10% deduction per day). I also chose to administer anonymous surveys in ELMS over conducting interviews to decrease any confusion about the instructor relationship I had established or any anxiety that could have resulted in students' desire to be truthful yet not jeopardize their grade.

There was also a potential conflict in my desire to see changes over the course of the semester in students' products, thus biasing my assessment of students' efforts and conceptual understanding over the course of the semester. To minimize my bias analyses of undergraduates' work I took several measures. First, I subjectively

audited⁴⁴ my role as a graduate teaching assistant, lab instructor, and researcher. After each lab, I recorded the communication and feedback I had with students both on-line as well as during lecture and lab in my structured practitioner researcher self-reflective journal (see [Appendix B](#)). These journal entries also included conversations from the weekly meetings with Dr. Benson. During these weekly meetings, I discussed concerns or questions that arose with respect to my pedagogical interactions with students as well as any conflicting researcher interests. For example, at the start of the semester I feared my interpretation of students' article exercise could be influenced by my researcher interest. As a result, it was determined that Dr. Benson would evaluate students' answers for a grade and I would inductively code their responses for epistemological understanding. I shared my interpretations with Dr. Benson after he was done assessing students' academic performance. Consequently, my interactions with Dr. Benson also gave me opportunities to discuss my analyses of the data, strengthening the reliability⁴⁵ of my findings. Over the course of the semester, I also had opportunities to share my reflections and data analyses as a teaching assistant as well as researcher to members of my dissertation committee, namely Dr. McGinnis and Dr. Mawhinney. These conversations offered insights into ways I could further my collection of data as well as my pedagogical practices.

Further, given the connection students had with their projects, I sought additional validation of my data analyses and their consent to share their personal

⁴⁴ Gall, Gall, and Borg (2002, p. 449) have defined subjective auditing as taking notes about situations connected to one's research that arouse strong positive or negative feelings.

stories. This was accomplished by member-checking. Analyses of my data ran beyond the one-year IRB approved limit. Resultantly, I also included an addendum when I renewed my IRB application (see [Appendix C](#)). This additional request gave me the chance to make students, whose data I have selected to describe the findings, aware of my interpretation of their data. However, perhaps more importantly it gave me the chance to ask participants if it was ok to share their personal story in an anonymous way to further science education. Those participants contacted not only validated my claims but also reassured me that I had their permission to share aspects of who they were, by disclosing their interests.

Summary

In this chapter, I have explained the conceptual framework, research setting, participants, pedagogy, instrumental design, procedural framework, and ethics and trustworthiness. I also included some foreshadowing into [Chapters 4](#) and [5](#), where I present my findings. More specifically, in [Chapter 3](#) I have reviewed the literature related to this student interest SSI-based theoretical framework. I have outlined the context of the study, which took place in a recently transformed general microbiology lab during the spring of 2008 and examined 26 diverse undergraduates. I have discussed the four main components of my teaching practices that I used to encourage learning. I have described the instrumentation used in this case-study, which included 9 instruments, 6 of which had been piloted in the spring of 2007. I also outlined my data collection and analyses procedures. The data were collected

⁴⁵ Reliability in case-study research has been defined as the extent to which other researchers would arrive at similar results if they studied the same case using exactly the same procedures as the first researcher (Gall, Gall, & Borg, 2002, p. 635).

through electronic interfaces, namely ELMS and KEEP. Data analyses included inductive coding with the use of NVivo software and descriptive statistics. I have also discussed the measures I took to ensure my trustworthy and ethical relationship with participants and their data. Additionally, [Chapters 4](#) and [5](#) were foreshadowed by using [Table 1](#) to illustrate how the instrumental data were triangulated by multiple data-collection methods and data sources. This table was also used to summarize how each instrument addressed the guiding research question and the relevant theoretical perspectives related to this student interest SSI-based curricular intervention. Finally, the discussion in [Chapter 6](#) combines the emerging insights that have come out of both [Chapter 4](#) and [5](#). As a result, [Chapter 6](#) to more completely establishes the implications of this doctoral dissertation to future science education research.

CHAPTER 4: Student Interest & Evaluation of SSI Information Findings

Overview

This chapter begins by introducing the focus and relevance of the findings in this chapter to the education research community. The next section reports the data relevant to the effects this curricular and pedagogical intervention had on undergraduates' evaluations of socio-scientific. Four participants, whose names have been protected, are used to illustrate the findings. When relevant, descriptive statistics have been interjected to relate these case profiles to the general learning trends of all participants. Additionally, throughout this results section are reflections on my pedagogical practices that may have influenced the learning environment and reported outcomes. Following the data and results section is a summary of the data analyses. A discussion of the limits of data analyses follows. This chapter concludes by reviewing some of the emerging insights of this data relevant to the educational research community, which is brought to a close by foreshadowing [Chapters 4](#) and [5](#).

Chapter Focus

There were two principle research questions proposed to examine how this SSI curricular and pedagogical intervention, including a student interest-focus, affected undergraduates' ability to informally reason. The first of these was "What effects did this curricular and pedagogical intervention have on undergraduates' evaluations of socio-scientific information (SSI)?" The other question proposed was "What effects did this curricular and pedagogical intervention have on undergraduates' Nature of Science (NOS) conceptualizations?" This chapter explicitly focuses on the first question.

One of the rationales behind the SSI movement is that popular science issues can promote scientific literacy by connecting to people's lives and promoting critical evaluation of scientific data and information (Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). Scientific literacy has been broadly defined as a functional understanding of science knowledge to answer questions about everyday life not just theoretical science (DeBoer 1991, p. 174). Scientific literacy can be evidenced through the ability to identify problems for investigation, formulate hypotheses, design and conduct research, as well as evaluate evidence and conclusions (Korpan, Bisanz, Bisanz, & Henderson, 1997; Roberts, 1995). However, scientific literacy can also be indicated by a person's open-mindedness, thirst for more information, ability to identify bias, and reflect critically (Kolsto, 2006; Oulton, Dillon, & Grace, 2004). Personal growth incorporates these latter indicators of scientific literacy as it includes development of self-understanding, self-confidence, self-discipline, intellectual curiosity, thinking about the acquisition of knowledge in a real world context, and clarifying personal beliefs (Belcheir, 1999; McLure, Srikanta-Rao, & Lester, 1999).

It has been argued that a person's belief about his/her own scientific knowledge is not necessarily reflected by one's ability to articulate science content or concepts formally learned (Hammer & Elby, 2002; Hogan, 2000; Sinatra, Southerland, McConaughy, & Demastes, 2003). It has also been shown that people's beliefs about science can influence their functional understanding of science knowledge to answer questions about everyday life (Toplak & Stanovich, 2003; Zeidler, 1997; Zeidler, Walker, Ackett, & Simmons, 2002). Resultantly, it has been

acknowledged that evaluations of participants' scientific literacy should not only include students' declarative formal understanding of science⁴⁶, but also their open-mindedness and ability to reflect upon their scientific knowledge beliefs (Hand, Lawrence, & Yore, 1999; Hogan, 2000; Zeidler, 1997). Understanding how a person's skills to evaluate scientific information develops as well as how one reflects upon his/her intellectual curiosity and beliefs about scientific knowledge is one way to more conclusively evaluate scientific literacy.

Educators and researchers who have advocated for the use of SSI-based interventions believe that social, epistemological, and evidential aspects of science can be learned in this type of educational setting (Kolsto, 2001a; Sadler, 2004a; Zeidler, 2003). This same group of educators and researchers contend that SSI offer the opportunity for learners to examine and develop their moral and ethical views about science, which in combination with the former will promote a functional understanding of scientific knowledge (McGinnis, 2003; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). However, SSI-based curricular interventions are a relatively new area of research (Sadler, 2004a, p. 515; Zeidler, Sadler, Applebaum, & Callahan, 2009). Those studies that have been identified as SSI interventions have explored primary or secondary student learning and have varied in scope and effectiveness (e.g., Barab, et al., 2007; Walker & Zeidler, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009). More research is needed to understand what components of a SSI-based curricular treatment are central to developing students'

⁴⁶ Declarative formal understanding includes aspects such as students' ability to evaluate evidence and conclusions based upon their conceptual understanding of content and the epistemology of professional science (Hogan, 2000).

scientific literacy. There is also a need to examine SSI-based interventions in postsecondary learning environments.

Motivational constructs in science education, such as interest, are often considered predictors of science-related decisions that affect learning, such as attending class, completing assignments, as well as the choice to engage and persist at a task (Koballa & Glynn, 2007; Palmer, 2005). A student's interest towards a science issue or activity has been defined as "specific, develops over time, is relatively stable, and is associated with personal significance, positive emotions, high value, and increased knowledge (Wade, 2001, p. 245)." Students' interests may also be viewed in the context of the "pupil's voice in education" (Baram-Tsabari & Yarden, 2007). In this case, student interest is associated with pragmatic as well as moral development of students by recognizing opportunities to learn about one's everyday world develops functional skills in addition to ethics and values (Baram-Tsabari & Yarden, 2007; Davie, 1996).

Sadler, Chambers, and Zeidler (2004) and others have shown that although SSI are believed to connect to a person's life, the use of SSI does not necessarily ensure students make personal connections to the science content (Zeidler, Walker, Ackett, & Simmons, 2002). In fact, Sadler (2004a, p. 531) has argued that SSI-based curricula need to begin including approaches that specifically focus on developing classroom science experiences with students' personal lives.

Seiler (2006, p. 338) has defined student interest-focused curriculums as responsive to or emergent from student interests. This type of learning environment provides an opportunity for students to influence their learning based upon questions,

curiosities, passions, or circumstances that influence them. Although studies have provided evidence to suggest student interests are integral to the construction of knowledge, recent reviews of science education research have also acknowledged a lack of empirical evidence identifying curricular strategies that stimulate students' interest (Koballa & Glynn, 2007; Palmer, 2005; Sadler, 2004a). Currently, the research literature examining how meaningful personal connections can be integrated into SSI-based curricula to foster scientific literacy is missing (Sadler, 2004a).

The SSI framework in this investigation sought to improve a diverse group of undergraduates' scientific literacy by stimulating their personal interest in science and developing their ability to evaluate scientific information. Diversity in this study, relative to Lee and Luykx's (2007) broad definition, has been defined by the limits of the data collected on the participants. Specifically, diversity in this study has been equated with issues of undergraduates' ethnicity, culture, prior science experiences, and gender. The student interest component of this curriculum incorporated opportunities for undergraduates to use their background, interests, and prior experiences to identify and then research areas of microbiology they recognized as personally relevant. The SSI chosen by students or infused into the laboratory experiments included topics such as Gene therapy and Antimicrobial resistance.

The data in this chapter have been analyzed to focus on how undergraduates' scientific literacy developed with respect to their personal growth towards science and the ability to evaluate information. Specifically, participants' ability to critically evaluate scientific information was measured by the examination of undergraduates' research projects, article exercise, and hands-on labs. Undergraduates' personal

growth was measured by their developed self-understanding, self-confidence, self-discipline, intellectual curiosity, clarified personal beliefs towards science as well as their acquisition of scientific knowledge in a real world context. Analyses of the data in this chapter comes from participants' 1) [Individual KEEP project](#), 2) [Group KEEP project](#), 3) [KEEP journals](#), 4) students' laboratory write-ups, 5) end of the semester lab quiz, 6) an anonymous end of semester evaluation, 7) anonymous mid-semester evaluation of students' study techniques, and 8) a start and end of the semester article exercise.

Data / Results

The discussion of the data from this study begins by introducing four participants, whose names have been protected. These four cases illustrate the diversity of students' interests and experiences with science. This section is followed by data demonstrating how opportunities to influence their learning affected undergraduates' ability to evaluate scientific information. Data is then used to show how this student interest SSI-based curriculum influenced students' personal growth. When relevant, descriptive statistics have been interjected to relate these case profiles to the general learning trends of all participants. Additionally, throughout the discussion of data on students' interests and ability to evaluate of scientific information I have given specific examples of ways my pedagogy may have influenced results.

Students' Diverse Interests and Experiences with Science

In this chapter Brandi, Rui, Wesesa and Gannon have been chosen to illustrate the diversity of students' interests and experiences with science. For example, two

education majors (Rui and Wesesa) and two non-education majors (Brandi and Gannon) students represent the percentage of non-science majors. Similarly, two of the four undergraduates were White Americans (Brandi and Gannon) while the other two were Asian and African American (Rui and Wesesa), representative of the ethnic diversity ratio. Three of the four cases (Brandi, Rui and Wesesa) were female. The students' reported that their desire to learn more about genetics, health/disease, diet/nutrition, or the environment stemmed from career, family history, or personal interests.

These four case's data also exemplify the different ways students' learning opportunities influenced their ability to evaluate scientific information. For instance, Gannon's case illustrated the minority of undergraduates who had prior successful experiences in science and who demonstrated relatively advanced abilities in researching, interpreting, and discussing scientific information. The other three undergraduates illustrated the ways the majority of the participants' scientific literacy skills developed over the semester. Each student also exemplified different ways undergraduates' epistemological beliefs were influenced by the SSI-based intervention.

The first participant, Brandi, was a local White American female from an upper middle class arts and technology high-school. Brandi was a freshman who declared a Government and Politics major with a particular interested in international relations. The classification of Brandi's undergraduate status (freshman, sophomore, excreta) and major are examples of manifestively coded data. Biographical

information such as year in school and major were obtained from students' first journal entry, where they explicitly stated their university status.

Brandi also claimed that she found science to be exciting, because "new scientific breakthroughs can completely change the way we function in society." Although Brandi viewed science as interesting, she acknowledged that science was challenging and not within her "comfort level." Despite Brandi's insecurities about science, her journal revealed open-mindedness towards bridge her career related interest in "government and society with science." As a result of this information, I coded (latently) Brandi's prior experience in science as insecure. I also assessed (interpretationally) her interest in biological weapons as a career related given her declared motivation to grow professionally. Specifically, Brandi stated that her interest in biological technology potential for warfare stemmed from her career aspirations, which she already acknowledged to be in government and politics.

Career Interest: I'm very interested in biotechnology and genetic engineering. I'd also like to learn about what scientists know about biological weapons. This is relevant to my life because I hope to concentrate my major in international relations, and because I may choose to minor in the study of responses to terrorism. In this field, and in today's world more than ever, the use of bio-weapons is a very current and urgent issue.

The second student, Rui, was an Asian American female born in the United States but her parents were born and raised in Korea. Rui was also a freshman, but had declared an Early Childhood Education major because of her passion "not just to help kids learn but also to help instill good moral values in them and show them that someone cares about them." Rui, found science to be hard and had not heard of microbes prior to this course. However, she was also open to learning about the role microbes' play in life and their impact on society. In Rui's first journal, she

identified an interest in learning more about the role microbes play in her family history. Specifically, Rui acknowledged that she was motivated to learning more about diabetes because of her grandfather's condition. As a result, I coded (latently) Rui's prior science experience as insecure and her interest in diabetes as family history.

Family History Interest: I would like to know more about the relationship with microbes in diseases and sicknesses such as diabetes. My grandfather has diabetes and I have been told my brother and I have a higher risk of getting it too. I am interested in how that works and what microbes have to do with that.

The third student, Wesesa, was a local African American female freshman majoring in early childhood education but was also interested in becoming a "paralegal for Family Court, to work with children who have been abused." Wesesa described her prior experience with science as being "rather boring... I really didn't like biology, chemistry or earth science in high-school because it really didn't captivate me." She also acknowledged that science did not come naturally to her. As a result, I coded (interpretationally) Wesesa's prior science experience as insecure.

Despite her negative experiences and insecurities, Wesesa claimed that the notion of learning about how microbes related to her life as an engaging concept. Wesesa identified an interest in learning more about the role microbes play in diseases that other family member suffer from. As a result, I coded (latently) Wesesa's interest as family history.

Family History Interest: My main interest in this class, has to deal with weight and genetics. I have always been told that me being overweight is normal because it runs in my family. I come from a family that is known for diabetes, high blood pressure, overweight, heart attacks and strokes for generations... which is why I am interested in what scientists know about it... This is relevant to my life because I want to be able to lose weight the correct way, I don't want to be left with the impression that I am always going to be big because it runs in my family. This is why Microbiology sparks my desire to learn... I realize that there is so much about microbes that I don't know, like the fact that I have microbes on and in me

The fourth undergraduate was Gannon, a middle to upper class White American male in his senior year. Although he stated that he was passionate about music, he declared himself an accounting major to ensure his future financial security. Gannon found science to be interesting, appreciated its logical nature, and in his pre-collegiate school science experiences had been successful at understanding concepts learned in biology and chemistry. As a result, I coded (interpretationally) Gannon among a minority of students who claimed to be confident and interested in science. Also because Gannon revealed that his interest in HIV and other deadly viruses stemmed directly from his current health condition, I coded (latently) his motivation to learn about microbes as being personal.

Personal Interest: I have an interest in what scientists know about preventing the spread of deadly viruses, such as HIV and Ebola... This subject is relevant to my life because everyday, for the rest of my life, I will be exposed to millions of microbes, which influence my health. Even if I were to live in a sterile bubble, my body would still be filled with many different species of microbes, which aid in digestion and other physiological processes. My intimate relationship with microbes is therefore inescapable, so I have resolved to learn more about them by taking this course on microbes and society.

In general, students' first journal entry revealed that the majority of students 21 out of 26 (81%) were insecure about their previous science exposure but expressed open-mindedness and curiosity towards learning how microbes were related to their life. Several of these students also admitted to finding science boring or uninteresting. Only a small percentage, 19% (5 students), claimed to be confident and interested in science.

All participants' initial interest(s) not only fell into one of the broad categories of genetics, health/disease, diet/nutrition, or environment, but also were latently

coded as either: 1) career related, 2) family history, or 3) personal. Career was related with students proclaimed future occupations. Family history was associated a student's desire to become more educated about their own life and life style because some family member has died or been diagnosed with a disease. Personal referred to students' desire for self-improvement but was not associated with a relative's death or illness. [Table 2](#) summarizes the four microbial biology areas students chose for their individual project by ethnicity and interest. [Appendix D](#) has more explicitly detailed the broad range of participants' individual and group projects by ethnicity, student, and connection to their topic.

Table 2. *Summary of Students' Individual KEEP Posters Topics by Ethnicity and Connection to Interest*

Ethnicity	Poster Interest	Connection to Interest			sum
		Family history	Personal	Career	
African American	Health & Disease	1	1	-	2 (50%)
	Diet & Nutrition	-	-	-	
	DNA & Genetics	1	-	-	1 (25%)
	Environment	-	1	-	1 (25%)
sum		2 (50%)	2 (50%)	0	
Asian American	Health & Disease	1	-	-	1 (20%)
	Diet & Nutrition	1	1	-	2 (40%)
	DNA & Genetics	1	-	-	1 (20%)
	Environment	-	1	-	1 (20%)
sum		3 (60%)	2 (40%)	0	
European American	Health & Disease	1	2	-	3 (18%)
	Diet & Nutrition	-	7	-	7 (41%)
	DNA & Genetics	-	3	3	3 (18%)
	Environment	-	1	-	1 (6%)
sum		1 (6%)	13 (76%)	3 (18%)	
Family history = some family member has died or been diagnosed with a disease					

Personal = has a personal vested interest
Career = related to student's future career

It was found that a higher percentage of African and Asian American undergraduates were interested in topics that affected a family member, while White European American students asked questions that were personal or related to their career.

Improved Evaluation of Scientific Information

Roberts (1995, 2007) has noted that scientific literacy can be demonstrated by evaluating evidence and conclusions as well as identifying problems for investigation, designing, and conducting research. Researchers examining a person's ability to evaluate scientific information have assessed skills such as discerning what constitutes scientific data (Tytler, Duggan, & Gott, 2001; Sadler, Chambers, & Zeidler, 2004), assessing the claims made in an article (Kolsto, 2001b; Kolsto, et al., 2006, Korpan, Bisanz, Bisanz, & Henderson, 1997), evaluating sources of information (Kolsto, 2001b; Kolsto, et al., 2006), and analyzing participants' use of evidence to support a position (Sadler, Chambers, & Zeidler, 2004; Sandoval, 2003; Wu & Tsai, 2007).

This section focused upon how this student interest SSI-based curriculum affected students' skills to evaluate scientific information. Specifically, data from students' research projects, writing assignments (on a popular scientific issue written for the popular press), and lab write-ups have demonstrated how participants' scientific literacy evolved with respect to their ability to evaluate scientific information. Undergraduates' lab quiz and journals supported the analyses of students' academic products.

KEEP Research Projects

Students' had two research projects infused into the laboratory curriculum to help develop their ability to evaluate scientific information by developing the skills to research, interpret, and discuss different perspectives about a socio-scientific issue. The first research project was individually based and completed mid-way through the semester. The final project was a team effort, concluded by the end of the course. The group project required that all students share an equal part in synthesizing their report. Students also gave a PowerPoint presentation, which required balanced participation. To ensure each member of the group was learning, students evaluated each other's effort within the group. Additionally, all students were evaluated and quizzed on their conceptual understanding of their topic during the final presentation by their peers and lab instructor. Interpretation of the data suggested that all team members demonstrated a conceptual understanding of their topic as well as played an essential role in the acquisition and comprehension of the information.

A comparison of students' individual and group projects suggested skills for researching reliable references and critically analyzing their issue improved. For instance, Brandi chose to research biological weapons and scientific censorship for her individual and group project. A comparison of Brandi's individual poster to the group report showed enhanced skills for identifying different theoretical perspectives, evaluating sources of information, and use of evidence used to support a position. Although Brandi's individual effort helped her begin to evaluate the issues related to biological weapons and scientific censorship, her individual poster also revealed that she 1) had an incomplete understanding of the different perspectives related to this

issue, 2) conflated theories and opinions, and 3) did not use data to support the claims she was making.

The overarching theory behind this issue is that, because our society's biotechnological abilities are constantly becoming increasingly advanced and powerful, terrorists from other countries will eventually become able to use microbiology research done in the US to attack our society, by manipulating dangerous microbes to develop biological weapons. Another important theory is that the same research used for good and beneficial purposes benefitting public health simultaneously has the potential to be used to develop weapons. The consequences of such a possibility are beginning to deter scientists from doing certain kinds of research. For example, this statement by Dr. J. Craig Venter is quoted in one article: "We were going to make a synthetic, harmless microorganism to study biology and evolution. But it became clear to me that if I developed those techniques, that would be publishing the blueprint to make a synthetic pathogen."

This section of Brandi's research poster reflects how her discussion of alternative perspectives related to biological weapons and scientific censorship really only focused on the potential for scientific research to be used in biological warfare.

Brandi did not reference studies or reports that support her use of "theory"⁴⁷. In this example, she supported her claim with an opinion statement of a renowned scientist.

Over the course of the semester, undergraduates not only received instructional feedback on their individual research poster, but the hands-on labs also included instructional time⁴⁸ focused on conceptualizing the differences between a testable question, hypothesis, theory, fact, inference, and opinion.

If this is a theory then where is the data to support this statement in your facts. You have not shown facts that suggest terrorists are capable of using the information in this manner. Remember that facts are occurrences, qualities, or relationships based upon measurements / observations of physical phenomena or may be inferred with certainty. A scientific question that can be tested asks if, when, or why and has defined limits. A hypothesis is a well tested explanation of the facts that seeks to predict future events. Theories are comprehensive explanations of hypothetical, conceptual, and pragmatic principles that predict future

⁴⁷ Theories are comprehensive explanations of hypothetical, conceptual, and pragmatic principles that predict future occurrences and have been repeatedly confirmed (Kinraide & Denison, 2003).

⁴⁸ Lab time dedicated to conceptualizing a testable question, hypothesis, theory, fact, inference, and opinion were often whole group discussions and PowerPoint presentations paralleling the scientific process to Maryland voluntary state curriculum 5-E model (Maryland State Department of Education, 1997).

occurrences and have been repeatedly confirmed. Theories build upon a hypothesis and have gained general acceptance within the scientific community but cannot be definitively proven.

This example demonstrates the type of pedagogical feedback I gave Brandi and others on their individual project. By the end of the semester the final group project, which Brandi was a part of, much more clearly and correctly identified different theoretical perspectives related to biological weapons and scientific censorship.

Specifically, we are interested in the acceptability of governmental attempts to classify or censor scientific research, and to coerce scientists to refrain from experimentation with certain pathogens that are potentially threatening... (One theoretical perspective is whether the risk of biological attack outweighs the potential benefits of research into disease prevention and other applications of biotechnology that would bring about advancements in scientific understanding and the arena of public health... Another theoretical perspective comes from, proponents of complete scientific freedom who predict that the limitation of information would accomplish little more than leaving the US woefully unprepared in the face of a biological attack... Too few precautions could mean that the US and the world are at greater risk of an attack, while too much limitation would impede scientific development.

This section of the research poster indicates how the group identified two alternative perspectives related to scientific censorship 1) the need to prevent terrorist abuse of biological technology and 2) resultant negative consequences to scientific advancements such disease prevention research. The group also cited reports that supported their theoretical discussion.

In Australia, a strain of mousepox was discovered, which had the effect of killing even mice that had been vaccinated, (Donohue, 2005). The mousepox was very similar to smallpox, and the findings of the experiment were published, despite the dangerous nature of the information. Though many scientists were dismayed that this research was published, its release resulted in members of the scientific community working together to find a vaccine for this pathogen... In 1920, The Irish Republican Army considered using typhoid-contaminated milk as a weapon against British soldiers. In 2005, a study by the National Academy of Sciences chose to suppress a report that analyzed the U.S. milk supply and the ease with which botulinum toxin could be introduced into it, and kill thousands of people.

This section illustrates two of several examples the group used to support or challenge scientific censorship. The discussion of mousepox supported the potential

threat scientific censorship could have on disease prevention. The National Academy of Sciences decision to withhold a report on introducing botulinum toxin into milk supports the need to withhold scientific research. Further, in Brandi's individual project she included 3 references at the end, but did not cite her claims throughout the paper. Of these 3 references, 2 made it into the Biological Weapons and Scientific Censorship group project which included 11 references cited throughout the paper.

With the exception of 3 students' individual projects, all group efforts showed similar progression with respect to evaluating scientific information even when members of the group chose a topic that was not based upon their individual poster. For example, Rui chose to research diabetes for her individual project. She was paired with Wesesa and one other student who expressed an interest in how microbes were related to health and genetic issues. As a group, these students chose to research the benefits and dangers of gene therapy in widespread medical treatments.

In Rui's diabetes project, she found 5 reliable sources of information (which were referenced at the end of her poster) and demonstrated some understanding of the different types of diabetes as well as how Type 1 Diabetes Mellitus (T1DM) has been linked to microbes. However, Rui did not demonstrate the ability to interpret the information in her own words. Rather she used direct quotes suggesting a lack of conceptual understanding. Rui also had alternative conceptions of what constitutes a theory, fact, inference, and opinion.

Many theories lead to the fact that everything is linked to microbes and microbial infections...."Type 1 diabetes mellitus **results from both environmental and hereditary factors**. It is suspected that microbial infections and their immunological consequences take part in the pathogenesis of T1DM. Congenital rubella infection has been strongly associated with increased disease susceptibility. In addition, infections with different strains of enteroviruses, human cytomegalovirus, and rotavirus have been suggested to be diabetogenic in susceptible individuals "... The generally accepted theory is that an "auto-immune"

reaction of the body physically destroys the beta cells in the pancreas where abnormal proteins get into the blood and in the body's attempts to destroy the proteins the beta cells in the pancreas are destroyed."

This section taken from Rui's individual poster shows her misunderstanding of what a theory is and demonstrated her heavy use of quotes rather than attempting to explain concepts in her own words. In Rui's discussion of the theoretical perspectives associated with T1DM, she used a quote that linked this disease to both genetic and environmental factors. However, in her subsequent discussion she never expanded upon the hereditary factors. Rather, she included more quotes that supported the role microbes (environmental factors) play in the pathogenesis. This suggests she did not have a complete conceptual understanding of the issue. Rui's journal further supported this interpretation.

In looking back at my initial scientific interest I realize... I learned so much about the different types of Diabetes, type one and type two... I still have questions about the detailed information about Diabetes... Although I researched information about Diabetes, early in the semester I wasn't necessarily confident in my ability to interpret all of the scientific information.

In Wesesa's case, she examined factors that have been associated with obesity. As with Brandi and Rui, Wesesa's individual project began to build her knowledge of the issue that she identified as most interesting and affecting her life. Wesesa's individual poster showed she had found 3 informative references, which she cited at the end of her poster. Wesesa, unlike Brandi and Rui, was able to identify different theories related to the causes of obesity. However, she did not demonstrate a conceptual understanding of them.

Theory 1: The bacteria that populate the gut play an important role in regulating weight including weight gain or loss. Theory 2: The interactions of genes and the environment are important in the obesity epidemic. Theory 3: Diet and exercise play a role in the prevention and treatment of obesity.

The fact about AD-36 is that AD-36 might affect fat cells directly by leading to an increase in fat-cell number and fat-cell size. The facts about gut micro flora are that they help create the capillaries that line and nourish the intestines... (It is also a) fact that there is a mismatch between today's environment and "energy-thrifty genes" that multiplied in the past under rather different environmental conditions.

This shows the 3 theories Wesesa identified but also reveals how she did not relate them to the rest of her report. This section also indicates some confusion about what is considered a fact. For example, she mentioned, "The fact about AD-36 is that Ad-36 might affect fat cells directly by leading to an increase in fat-cell number and fat-cell size." AD-36 is one of 51 types of adenoviruses known to infect humans and has been identified in 30% of obese humans and 11% of non-obese humans (Atkinson, 2007). Wesesa's claim of AD-36 affecting fat cells is a fact indicated that she did not have a conceptual understanding of what constitutes a fact. A fact is an occurrence, quality, or relationship based upon measurements / observations of physical phenomena or may be inferred with certainty (Kinraide & Denison, 2003). She also did not indicate that she recognized AD-36 as a virus, which further related obesity to microbes (American Society for Microbiology, 2006). Although AD-36 could be an environmental factor that affects the genetic regulation of cells since it stimulates enzymes and transcription factors involved in the accumulation of adipose (Atkinson, 2007), it was unclear if Wesesa had used this statement to support one of the theories. It was also not known what she understood about "gut micro flora" and "energy-thrifty genes" or if she was identifying them with one or more of the theories.

Wesesa's final journal further confirmed this interpretation of data.

I still have questions about the specific role of our gut flora and AD-36. I would like to have done more research on these topics...

The group project on Gene Therapy showed many improvements from Rui and Wesesa's individual project. The Gene Therapy poster not only cited 17 reliable references, but also included a discussion of two alternative perspectives supported by data that the students discussed in their own words.

Gene therapy has proven extremely controversial because there have been both great successes, as well as huge failures in clinical trials. There is much evidence that suggests that human testing is a "risky" venture and can lead to deaths. Jesse Gelsinger, an 18 year-old boy who suffered from ornithine transcarbamylase (OTC) deficiency, participated in a gene therapy study at the University of Pennsylvania. After receiving the treatment, Jesse experienced multiple-organ failure due to an auto-immune response to the transfer vector (Stolberg, 1999). Jolee Mohr, a 38 year-old woman who suffered from arthritis, received gene therapy treatment and later died of liver and kidney failure (Paddock, 2007)... On the other hand, there are multiple gene therapy trials that have been successful. A team from the National Cancer Institute successfully treated cancer using gene therapy. There were 17 patients who had melanoma and the team genetically engineered the patients' own white blood cells to recognize and attack cancer cells (National Cancer Institute, 2006). In 2006 an international group of scientists successfully treated two adults who had myeloid blood disease using gene therapy (Cincinnati Children's Hospital, 2006)....

This quote illustrates that students had an understanding of their socio-scientific issue. Students demonstrated an ability to identify and discuss different points of view surrounding Gene Therapy issue. The group also supported their discussion of the different perspectives related to Gene Therapy with relevant data.

Gannon's evaluation of scientific information in his individual poster was one of the three exceptions that did not demonstrate much progression with respect to his group's project. In Gannon's case, he not only demonstrated a sincere passion in his topic but also displayed mature academic skills that may have been the result of his senior status and prior success with science. For example, he sought the lab instructor's help in finding additional references on the benefits and negative side effects of using anti-retroviral medications to treat Human Immunodeficiency Virus (HIV) infection. Gannon felt the general public information he found did not disclose what questions scientists have about HIV and anti-retroviral medications. Gannon

desire to know more about HIV and the anti-retroviral treatment went beyond the literature written for the non-scientific community, but he did not know how to begin to access this type of information. I recommended he look at HIV InSite Gateway to HIV infection and knowledgebase (University of California San Francisco, 2008). Gannon not only studied textbooks to help him interpret what scientists had published in journals written for a scientific community, he also spent hours at the Marian Koshland Science Museum's HIV/AIDS exhibit to more completely understand his topic. Consequently, Gannon's individual project included 13 references, 5 of which were written for a scientific audience. He described the theory of HIV infection and replication with supported references. Gannon acknowledged the alternative perspectives of physicians' treatments for HIV infected patients. His individual project also demonstrated conceptual understanding and synthesis⁴⁹ of thought based upon the information he had gathered.

While the exact causes of the side effects associated with so many of the currently available antiretroviral medications remain unknown, there are several theories about how these drugs interact with cellular functions... For example, Non-nucleoside reverse transcriptase inhibitors (NNRTIs), Nucleoside reverse transcriptase inhibitors (NRTIs), and Protease inhibitors (PIs) can cause hepatotoxicity (liver damage), including hepatitis (inflammation of the liver), hepatic necrosis (death of liver cells), and hepatic steatosis (excessive fat in the liver, which may be life-threatening)... One theory is that liver damage caused by many antiretroviral drugs is likely due to the inability of liver enzymes to efficiently and effectively metabolize the chemicals in these drugs... (AIDS Treatment Data Network, 2006)... Another theory is when certain PIs are metabolized by liver enzymes, chemicals are produced that may interfere with glucose metabolism in the liver, leading to excessive glucose in the blood (hyperglycemia) (Mayo Clinic Staff, 2008)... It has also been theorized that when certain PIs are metabolized by liver enzymes, chemicals are produced that may interfere with lipid metabolism in the liver, leading to an accumulation of fatty acids in the blood (hyperlipidemia) (Mayo Clinic Staff, 2008)....

"I have concluded that developing a vaccination against HIV would be nonviable and unreliable. This season's influenza vaccination, for example, did not effectively prevent millions of U.S. residents from contracting this illness caused by the rapidly mutating

⁴⁹ Synthesis refers to the major category in the Bloom's Taxonomy of Educational Objectives. Thus, synthesis includes the ability to generalize from given facts, relate information to one's prior knowledge, and predict or draw one's own conclusions (Anderson & Krathwohl, 2001; Krumme, 2005).

influenza virus. It is unlikely then that a vaccine could be formulated to stop the spread of HIV given this virus mutates its nucleotide base sequence so rapidly that the provirus present in the genome of each infected white blood cell is different... I believe we must call to arms genetic engineering to fight HIV. Studies have found that a genetic mutation involving a naturally occurring deletion of 32 base pairs in the CCR5 gene, results in almost complete resistance to HIV infection (Greene & Peterlin, 2006)... Genetic engineering technology is currently capable of modifying the genomes of many organisms, including humans... Although it is presently illegal and unethical to genetically engineer humans, I believe it is unethical not to use available scientific knowledge to improve the quality of human life... I therefore conclude genetic engineering should be further researched to eradicate HIV from future generations.

These two sections of Gannon's research poster illustrates his ability to identify different scientific perspectives related to the side effects of antiretroviral treatments. It also shows his conceptual understanding of the information as he creatively applied his knowledge to propose a way to prevent HIV infection. Although Gannon's solution to eradicating HIV is more complicated than he acknowledged in his poster, he recognized that this was an area he would like to understand more about in his final journal.

I still have questions about the genetic aspects of these scientific processes... Through this course, I have learned that scientists still do not know many things about the functions of genes... My questions about this topic specifically relate to the use of genomic manipulation in preventative medicine.

Yet, given Gannon's limited laboratory experience and knowledge of genomics his idea was insightful and may one day be feasible. Consequently, the group project comparing the Human Immunodeficiency Virus to the Ebola Virus did extend Gannon's understanding of viruses, but could not significantly improve upon his individual effort. The group effort was equally impressive with respect to the level of understanding students demonstrated both in their KEEP poster and in the final presentation, where each team member shared an equal role in presenting their topic.

In general, it was determined that the individual project enhanced all undergraduates' understanding of how microbes affect their lives. All students also began to develop their ability to research, interpret, and discuss science issues. However, the majority of students' individual projects (54%) revealed some level of confusion about what constitutes a theory, fact, inference, and/or opinion. Interpretation of the data also indicated that 73% had difficulty identifying and/or discussing different perspectives related to their issue. Additionally, only a few individual posters also showed undergraduates were using higher-ordered synthesis or evaluation⁵⁰ skills. This may have been in part due to their inability to interpret the information discussed in the article. By the end of the semester, group posters showed each team had identified alternative points of view related to their topic and supported students' conceptual understanding of the socio-scientific issue.

Article Exercise

Students not only showed progression in evaluating claims surrounding a socio-scientific issue in a group, but the data from their article exercise also indicated they developed this skill individually. For example, within the second week of class Brandi chose to read *In Microbe, Vast Power for Biofuel* (Mufson, 2007), which was the article (out of 4 students chose from, see [Appendix B](#)) that most strongly aligned with her identified interests. A comparison of her start and end of the semester article summary and response to the 6 open-ended questions showed that she misinterpreted

⁵⁰ Evaluation refers to the major category in the Bloom's Taxonomy of Educational Objectives. Thus, evaluation includes skills such as comparing and questioning information, assessing the value of theories, making choices based on rational reasoning, verifying value of evidence, and recognizing subjectivity (Anderson & Krathwohl, 2001; Krumme, 2005).

some of the information and only once demonstrated higher-order evaluation of the ideas discussed in the article during the second week of class.

The author of the article presents the debate of natural versus synthetic microbes to accomplish the task of converting cellulosic material into ethanol. This is a two-step process. First, the cellulose must be broken down into sugars. Next, the sugars must ferment in order to produce ethanol. The author focuses on the advantages of using natural microbes, albeit in an unnatural way—such as using the microbe to break down plant material that would not be found in the microbe's natural environment... (Leschine's natural Q microbe) has become a very big project. Energy Department grants have already provided \$385 million in funding, and SunEthanol, the company that is hoping to market ethanol generated by Leschine's microbe, is hoping there are more grants to come... The Senate has proposed an energy bill that would require 21 billion gallons of biofuels to be used by the oil industry by the year 2022.

In this section, it was not clear if Brandi understood that only synthetic microbes produce ethanol in two steps, while the natural Q-microbe does both steps. This early response also suggests that Brandi had the ability to restate the content of the article to address the 6 open-ended questions, but did not creatively or divergently apply prior knowledge to synthesize her own ideas.

By the end of the semester Brandi acknowledged that “my analysis of this article has changed from my original response.” She also correctly represented the information and frequently used higher-order epistemological syntheses and evaluation of the data, opinions, and societal factors that were presented in the article.

Leschine (in favor of natural microbial production) and Venter's (in favor of synthetic microbial production) perspectives seem to differ when discussing the commercialization of their discoveries (of cellulosic biofuels). While the author asserts that Venter "raced the government" in the human genome project and explains that he is the head of a company, Synthetic genomics, Leschine is portrayed by the author as being more removed from the commercialization of her discoveries. The author quotes her saying "the last thing I wanted to do was start my own company," suggesting that she is more hesitant and reluctant to utilize her discoveries for business than Venter...

Data is given in the form of dates by which the Federal Government would like to see a significant amount of cellulosic biofuels in use (year 2022), amounts of money in funding and grants (\$385 million in Energy Department grants), and the number of machine-like proteins for absorbing sugars most microbes have (20) as compared to the Q microbe (100). However, very little data is given about the question of whether a natural microbe should be sought for production of cellulosic biofuels, as opposed to a synthetic or genetically modified

one. Only broad, general statements are made, such as the fact that genetically engineered enzymes tend to be expensive, whereas natural microbes that both perform the breakdown of plant fibers and facilitate the production of ethanol are difficult to find and harness.

These paragraphs of Brandi's final response highlight how she began to more critically evaluate the way the author told Leschine's Q microbe story. Further analysis of Brandi's final response also demonstrated she clearly understood the differences between synthetic and natural microbial processes involved in the production of ethanol.

Rui chose to read *Slimming for Slackers* (Trivedi, 2005), the article that most strongly aligned with her identified interests. Rui's first response to the article resembled her individual project in that she tended to use direct quotes rather than demonstrate conceptual understanding of the information in her own words.

(Jeffrey Gordon, director of the Center for Genome Sciences at Washington University) believes that gut microbes are very important in digestion... However, he also acknowledges that "*An individual's microbial brew is unique and reflects the history of the first two years of their life.*" And that right now we do not know all of the species of bacteria in our gut. "*Gordon's hypothesis is that this variation between individuals might mean that some people are significantly better than others at extracting energy from food and routing it for storage in the fat bank.*" ... He believes that there is a way to manipulate the gut bacteria that makes us fat into making us thin again. In order to do that you must "*find out whether gut flora differs in the quantifiable way between the lean and the obese.*"

This section illustrates Rui's frequent reliance on the author's interpretations rather than synthesizing her own interpretations or evaluating the information.

However, by the end of the course she demonstrated frequent higher-ordered thoughts and the ability to interpret what she had read in her own words.

Jeffrey Gordon, took on the challenge to find out whether there is a correlation between bacteria in the gut flora and body weight. An experiment took place where mice were housed in plastic bubbles where everything was sterile and bacteria-free. I find this part a little controversial because I wonder if it is possible to have a hundred percent germ free surrounding. And is it possible to live under those conditions? Wouldn't the mice be more susceptible to sickness if exposed to the outside? However, the author claims that the food

that the mice ate was bacteria-free and the mice were germ-free. The experiment showed that when the germ-free mice ate and ate they did not blow up like the normal mice but in fact were slimmer with "42% less body fat" than the normal mice... When the mice were exposed to microbes and ate normal food they practically gained the same weight as the normal mice within weeks. This shows that there is some kind of correlation between bacteria and weight, but the question is how and why...

In this corresponding segment of Rui's response, she no longer used direct quotes from the article. Rather, Rui demonstrated the ability to paraphrase the content of the article as well as interjected her own synthesis of thought based upon the knowledge she had acquired over the semester⁵¹.

Wesesa also chose *Slimming for Slackers* (Trivedi, 2005), which like Rui most closely aligned with her individual project. As with Wesesa's individual research project, her first interpretation of the article suggested she did not have a firm conceptual understanding of what she was reading. She also did not demonstrate an ability to synthesize or evaluate the information. For example, it was found that in her initial summary of the article she believed that Trivedi's (2005) presentation of research was chronological.

A researcher named Jeffery Gordon did some studies dealing with germ-free mice that led him to question whether or not gut microbes affect obesity in our country... Because of Gordon's experiment, two scientists (Edward and Lilian Moore) were able to collect flora gut and therefore Gordon expanded more on his idea of the link between obesity and gut microbes... Another researcher (Ruth Lay), based off of Gordon's findings, also experimented with germ-free mice and tried to approximate just how many gut microbes we have inside of us... So then another researcher, Jeremy Nicholson, came along with his interpretation that gut microbes were indeed linked to obesity, based off of his own experiment with germ-free mice... So basically the article was about a researcher named Gordon who found a link between obesity and gut microbes, which other scientists elaborated on...

This illustrates how Wesesa believed other scientists' work was the result of Gordon's experiment. However, Edward and Lilian Moore began characterizing and

⁵¹ Concepts such as microbes are everywhere and that scientists have only characterized approximately 1% of the microbial population were learned over the semester.

naming human gut bacteria in the 1960s. Ruth Lay was Gordon's postdoc, and both researchers published the study on genetically altered mice for the gene that codes the hormone called leptin (Ley, et al. 2005). This also shows that Wesesa summarized the article but did not attempt to synthesize her own thoughts or critically evaluate contradictions mentioned in the article.

Wesesa's end of the semester response not only indicated she had a better conceptual understanding of the article but she also demonstrated the skill to critically analyze the contradicting statements made by Trivedi (2005).

The article talked about microbes and their role in digestion. This idea was related to the experiments done with sterile mice that were germ free... My concern with these experiments is that these mice were suppose to be germ-free, meaning that they were not exposed to microbes. How is it, if microbes make up most of the earth including the animals and humans, that scientists are able to keep mice germ-free and unexposed to microbes? Also if the mice were germ-free and in a sterile bubble, then that must mean that the mice were born in this sterile environment. The article said, "A newborn gets its first major bacterial inoculation as it slides down the birth canal (Trivedi, 2005)." This must mean that in order for the so-called germ-free mice to be germ-free, than the mother mice had to be germ-free and born in this bubble too. Also, "a baby's bacterial community continues to expand during suckling and weaning (Trivedi, 2005)." So, I am still astonished at how these mice were germ-free and unexposed to microbes...It was found that the germ-free mice ate more than the regular mice, but were much thinner. However, when these germ-free mice were exposed to microbes; they gained weight...Gordan and Backhed think this is similar to humans. Microbes inside us, just like in the mice, break down plant fibers (Trivedi, 2005). The article talked about how our bodies are also affected by these gut microbes, but that microbes between two people or species are not the same... Personally, I feel that researchers should not make assumptions about the findings on the germ-free mice yet alone any mice, to humans.

This corresponding section of Wesesa's final response shows how she began to ask critical questions about the information presented by the author. Wesesa noted that Trivedi (2005) stated "a newborn gets its first major bacterial inoculation as it slides down the birth canal." Given that Trivedi (2005) also claimed the mice in Gordan's experiment were sterile, Wesesa's question about how this was possible was insightful. Although scientists would accept the term sterile if the mice were treated with antibiotics at birth and then placed in an environment that inhibited microbes

growth as detected by current assay techniques, this was not explained in the article.

These insights as well as Wesesa's discussion of the article indicated that she not only had a better understanding of the information she was reading but was also able to critically evaluate the claims made.

Gannon chose the In Microbe, Vast Power for Biofuel (Mufson, 2007) article even though Confusion in the Joints (Clayton, 1991) was closer to his identified health/disease interest. However, it was noted that despite 5 other undergraduates professed interest in health/disease only 2 students chose the Clayton (1991) article. Interpretation of this finding suggests that this article may have been more of a challenging read, was of less interest to the majority of undergraduates, or that many students had a general interest in alternative energy sources given the increase in gas prices. Gannon claimed "my initial response to this article has remained largely the same. Most of the changes I have made to my first submission involve the organization of my response to more clearly reflect my understanding of each aspect of this article." It was determined that both of Gannon's responses showed signs of applying prior knowledge to produce original thought and critically evaluating the claims made in the article.

I believe it may well be impossible for cellulosic ethanol production by the Q microbe, or by any microorganism, to meet worldwide demands for fuel. While the small size of microbes facilitates their storage in laboratories, and many species of microorganism can proliferate rapidly under optimal conditions, their diminutive nature makes the challenge of commercial scale production of cellulosic ethanol potentially insurmountable.

This quote highlights how Gannon not only had an understanding of the article. This excerpt also shows that he included his own insights and critically analyzed the claims made by Mufson (2007). It was also found that Gannon's reflection upon his

re-analysis of the article was accurate. Although he did expand upon his first response to this article, his insights remained the same and both responses showed insightful commentary.

Overall, there were 4 students who did not complete either the start or end semester article exercise and were not considered in the data analyses. Of the remaining 22 students, 19 included alternative conceptions about the information discussed early in the semester. However, only 2 students still indicated similar alternative conceptions by the end of the semester. Analyses of the data have suggested that these students used their original response as a template for their final summary of the article, which may have resulted in the same alternative conceptions carrying over from the start of the semester. It was also found that only 7 students' first summary of the article included application of their prior knowledge and/or judgment of the author's claims. However, by the end of the semester there was only one student that failed to include higher-ordered epistemological syntheses and evaluation of the data, opinions, and societal factors discussed in the article. Although, this student did show improved understanding of the content discussed in the article.

Laboratory Write-ups

The data from students' lab write-ups also indicated participants' epistemological understanding of science improved their evaluation of scientific information over the semester. For example, Lab 7 Ice Nucleation, was the first opportunity students had to design their testable question. When asked if their testable question was answered, 70% believed their data supported a conclusive

answer. The remaining 30% who decided that they had not answered their testable question attributed their inconclusive results to a procedural experimental error. During this lab, no students demonstrated a comprehensive understanding that even the most elaborate experimental protocols have uncontrolled variables, which prevents absolute conclusions. However, by their last experimental lab, all 22 students (completing their lab write-up) realized that their testable question could not be definitively proven. Rather, students discussed their data to support an experimental hypothesis they could test further. [Table 3](#) exemplifies how Gannon's reflected on factors that influence scientific results developed.

Table 3. *Summary Showing Gannon's Evolving Ability to Interpret Experimental Data*

Instances the testable question was:	Answered	NOT Answered
Lab 7 Ice Nucleation	14 (70%)	6 (30%)
Lab 10 Hand Washing 1	11 (48%)	12 (52%)
Lab 11 Hand Washing 2	6 (26%)	17 (74%)
Lab 13 Antimicrobial Substances	0 (0%)	22 (100%)

Lab 7 Ice Nucleation
Example: Testable question answered
<p>Testable question: Which of the following substance will nucleate ice formation in supercooled water: Ps, E.coli lac +, E.coli lac -, S. marcescen, B. subtilis, chalk dust, and soil?"</p> <p>Response: "Yes, my testable question was answered. I wanted to know which substances will nucleate ice formation in supercooled water, and my results demonstrate that all of them will. I suspect that all of these substances nucleated ice formation in this experiment because the temperature of the supercooled water was so low.</p>

Lab 13 Antimicrobial Substances
Example: Testable question NOT answered

Testable question: How do the household remedies of mouthwash, Purell, tea tree oil, and curry powder compare to the antibiotics of penicillin, streptomycin, and tetracycline (with respect to killing the bacteria *Bacillus subtilis* and *Escherichia coli*).

Response: Although a testable question can never be definitively answered, our results suggest that mouthwash, Purell, tea tree oil, and curry powder are not nearly as effective at killing microbes as are the commercial broad-spectrum antibiotics Tetracycline and Chloramphenicol. While these two antibiotics had average kill zone radii of 8 mm, Purell and tea tree oil each had an average kill zone radius of only 1 mm, and mouthwash and curry powder had no kill zone at all. I believe that two major variables affected our results: 1) movement of the paper discs after they were placed on the agar plates, and 2) inconsistent saturation of the sterile paper discs with Purell and curry powder... These experimental conditions should be considered to improve our results. If we were to repeat this experiment, we would use an electronic balance to measure equal amounts of Purell and curry powder and then place these substances directly on the agar plates, instead of trying to coat the paper discs with them. We would also incubate the plates somewhere they would remain stationary.

Although Gannon's data has been exemplified, this table also illustrates the types of simple questions all students designed for two of their laboratory experiments.

Gannon's conclusions also demonstrate how undergraduates reasoning of whether they answered their testable question improved. As a class the findings have indicated that over 4 labs students developed an awareness that data cannot definitively prove an event; rather data are used to support conclusions (hypothesis or theories) that attempt to predict future events. For example, in Gannon's first response he did not attempt to discuss the unexplainable variables his group generated when performing their experiment. However by the end of the semester students realized the importance of reporting inconsistencies in their data that need to be further examined.

The results from students' end of the semester lab quiz strengthened the analysis of their lab write-up. For example, when asked to "Explain whether the scientific process is linear or circular. Justify your answer with a specific example." All students 26 claimed they believed it to be circular process that does not result in conclusive results. All 26 participants also referenced their laboratory experiences

where they had an opportunity to design and redesign their experiment based upon their first protocol's results as a specific example. For example, Brandi, Rui, Wesesa, and Gannon claimed:

Brandi: The scientific process can be better compared to a circular model than a linear one. This is something I have learned throughout this year, especially as we started making up our own experiments in lab. For instance, at the start of this course, I imagined that in lab we would do experiments by following a linear progression of steps, and coming up with a simple end result. But this year, I have learned that there is much more to the scientific process. When I invented my procedure for the labs, I always ended up finding myself re-working my protocol or re-doing my experiment after gaining additional knowledge or data that I needed to factor in. Thus, my own process in lab ended up being much more circular than linear.

Rui: Circular, it is a never ending circle that more can be added on to. Before this class I would have said it was linear because in my science classes it was always a constructed list of question/hypothesis, procedures, etc. But my eyes were definitely open to how the scientific process can be very much circular... One example would be the two Hand-washing labs where we had a chance to repeat the same experiment but better the question and procedures. My group did the same question but found more interesting data the second time around that we didn't expect at all...

Wesesa: The scientific process is circular. The processes involved creates a cycle where information is used and gathered based on questions and information amongst each process that elaborates on the previous process by facts, observations and data. At the beginning of this course, I would have taken a wild guess and said circular... because I had the opportunity to test my own experimental designs, I have learned a lot about the scientific process... The hand washing labs were good examples of this. We had to change our protocol and even question, based off of the evidence found in previous experiments... Also this my research projects have allowed me to see the many different viewpoints and criticism that arise from scientific information. For example, there are many who support genetic therapy because of the successes, but at the same time, there are many who do not support it because of its failures...

Gannon: The scientific process is circular. Testable questions stimulate investigation through experimentation, which produces results from which conclusions may be drawn that often lead to more questions, thus beginning the circle again. At the start of this course, I would have said that the scientific process is linear because that was the way it was presented to me during high-school, and I therefore believed that every experiment that was appropriately designed to answer a testable question provided a definite "yes" or "no" answer. I have learned that scientific knowledge distinguishes itself from other ways of learning by possessing an inherent skepticism not found in other forms of learning... Through my experiment in Microbes and Society laboratory, I have learned that science cannot exist without skepticism... In testing my experimental designs, I was grateful for the skepticism of the lab instructor and my classmates, as their questions about the conclusions I drew from my experimental results always prompted me to change my protocol and control for errors, and, in doing so, obtain more accurate results.

Science educational research has shown that viewing a lack of data, as a weakness for a claim is a skill that most students do not demonstrate (Sandoval, 2003). It has also been found that although students may have an awareness of the

tentativeness of science, they do not use this knowledge when reasoning their positions to others (Walker & Zeidler, 2007). Yet, proponents of the SSI movement believe learning environments that use this framework can facilitate students' reasoning such that the tenacious and social aspects of science are considered (Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). The findings from this study have suggested that students learned to recognize a lack of data as a weakness for a claim and used this knowledge when evaluating scientific information.

The Motivational Effectiveness of This Curriculum on Students' Personal Growth

Considering the majority of data presented thus far from a contextual constructivist perspective⁵², an argument could be made that perhaps students' demonstration to more critically evaluate scientific information did not evolve over the semester. Rather, undergraduates' developed an understanding of how to respond to course assignments based upon the explicit feedback they received over the semester. If this were the case, then students' personal reflections upon their research and lab activities would not have correlated with the data analyses showing participants improved their ability to critically evaluate scientific information.

It has been argued that the incorporation of SSI into curricula should enhance students' scientific literacy in a way that fosters open-mindedness, thirst for more information, an ability to identify bias, and reflect critically (Kolsto, 2006; Oulton, Dillon, & Grace, 2004). Personal growth refers to the development of self-

⁵² A contextual constructivist model is often associated with examining student learning and understanding with respect to the social or environmental structures forming the educational experience (Finkelstein & Pollock, 2005 pg 6; Hammer & Elby, 2002). That is, the cognitive

understanding, self-confidence, self-discipline, intellectual curiosity, thinking about the acquisition of knowledge in a real world context, and clarifying personal beliefs (Belcheir, 1999; McLure, Srikanta-Rao, & Lester, 1999). Consequently, understanding more about how undergraduates grew on a personal level is another way to assess how effective this SSI-based curriculum was at fostering students' scientific literacy. This section discusses the effects of the student interest SSI-based curriculum on students' personal growth.

Acquisition of Knowledge in a Real World Context and Personal Beliefs

Interpretation of the data suggests that undergraduates' furthered their thinking about the acquisition of knowledge in a real world context and clarified their personal beliefs. It was found that all students perceived several benefits to exploring areas of microbiology that they acknowledged as most relevant to their life. Brandi, Rui, Wesesa, and Gannon's final reflective journal illustrate the impact this student interest SSI-based curriculum had on their personal growth.

Brandi: My interest in science initially was founded in the same things I am interested now, but this class has helped me see some of the things I care about in a different light, or from a different perspective. Looking back at my initial interest, I realize that science has an influential role in government and politics (my intended major) and depends on an array of knowledge and factors... My individual and group projects (on biological scientific censorship issues have) especially helped me explore this idea... Being in this class has helped me learn how to make scientific information more accessible. I feel more confident about being able to learn and understand scientific information on my own...After understanding more about science, how we know what we know, and how that knowledge affects society, I find myself agreeing with my original assumption that society, government and politics, and microbiology are all linked and are relevant to one another.

Rui: In looking back at my initial scientific interest I realize that there is so much more to microbes role in society than I ever thought... For example, in researching Diabetes, for my individual project, I learned so much about how there are two different types and some of the facts and issues about Diabetes... Although, I still have questions about the detailed information I found when researching Diabetes... I'm really glad that I researched this topic because now I have background knowledge on my Grandpa's condition... I also believe I can make sure that my family and I have healthier diets and lifestyles... I was also excited about

structures determining a student's understanding and processes for learning are circumstantial in nature (diSessa, 1993).

my group project topic because I had no idea what gene therapy was but I now realize it is an interesting topic that has a lot to do with microbes...

Wesesa: In looking back at my initial scientific interest, I realize that the relationship between weight and genetics is broad. I was unaware but impressed at the many different explanations for obesity... I have learned a tremendous amount of information about my initial scientific interest that I did not know about before... I wanted to know if genetics were the main reason why some people in my family are bigger or smaller than others... After understanding more about our gut flora, exercise, healthy eating habits, and the role that metabolism plays, I find myself disagreeing with my initial belief that genetics caused obesity in my family... I now know that all of these factors contribute to a person's size... My group project, on genetic therapy, has also showed me how scientists have many different viewpoints and there are criticisms that arise with scientific information. There are many who support genetic therapy because of the successes, but there are many who do not support it because of its failures.

Gannon: Looking back on my initial scientific interest (HIV) I realize that my enthusiasm for learning about the scientific processes that occur inside my body and in the natural environment around me energized me to learn a great deal of information about the relationships between microbes and society... I have learned so much about my initial scientific interest in understanding the scientific processes inside my body that I have become more conscious of healthy habits and methods of preventing the spread of infectious disease... My initial opinion about HIV and Ebola was that these diseases were very different, almost polar opposites... Approaching this topic, which was the focus of my Group Project... I find myself disagreeing with my initial beliefs... I now believe that (scientific) knowledge could be used to develop an effective (treatment to prevent viral) infections in the future.

These journal entries show how important this learning environment was to students' growth as individuals. Students not only applied their acquired knowledge to their everyday lives, but also had the opportunity to clarify their personal beliefs. Out of the 26 participants in this investigation 23 realized their initial perspectives of their topic had changed after having the chance to examine their socio-scientific issue(s). The three students that claimed they confirmed their initial beliefs still acknowledged that this course helped them see some of the things they "care about in a different light, or from a different perspective", as Brandi stated.

As was mentioned in the improved evaluation of scientific information section, the article exercise and the hands-on labs also provided opportunities for undergraduates to clarify their personal beliefs and apply their knowledge to their everyday life. For instance, Brandi and several other students stated in their final

response to the article exercise that their initial interpretation had changed and/or their skills to critically evaluate the claims made by the author had improved. Data on participants' explanation of whether the scientific process is linear or circular also provided personal belief insights. Students' lab quiz indicated that the majority of students (16) acknowledged that their original linear perception scientific process had evolved into a more circular model based upon their laboratory opportunities. Of the remaining 10 students, only 3 claimed their circular view of the nature of scientific processes was confirmed; while the other 7 students did not comment upon the impact this course had upon their understanding.

Acquisition of Knowledge in a Real World Context and Intellectual Curiosity

The anonymous end of the semester evaluation can also be used to show how participants were thinking about science in a real world context. In addition, the anonymous end of the semester evaluation and students' journal show how undergraduates' intellectual curiosity towards science increased. For instance, the Likert Scale question "The individual project helped me to learn more about how science relates to my life" and the open-ended question "Explain your response" showed 95% of students who responded to this question agreed they learned more about how science related to their everyday life.

The issue (HIV) that I investigated definitely applies to everyone and influenced my life. My new understanding has helped me understand how it affects me... I liked how we were able to pick our own topics so that we were all interested in our topic.

When asked if "the individual project engaged my interest" 90% of students who responded to this question agreed. The paralleling questions for the group project revealed similar findings.

The hands-on labs were another way students' interest in science was fostered. When asked to anonymously reply and explain whether the laboratory activities increased their interest in science again 90% of students agreed.

I found the Hand-Washing Lab interesting because it caused me to become more careful in my activities and how easily you can spread diseases and germs... (I also liked that) we designed our own experiments and were able to tweak them and do them again, considering other variables.

The Antimicrobial Substances Lab piqued my interest about what kind of products actually clean the best and how they can make such claims as "KILLS 99% of GERMS!... I liked how we could design our own experiment.

Undergraduates' open-ended response indicated that they correlated their heightened interest in science with the pragmatic applications of the labs and their opportunities to design and test questions.

It was also found that despite the majority of participants' negative prior science experiences, all students' journal entries identified questions that they would like to explore further. Brandi, Rui, Wesesa, and Gannon's end of the semester journal entry illustrate the types of questions students' wanted to know more about.

Brandi: I still have questions about how we gain information and verify a lot of the scientific information we use. Of course, I don't expect an intro level non-major science class to reveal all of the ways we use and gain scientific knowledge. However, it is something that I am interested in learning more about, and I'm sure that I will...

Rui: I still have questions about the detailed information about Diabetes and different diseases... Scientists and researchers are still in the process of finding the unknown questions about diabetes and how it initially occurs...

Wesesa: I still have questions about the specific role of our gut flora and AD-36... I would like to have done more research on carbohydrates and maybe even calories.

Gannon: I still have questions about the genetic aspects of these scientific processes... I have learned that this is a very technical subject and that scientists still do not know many things about the functions of genes. My questions about this topic specifically relate to the use of genome sequencing in preventative medicine...

Consequently, data from the anonymous end of the semester evaluation and students' journaling supported participants thinking about science in a real world context and continued curiosity to learn more about how science relates to their life.

Self-Confidence and Self-Understanding

The end of the semester anonymous evaluation and students' journal also shows how undergraduates' self-confidence and self-understanding developed. For instance, all students responding to the question "I am more confident in my ability to read scientific information" agreed. Similarly, 95% felt they were more confident in their ability to find and discuss scientific information. Undergraduates' journaling supported their anonymous beliefs.

Brandi: I definitely feel more comfortable gathering and taking in scientific information than I did at the beginning of this semester. I think that is one thing I have gained the most from being in this class. I have also noticed myself thinking about and discussing other unrelated subjects, like government and literature, with an increased awareness, and in the context of science. I must admit that at the beginning of the semester I felt a little scared of science; I felt like I was just not a science person and I was worried about whether I would do well in the class, but I have gotten a lot more comfortable since then.

Rui: I definitely feel more confident and comfortable discussing scientific information. Science was never a strong point for me and in the beginning of the semester I was really lost but now I definitely feel much more comfortable. I enjoyed how the hands-on labs were practical and related to my everyday life. For example, I recently got a cut and from my knowledge about anti-bacterial products, I knew how to keep it from getting infected... I began this course with not being confident or interested in science, but I realized through out the course of the semester how important science is to my life. As a result, I see how everything in the world relates to science and I feel more confident in my skills to find answers to my questions, such as issues related to health and diseases.

Wesesa: I feel a lot more comfortable than before discussing, reading, hearing, or finding scientific information. Before this course, I would have not made much sense of scientific information. I would have read the information and would have had no clue of what was going on. Also, I would not have been able to engage in a discussion about scientific information. However, now I feel very comfortable with myself and science. Now I can explain the scientific information I read, hear, and find...I do not feel a 100% confident with reading, hearing, finding, or discussing scientific information, because I realize that I still do make mistakes interpreting the information, but not as many.

Gannon: I feel much more confident and comfortable reading, hearing, finding, and discussing scientific information. Through the writing assignments and the projects in lab, I have gained confidence in my ability to read a piece of scientific literature that I would have considered way over my head just last semester, and actually understand it... During lab, I asked many questions about concepts, experimental procedures, and interpretation of results... The individual and group projects improved my confidence in finding and discussing scientific information. During my high-school science courses, I was required to write a few research papers, but these never required more than the course textbook and a quick Google web search. Through these projects, I have learned to find scientific information in primary sources like peer-reviewed journal articles... I have learned that this type of information can be found easily with Google Scholar, PubMed, and various U.S. Government databases... I believe this knowledge will (benefit me in the future) in the field of science or in any other subject.

As with Brandi, Rui, Wesesa, and Gannon all undergraduates' reflections suggested they had a new found self-confidence, which changed how they viewed their *self* with respect to evaluating and understanding scientific information.

Self-Discipline

With respect to self-discipline, researchers have found that a students' interest can predict those decisions that affect learning such as attending class, completing assignments, as well as the choice to engage and persist at a task (Koballa & Glynn, 2007; Palmer, 2005). Given that the majority of participants (81%) had negative prior experiences with science, they demonstrated engagement and persistence towards learning over the semester. The data from this doctoral dissertation have suggested that this SSI-based curricular and pedagogical intervention was effective at motivating students to learn about science.

The anonymous mid-semester evaluation instrument was one way students' motivational self-discipline was assessed over the semester. Frequency counts of students' Likert Scale responses indicated that on average 18 students (over 68%) spent over 3 hours preparing for each exam by studying independently and/or in groups, and no student reported studying less than an hour on 2 exams. The anonymous mid-semester evaluation also revealed that over half of the undergraduates attended a study group for the first 2 exams. It was also recorded that weekly attendance to lecture was above 80% even though students were not required to attend.

Analysis of students' prior science experience relative to their final grade⁵³, ethnicity, and gender supported all students were successful in learning about ways microbes relate to society and demonstrated increased scientific literacy, as no student performed below average (below a C). What was even more encouraging was that the majority of the class 21 out of 26 students (81%) received an above average (B or better) final grade. [Table 4](#) summarizes students' prior science experience relative to their final grade, ethnicity, and gender.

⁵³ Over the course of the semester, students' final grades were assessed from content examinations, writing assignments, research posters, and laboratory performance.

Table 4. *Students' Diversity and Overall Curricular Achievement*

Prior Science Experience	European American				Asian American				African American				Total	Final Grade
	F	Final Grade	M	Final Grade	F	Final Grade	M	Final Grade	F	Final Grade	M	Final Grade		
Confident and likes science	3	3 A 0 B 0 C	2	2 A 0 B 0 C	0	0 A 0 B 0 C	0	0 A 0 B 0 C	0	0 A 0 B 0 C	0	0 A 0 B 0 C	5	5 A 0 B 0 C
Insecure but interested in science	5	2 A 2 B 1 C	3	1 A 0 B 2 C	3	0 A 3 B 0 C	0	0 A 0 B 0 C	3	0 A 3 B 0 C	1	0 A 0 B 1 C	15	3 A 8 B 4 C
Has never been motivated to learn science	3	1 A 2 B 0 C	1	1 A 0 B 0 C	0	0 A 0 B 0 C	2	0 A 1 B 1 C	0	0 A 0 B 0 C	0	0 A 0 B 0 C	6	2 A 3 B 1 C
Total	11	6 A 4 B 1 C	6	4 A 0 B 2 C	3	0 A 3 B 0 C	2	0 A 1 B 1 C	3	0 A 3 B 0 C	1	0 A 0 B 1 C		

This table shows the five students who were confident in science initially did very well throughout the semester and were White European Americans. However, out of the 21 students who claimed to be insecure in their science ability or have never found science interesting, 16 also achieved an above average score. The data from this case-study also indicated that none of the 9 African and Asian American students achieved an A in this course.

The weekly notes I took in my practitioner journal also supported the time and effort students were putting into their work. Examples of the ways students showed interest and effort included 1) staying late after lab to get advice on their research topic or material covered in lecture and lab, 2) asking for study groups, and 3) posting questions in the ELMS help thread. Scoring of my weekly practitioner journal indicated that I interacted with 20 out of the 26 students several times over the

semester in two or more of these ways. I also recorded the pedagogical techniques I used to facilitate students continual engagement with the course. For example, when students shared with me some of the initial references they had found for their individual project I made sure they were reliable. If students had difficulty finding reliable sources, I would give them some example resources and explain (both in person and on-line) why some sources offered questionable information. Many students were also interested in study groups at the start of the semester but expressed concern in getting help from their peers because they did not know their classmates well enough. Consequently, for the first two exams I asked a few strong students to hold review sessions. I wrote on the board days and times these selected students suggested they could meet and others signed up for one or more sessions. After the first few exams, students had established relationships and formed their own study groups.

Another way students' motivational self-discipline was measured, relative to their choice to engage and persist at a task, was by analyzing how frequently undergraduates chose to research their identified interest over the semester. Although students were asked to journal about an interest they had that related to microbes, they were not required to investigate this issue for their research projects or the article exercise. Analysis of undergraduates' journal relative to their research projects showed that 24 out of 26 students did in fact investigate their initial questions as an individual and in a group. Further, the analyses of group projects, which were completed at the end of the semester, indicated students' ability to research and evaluate scientific information improved. It was found that one student wished she

had focused more on her initial topic of interest, the spread of disease but chose Bt corn⁵⁴ for her individual project and her group settled on researching biofuels. The other student chose a topic for both the individual and group poster she already knew something about, *Escherichia coli* (E. coli). This same student felt she would have gained more from doing more lab experiments, although she did admit to gaining some insight from working in a group.

Karina: In looking back at my initial scientific interest of disease and the spreading of bacteria I realize that there is a lot more that I have to learn. I wish I would have done my projects on disease rather than BT corn and Biofuels.

Freya: I have learned not really that much about my initial scientific interest. For my individual and group project I focused on E. coli and not Parkinson's disease... I kind of already knew about the effects of my individual project... I felt like we could have spent more time focusing on labs instead of projects... It helped me a little because we looked at different view points. Again, I feel like lab would have been more beneficial if we were actually doing LABS instead of PROJECTS.

It was also found that 21 students chose the article that was most closely associated with their identified interest(s). Analysis of the data from the article exercise indicated that although few undergraduates demonstrated the ability to synthesize and evaluate data, opinions, and societal factors at the start of the semester, over 95% were applying their prior knowledge and/or judging the author's claims by the end of 15-weeks.

In addition to undergraduates' recognition of the hands-on labs fostering their interest in science, opportunities to design laboratory experiments further supported students' motivational self-discipline. Over the course of the semester, the hands-on labs challenged students to go beyond identifying controls and analyzing data to also

⁵⁴ Bt corn is a variant of corn (aka maize) that has been genetically bioengineered to be toxic for select insects, such as corn borers. Specifically, the gene from the soil-dwelling microorganism *Bacillus thuringiensis* (thus Bt) has been inserted into the corn genome. This gene codes for a toxin that crystallizes in the digestive tract of insect larvae, which leads to its starvation (Wolt, Peterson, Bystrak, & Meade, 2003).

synthesizing and designing a testable question. These later labs not only required undergraduates to spend more time preparing for lab, but also necessitated more time be given to their recording and evaluation of data. It was found that students' laboratory write-ups showed more in-depth reports of their procedure and data analyses. Despite the increased effort required for each lab, the anonymous end of the semester evaluation indicated that 86% of the undergraduates' responses correlated their heightened interest in science with one of the later labs (ice nucleation, hand-washing, or antimicrobial substances).

Summary

Overall, this study has suggested that having the opportunity to explore SSI and influence one's educational environment were important factors toward developing undergraduates' scientific literacy. Brandi, Rui, Wesesa, and Gannon were used to illustrate the different ways learners' scientific literacy improved over the semester. Scientific literacy was measured by students' personal growth and ability to evaluate information.

With respect to evaluating scientific information, Brandi, Rui, and Wesesa as well as the majority of undergraduates began the semester with apprehensions about their ability to understand science. They also demonstrated difficulties researching, interpreting, and discussing science knowledge. Consequently, Brandi, Rui, and Wesesa exemplified the different ways the majority of undergraduates' skills to evaluate scientific information improved over the semester. In Brandi and Rui's case both had trouble identifying different theoretical perspectives and conflated theories and opinions at the start of the semester. However, Brandi also had trouble

supporting her claims, while Rui did not demonstrate the ability to interpret scientific information in her own words. Wesesa on the other hand, was able to identify alternative scientific perspectives related to the causes of obesity at the start of the semester but did not indicate a conceptual understanding of them. Wesesa also had a misconception about what constitutes a fact. All undergraduates had naive perceptions of how scientific data are generated and used to answer questions about everyday life. In general, by the end of the semester Brandi, Rui, Wesesa, and the majority of undergraduates showed the greatest gains in 1) researching and interpreting scientific information, 2) identifying and critically analyzing perspectives related a socio-scientific issue, 3) supporting their claims with relevant information, and 4) understanding the epistemology of the scientific process.

In Gannon's case, as well as a few other undergraduates, he acknowledged and demonstrated an interest in science as well as the ability to understand scientific information at the start of the semester. However, this is not to say that Gannon and the other undergraduates did not benefit from this student interest SSI-based curriculum. In fact, Gannon's story has further exemplified why it is important to offer learners more chances to influence their educational environment. It was found that opportunities to shape his learning acted as an incentive, which resulted in his desire to excel at researching, interpreting, and discussing scientific information. Specifically, Gannon's greatest gains were in finding and interpreting information written for a science audience as well as advancing his epistemological understanding of the scientific process.

However, Gannon along with Brandi, Rui, Wesesa, and the other participants in this study recognized how beneficial this SSI-based curricular framework was to their personal growth. In Gannon's case, he recognized the value to his life in having a much more in-depth understanding of what scientists actually know about HIV and anti-retroviral treatment research. Gannon's personal connection to HIV resulted in his passionate demonstration of self-discipline in being able to read and comprehend information written for scientists. However, the majority of undergraduates used their research opportunities to develop their understanding of an area of microbiology that they recognized as influential to their life. In Brandi's case, she focused on furthering her career by learning about how science, society, government, and politics are connected. Rui and Wesesa reflected on health related issues that affect their life and family. Whether undergraduates identified career, family, or personal SSI, in general it was determined that students developed their self-understanding, self-confidence, thinking about scientific knowledge in a real world context, and clarified their personal beliefs.

It was also found that all undergraduates' awareness of the epistemology of the scientific process changed their personal beliefs about how scientific knowledge differs from other ways of knowing. Undergraduates associated their newly formed opinions with the opportunities they had to design and test pragmatic questions in lab such as the importance of washing one's hands.

Despite over 80% of the participants beginning the semester with negative science experiences and apprehensions about their ability to understand science, students demonstrated self-discipline and intellectual curiosity towards SSI. The fact

that all students showed improved scientific literacy skills supports the effectiveness of this student interest SSI-based curricular framework.

Limits of the Data Analyses

However, it is not known how students' conceptual understanding of microbiology influenced their ability to evaluate scientific information. Several studies have suggested that students' conceptual understanding of science content can influence their ability to evaluate socio-scientific information (Hogan, 2002; Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002; Tytler, Duggan, & Gott, 2001). It has also been argued that "a large sophisticated knowledge base in a content domain does not determine the quality of thinking skills used in the domain (Kuhn, 1991, p. 39)." Sadler and Donnelly (2006) and others have proposed that a student's ability to justify a claim is reflective of their knowledge threshold (Sadler & Fowler, 2006). A person's knowledge threshold is a point where one has a sufficient conceptual understanding of the science content to demonstrate correct use and reference of the subject matter to support his/her claims (Sadler & Donnelly, 2006; Sadler & Fowler, 2006). It has also been suggested that a SSI-based curricular intervention can positively affect students' conceptual understanding of science content (Zohar & Nemet, 2002). This investigation has offered no insights to prove or disprove these speculations, as the data analyzed did not focus upon how participants' content knowledge may have affected their ability to evaluate scientific information.

It is also not clear to what degree students' demonstrated scientific literacy, with respect to more critically evaluating scientific information will translate into

their everyday living. Considering epistemological theoretical frameworks (Buehl & Alexander, 2001; Hammer & Elby, 2002), it is quite possible that this SSI-based curriculum and the instruments used in this study affected undergraduates' responses in a domain-specific manner. Domain-specific responses suggest that students' scientific thinking would only be characterizable within the context of this course and the instruments used (Hammer & Elby, 2002). For example, students' journal at the end of the semester explicitly asked participants to reflect upon their initial interest(s) and opinion(s) in the context of this course. Despite undergraduates professed beliefs that their initial perspectives of their identified topic(s) have changed, no data was collected on if and how students applied this knowledge outside of this course. However, several students made claims in their journals that leaned towards supporting this idea.

This class has definitely given me a new perspective on many aspects of life. Mostly, it has taught me not to settle for convenient answers, but rather to question everything. For example, my friend was talking to me about something she had read in a magazine about losing weight by drinking soup. Normally I would just say, "cool," and take her word for it. But this time I starting asking her a lot of questions about the theory, including who claims this?, is the person qualified in the nutrition field? What studies have they done to come to this conclusion? etc. It seems that I have become much more skeptical of credentials and the researching process.

Overall I think that I have learned to enjoy science...(I have also) realized that learning how (science) affects our everyday lives does not have to take place in a classroom, but can take place in our world.

Even though I am still not planning on making science my career, this course has added greatly to my understanding of the world around me, and this is something I can carry with me for the rest of my life. When my kids ask me how they got chicken pox or why the milk went bad, I will be happy to have my microbial answer at hand.

This study did not seek to verify these statements. It has also been argued that domain-specific experiences are an essential step in developing students' ability to reason in SSI-based frameworks (Zeidler, Sadler, Applebaum, & Callahan, 2009).

Further, questions can be asked about what role the SSI framework played in promoting students' ability to more critically evaluate scientific information to make more informed decisions about science issues that affect them everyday. That is, could another student interest focused curriculum built upon a different educational model for teaching science, such as Science-Technology-Society (STS) or inquiry based learning, have promoted a similar outcome? Similarly, the same question could be asked about the significance the student interest aspect with respect to the SSI-based curricular activities. For instance, would students have demonstrated the same level of skill development with respect to evaluating scientific information if the learning activities were more scripted? Given the recently transformed general microbiology laboratory setting of this case-study, where the student interest focus was an aspect of the SSI-based learning activities and no other treatments were tested, these questions have not been definitively answered. However, the data from this chapter supporting students' improved functional scientific literacy skills warrants further investigation of the uses and limits of this curricular model. A more complete discussion of these questions can be found in [Chapter 6](#).

Foreshadowing Emerging Insights

Until now, researchers had not examined how meaningful personal connections can be integrated into SSI-based curricula (Sadler, 2004a). In fact, studies that have been identified as SSI-based interventions (e.g., Jimenez-Aleixandre & Pereiro-Munoz, 2002; Keselman, Kaufman, Kramer, & Patel, 2007; Zohar & Nemet, 2002) have mainly focused on primary and secondary learners. As well, motivational factors that are known to engage students have rarely assessed

postsecondary learning environments (e.g., Palmer, 2005; Rivet & Krajcik, 2008; Seiler, 2001, 2002, 2006). Consequently, this study has expanded the SSI-based framework by showing how effective personalized hands-on SSI-based labs and research opportunities can be at fostering undergraduates' scientific literacy.

It has been suggested that one way to help students become more scientifically literate 21st century learners is to rethink the way science content is acquired and encourage students to search independently for information and then evaluate it (Solomon, 2000). Solomon (2000) has contended that this type of approach to science can help to motivate learners who are more interested in exploring their self-identity than of the sciences. The findings from this investigation have supported Solomon's (2000) assertion.

It was determined that students' personal beliefs were reassessed and their skills to evaluate scientific information improved after having opportunities to influence their learning. When given a chance to choose what topics they could learn more about, the majority of students frequently selected social issues about microbiology relevant to their life. For students' KEEP projects, 92% of students researched their initial interest(s). Although generalizations were made about the type of connections students formed with their research interest, it was found that the diversity of students' lives and experiences resulted in unique associations with their topic. For the article exercise, 81% chose an article related to their identified interest. Similarly, laboratory experiments that required students to design their experimental protocol about real science issues affecting society (such as the importance of washing your hands) were experiences the students valued and found stimulating.

These motivational connections encouraged students to engage with the science content, despite many having negative prior experiences with science.

Interpretation of the data have also shown how undergraduates developed skills to evaluate scientific information. Students' individual and group projects suggested improvement in researching and discerning scientific information, which in turn helped them re-evaluate prior beliefs. Data from the writing exercise showed 95% of the undergraduates were using higher-ordered epistemological syntheses and evaluation the data, opinions, and societal factors that were presented in their article by the end of the semester. The data from students' lab write-ups and lab quiz indicated participants' epistemological understanding of science improved their evaluation of scientific information over the semester.

However, the interpretation of data in this chapter can be expanded further to more closely examine the effects this curricular and pedagogical intervention had on undergraduates' epistemological conceptualizations. Investigating students' understanding of the NOS with respect to their ability to informally reason and their personal beliefs will provide more insight into how this curricular and pedagogical framework contributed to developing participants' scientific literacy. [Chapter 5](#) focuses more exclusively on the analyses of participants' data to show how undergraduates' conceptually based formal knowledge about the epistemology of professional science matured, which influenced their informal reasoning and beliefs.

Yet as I examined the data further to more completely understand the effects this student interest SSI-based curriculum and pedagogical intervention had on undergraduates' scientific literacy, more questions arose. In addition to understanding

how conceptual knowledge and domain-specific responses may have affected the reported findings, questions can be asked about how universal this curricular framework is to other science disciplines and grade levels. Further, how prepared are teachers to implement a student interest SSI-based curriculum? The discussion in [Chapter 6](#) combines the emerging insights that have come out of both [Chapter 4](#) and [5](#). Resultantly, [Chapter 6](#) more completely establishes the implications of this doctoral dissertation to future science education research.

CHAPTER 5: Nature of Science Conceptualizations Influence on Informal Reasoning

Findings

Overview

In [Chapter 4](#), the data analyses alluded to ways in which participants' Nature of Science (NOS) conceptualizations developed. For example, it was discussed that early in the semester the majority of undergraduates had some level of confusion about what constitutes a theory, fact, inference, and/or opinion. This chapter more exclusively focus upon students' understanding of the nature of scientific discovery, processes, and justification with respect to their ability to informally reason and their personal beliefs.

Similar to [Chapter 4](#), [Chapter 5](#) begins by introducing the focus and relevance of the findings to the education research community. The next section has reports the data relevant to the effects this curricular and pedagogical intervention had on participants' understanding of the nature of scientific discovery, processes, and justification with respect to their ability to informally reason and personal beliefs. Emerging insights related to educational research literature are discussed within each NOS domain (discovery, processes, justification, and personal beliefs). Quotes from students' data and descriptive statistics are used to report the general findings. When relevant, I have included reflections on my pedagogical practices that may have influenced the learning environment and reported outcomes throughout this results section. Following the data and results section, I summarize the significant findings. A discussion of the limits of data analyses follows. I conclude this chapter by foreshadowing the emerging insights in [Chapter 6](#).

Chapter Focus

Two principle research questions were proposed to examine how this SSI curricular and pedagogical intervention, including a student interest-focus, affected undergraduates' ability to informally reason. The first of these was "What effects did this curricular and pedagogical intervention have on undergraduates' evaluations of socio-scientific information (SSI)?" The other question proposed was "What effects did this curricular and pedagogical intervention have on undergraduates' Nature of Science (NOS) conceptualizations?" Given that [Chapter 4](#) explicitly focused on the first question, this chapter focuses on the second question.

The NOS, also known as the epistemology of science or science as a way of knowing, defines values, assumptions, and processes inherent to scientific knowledge (Bell & Lederman, 2003, p. 353; Bell, Lederman, & Abd-El-Khalick, 2000, p. 564). These values, assumptions, and processes include science being a product of human imagination and creativity, a social process, empirically based, and limited by technology, as well as the epistemological activities related to the collection and interpretation of data (Abd-El-Khalick, 2003, p. 42; Aikenhead & Ryan, 1992; Hogan, 2000). The NOS has been explicitly emphasized in recent reform movements as an essential component in achieving scientific literacy (AAAS, 1989, 1993; NRC, 1996). Educators and researchers who advocate for the use of SSI-based interventions have claimed that social, tentative, and empirical aspects of science are learned in this type of educational setting, which in turn promotes more informed reasoning about scientific issues in an everyday context (Sadler, 2004a).

Informal reasoning, has been defined by Perkins (1985, p. 562) and Mean and Voss (1996, p. 140), among other cognitive and developmental physiologists, as the process of considering a claim where the reasoner weighs and synthesizes the pros and cons to arrive at the best sound judgment. Theories of informal reasoning also assume people's positions change as additional information becomes available and they ponder causes, consequences, positions, and alternative solutions (Mean & Voss, 1996; Perkins, 1985). SSI have been identified as ideal candidates for developing informal reasoning skills about science issues affecting one's life as they are 1) inherently complex, 2) open-ended with multiple perspectives, and 3) lack definitive answers (Sadler, 2004a, p. 515).

It has been argued that an individual's informal reasoning about science issues is influenced by a person's beliefs (e.g., Baron, 1991, 1995, 2000; Toplak & Stanovich, 2003; Zeidler, 1997). For example, Baron (1991, 1995, 2000) and others have noted that the lack of open-minded thinking can impede how rigorous a person is about evaluating opposing beliefs when informally reasoning (Toplak & Stanovich, 2003; Zeidler, Walker, Ackett, & Simmons, 2002). Sadler, Chambers, and Zeidler (2004) have indicated that students favor socio-scientific perspectives that are aligned with their prior beliefs, resulting in evaluative decisions based on personal relevance rather than contemplation of evidence. Zeidler (1997, p. 787) has also contended that beliefs and inferences can cause a person to conflate the truth and validity of alternative scenarios.

Additionally, others have acknowledged that a person's epistemological beliefs about his/her own scientific knowledge is not necessarily reflected by one's

ability to articulate that knowledge (Hammer & Elby, 2002; Hogan, 2000; Sinatra, Southerland, McConaughy, & Demastes, 2003). For example, a student may learn to acknowledge in a survey or questionnaire that scientific knowledge is tentative in nature but can still hold the personal belief that scientific data are definitive proof of an event. It has been found that high-school and undergraduate students' beliefs about the NOS have influenced the way in which they learn science (Leach, Millar, Ryder, & Sere, 2002; Ryder & Leach, 2000; Ryder, Leach, & Driver, 1999; Sere, et al., 2001; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006).

Hogan (2000, p. 57) has defined students' proximal knowledge structures as beliefs, commitments, or personal theories about the nature of science because they are associated with personal relevance and experience (knowledge structures nearest to the individual). An individual's beliefs about the NOS can be developed from personal experiences such as engaging in television, radio, and newspapers as well as learning from family, friends, formal education, and life experiences (Schommer-Aikins, 2002; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006). In contrast, she has described declarative knowledge formally taught about the methods and goals of professional science as distal knowledge (Hogan, 2000, p. 57). An example of an individual's conceptual knowledge of the epistemology of professional science includes being able to distinguish an observation from an inference and a scientific law from a theory. Resultantly, Hogan (2000) and others have acknowledged that if the goal of understanding NOS conceptualizations is to help enrich students' lives to make better informed decisions, then it is important to examine both students' declarative formal knowledge about the scientific enterprise and their beliefs about

the nature of science (Hand, Lawrence, & Yore, 1999; Hogan, 2000; Yang, 2004; Zeidler, 1997).

Recently, Vhurumuku, Holtman, Mikalsen, & Kolsto (2006) have shown that analyzing high-school students' laboratory work and written responses to NOS questions provided insights into participants' proximal and distal images of the NOS. In this investigation, a SSI framework has been used to measure as well as develop undergraduates' proximal and distal knowledge of the NOS. Specifically, social issues in science were used as a framework for both hands-on laboratory and research experiences to uncover participants' conceptual understanding of the NOS as well as challenge students to examine their prior beliefs and reasoning (Sadler, Chambers, & Zeidler, 2004; Zeidler, 1997; Zeidler, Walker, Ackett, & Simmons, 2002).

This chapter advances what is known about undergraduates' proximal and distal knowledge of the NOS and SSI-based curricular interventions. Consequently, the data analyses focus on how undergraduates' NOS conceptualizations developed with respect to their informal reasoning and social beliefs about science. Specifically, participants' NOS conceptualizations were measured by their 1) [KEEP journals](#), 2) [Individual KEEP project](#), 3) [Group KEEP project](#), 4) laboratory write-ups, 5) end of the semester lab quiz, 6) anonymous end of the semester evaluation, and 7) article exercise responses.

Data / Results

This section discusses the results of this investigation with respect to the nature of scientific discovery, processes, and justification. The focus of these three sections demonstrates how students' distal knowledge structures of the NOS affected

their ability to informally reason. This discussion is supported by data that have shown undergraduates' proximal knowledge of the NOS also developing.

The nature of scientific discovery has been defined as being a product of human imagination and creativity, a social process, rational, objective, empirically based, and limited by technology (Abd-El-Khalick, 2003, p. 42). The nature of scientific processes have been defined as more specific extension of the rational, objective, and observable aspects of the nature of scientific discovery. Consequently, the nature of scientific processes includes those values and epistemological assumptions underlying the activities related to the collection and interpretation of data, as well as the derivation of conclusions. However, Lederman, Abd-El-Khalick, Bell, and Schwartz (2002, p. 499) have pointed out that the nature of the scientific processes should not be conflated with science processes, which are the actions of collecting, interpreting, and deriving conclusions from data. For example, the scientific process of observing have been referred to as physical process of examining phenomenon (or group of phenomena) undergoing manipulation. This is restricted to a limited number of variables observed at one time and includes control variables by which change has been measured. Consequently, the nature of scientific processes includes an understanding that observations are constrained by our perceptual apparatus and some level of subjective interpretation. The nature of scientific justification has been referred to science being theoretical. This also includes tenacious characteristics of scientific interpretations that are subject to change based upon the limitations of human interpretation and infinite complexities (Abd-El-Khalick, 2003, p. 42).

The Nature of Scientific Discovery

Differentiating facts, theories, and opinions

Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) and others have asserted that it is important for students to be able to understand how scientific knowledge, which seeks to be objective and empirically based, is also influenced by underlying epistemological assumptions (Lederman, 2007). However, science education researchers have found that high-school and collegiate students may not possess the ability to differentiate theories, conclusions, hypotheses, and conjectures from opinions (Zeidler, Walker, Ackett, & Simmons, 2002). It has also been shown that many high-school students are not able to identify and explain the use of data in any meaningful context (Sadler, Chambers, & Zeidler, 2004).

At the start of this study the majority of students', 54%, individual KEEP poster revealed some level of confusion about what constitutes a theoretical perspective. Most students conflated theories and opinions. Additionally, analyses of the data indicated that only 7 students (27%) were identifying and supporting their claims about scientific perspectives with facts. The remaining 19 students (73%) failed to identify and / or support their assertions with relevant facts.

Data from students' start of the semester article exercise also supported the results from participants' individual KEEP posters. For example when asked, "Are data used to support the perspective(s)? If so, describe the data and how they are used?" At the start of the semester, 59% (13 out of 22 students⁵⁵) did not recognize

⁵⁵ Four students did not complete either the first writing exercise or final writing exercise. Consequently, the data from this instrument only included 22 student responses.

data in their article, conflated opinions with facts, and / or cited the author's concluding summary statements as supporting data.

Over the course of the semester undergraduates not only received instructional feedback on their individual research poster, but the hands-on labs also included lessons explicitly focused on helping students' conceptualize the differences between a testable question, hypothesis, theory, fact, inference, and opinion. One example of how this was accomplished was the use of the Maryland Voluntary State Curriculum 5-E Pedagogical Model (Maryland State Department of Education, 1997). Over the course of the semester, students became more responsible for defining and testing their experimental questions. I used the Maryland Voluntary State Curriculum 5-E Pedagogical Model (Maryland State Department of Education, 1997) explicitly discuss NOS conceptualizations. For instance, to help students conceptualize that the scientific process was not a defined set of steps that advance in a linear manner connections I created a PowerPoint presentation which used a circular diagram to discuss the 5-E's, see [Figure 4](#).

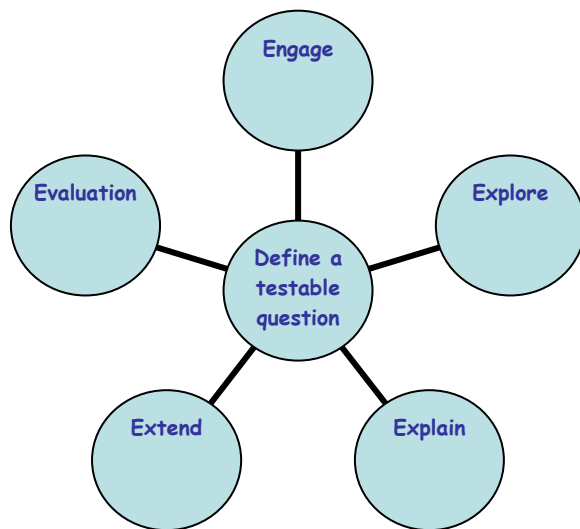


Figure 4. This figure is an illustration of the diagram used in a PowerPoint presentation to facilitate explicit discussion on the nature of scientific processes.

Table 5 shows the connections that I made during lab between the 5-E model and conceptual definitions related to the scientific process.

Table 5. *Associating the 5-E's Model to the Circular Scientific Process*

5-Es	MVS* Pedagogical Model Focus	Circular Scientific Process Focus
Engage	Activities focus on capturing the student's attention, stimulating their thinking, and accessing their prior knowledge	Defining a testable question Definitions of a fact ¹ , inference ² , testable question ³ , hypothesis ⁴ , and theory ⁵
Explore	Focus on thinking, planning, investigating, and organizing collected information	Observation of a phenomenon (or group of phenomena) undergoing manipulation with a limited number of variables Creating control variables to measure change by collection of data
Explain	Analysis of exploration	Interpretation of results Discussion of NOS concepts related to data interpretation (dependence upon accuracy of instrumentation, expertise using and interpreting instrumentation, and subjective interpretation)
Extend	Expand and solidify understanding of the concept and/or apply it to a real world situation	Assessment of the data relative to the testable question (is the data logically measuring the question asked, what claims can be made given the data limits)
Evaluate	Evaluation occurs throughout the lesson. Scoring tools developed by teachers to target what students must	Comparing result interpretation(s) with respect to expected outcomes

know and do.

* MVS = Maryland Voluntary State

1 = A fact is an occurrence, quality, or relationship based upon measurements / observations of physical phenomena or may be inferred with certainty (Kinraide & Denison, 2003).

2 = Inference is the method of testing a hypothesis by deliberately attempting to demonstrate the falsity of the hypothesis (Kinraide & Denison, 2003).

3 = A scientific question that can be tested asks if, when, or why and has defined limits (Kinraide & Denison, 2003).

4 = A hypothesis is a well tested tentative explanation of the facts that seeks to predict future events. A hypothesis that repeatedly withstands attempts to demonstrate its falsity gains credibility, but remains unproven (Kinraide & Denison, 2003).

5 = Theories are comprehensive explanations of hypothetical, conceptual, and pragmatic principles that predict future occurrences and have been repeatedly confirmed. Theories build upon a hypothesis and have gained general acceptance within the scientific community but still cannot be definitively proven (Kinraide & Denison, 2003).

This table demonstrates how the desire to prepare future K-8 science teachers, an aspect of the NSF funded project (Marbach-Ad, et al., 2008; Project Nexus, 2005), was integrated with fostering students' conceptualization of the scientific processes.

By the end of semester, group posters cited relevant facts to support the different theoretical points of view identified. As well, students' final article exercise revealed that 91% (20 out of 22 students) identified data in their article. Further, students' lab quiz has also suggested that students recognized, over the course of the semester, how personal opinions differ from scientific knowledge. When asked "In what ways is scientific knowledge different from other ways of knowing?" All 26 students' responses indicated they recognized the process of science as being based upon observed phenomena (facts) and seeking to be objectively rational.

Scientific knowledge is different from other ways of knowing in its inherent presence of doubt and questioning. Throughout our lives, many people make statements to us that they do not support with facts or evidence... The hallmark of scientific knowledge is that it has been supported by experimentation to test questions about the nature of many aspects of the universe. Scientific articles published in journals are peer-reviewed by experts and researchers who often repeat each other's experiments to confirm their findings. Scientific knowledge is advanced every day by doubt and questioning. Scientists strive to learn why certain events and processes occur and frequently question historical explanations and interpretations, pushing the world closer to the ultimate, yet unattainable goal of absolute truth... I have learned that scientific knowledge distinguishes itself from other ways of learning by possessing an inherent skepticism not found in other forms of learning. Throughout elementary, middle, and high-school, I was always taught to

accept my teachers' statements as absolute fact simply because the teacher said they were... I accepted that these things just happened, that I did not need to know why... Though my experiment in the Microbes and Society laboratory, I have learned that science cannot exist without skepticism... In testing my experimental designs, I was grateful for the skepticism of the lab instructor and my classmates, as their questions about the conclusions I drew from my experimental results always prompted me to change my protocol and control for errors... This helped me to realize how scientific knowledge is supported by experimentation, which is advanced every day by doubt and questioning... Scientists strive to push the world closer to the ultimate, yet unattainable goal of absolute truth.

Additionally, 20 students (79%) also acknowledged that their exposure to this course had fostered this same understanding. The remaining 6 students did not mention in their responses the role this course had on developing their awareness of the nature of scientific discovery.

Societal Factors Influence on Scientific Discovery

Studies examining NOS conceptualizations have shown most high-school and collegiate students are able to identify societal factor's influence on scientific discovery such as economics, personal interests, as well as social causes and effects (Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002).

The data from students' KEEP research posters, article exercise responses, and end of the semester lab quiz aligned with these findings. All participants in this study were able to identify ways that societal factors influence scientific discovery. However, data analyses indicated that students' general understanding of how societal factors can influence the nature of scientific discoveries grew over the 15-weeks. For example, when asked to identify "How societal factors might have influenced the perspective(s), explain?" All students identified at least one societal influence that possibly affected the author's perspective at the start of the semester. The most common factors identified were economic and societal causes. However, at the start

of this course, only 7 students showed signs of synthesizing⁵⁶ and evaluating⁵⁷ the societal factors they identified. After continuously being asked to reflect upon the connections between microbes and society during their research projects, hands-on labs, and lecture all 19 participants by the end of the semester, included higher-order thoughts in their final discussion of the article. [Table 6](#) provides examples, for the two most commonly selected articles, illustrating how students began to use higher-ordered epistemological thinking when identifying societal factors influence on scientific discovery.

Table 6. *Students' Evolving Ability to Synthesize and Evaluate Societal Factors*

Article	Instance	Response
Biofuel	Start	Brandi: "The societal need for a cost-effective, efficient alternative to fossil fuels seems to be driving the project."
	End	Brandi "One societal factor that might affect the perspectives is the fact that these scientists are not only trying to discover a microbe, but they are also in business, attempting to market a microbe to alternative energy companies. Also, the Senate has passed legislation, which may be driving the project, in that the government is offering tax cuts and subsidies for oil refineries that mix cellulosic ethanol into their gasoline. Thus, the societal factors driving this project are the personal needs of each person or entity involved: the gas companies want to maximize their profit, scientists are patenting and wanting to sell their microbes, those giving grants want to see the money put to good use, and alternative energy companies like VeraSun Energy want to be able to produce enough cellulosic ethanol to turn the power of microbes into a business."
Slimming for slackers	Start	Liza: "Social factors defiantly made a difference in what Jeffery Gordon cited as his first reason for the experiment and the name of the article. He said, "[Helping] people eat fewer calories without focusing on their calorie intake – that really is the zillion dollar question (Trivedi 2005)."
	End	Liza: "Social factors are a big issue when reading this article."

⁵⁶ Synthesis refers to the major category in the Bloom's Taxonomy of Educational Objectives. Thus, synthesis includes the ability to generalize from given facts, relate information to one's prior knowledge, and predict or draw one's own conclusions (Anderson & Krathwohl, 2001; Krumme, 2005).

⁵⁷ Evaluation refers to the major category in the Bloom's Taxonomy of Educational Objectives. Thus, evaluation includes skills such as comparing and questioning information, assessing the value of theories, making choices based on rational reasoning, verifying value of evidence, and recognizing subjectivity (Anderson & Krathwohl, 2001; Krumme, 2005).

Everyone wants a quick fix to weight loss, without giving up his or her life style. After all, why give up chocolate when you can just take a microbe pill and not gain any weight from it? So when reading this article for the first time the reader is more inclined to ignore the subtle holes poked in the research by the author and get excited about the possibility of the quick fix to be discovered soon. I think the author may have done this intentionally. He/She fulfilled their obligation to show both sides, but did it in a way that left the reader excited and wanting more. After all, that is what sells papers. Purely looking at the research side there is also a social influence. The weight loss industry, especially in America, is huge. And if Gordon's lab can come up with a quick fix that actually works, they would be rich, and so would their investors. So there is an incentive to skew the results or only report positive results. Finally Gordon cites helping the poor people in other countries as a reason for this study. But the reality is that if these people can't afford enough food to eat, they will not be able to afford to get their gut microbes catalogued. And even if this service were provided for free, if you are starving you are not going to be picky about what you eat. It just doesn't make sense. I think this is his attempt to feel like his is doing something good for humanity and not just researching the latest weight loss craze."

This table exemplifies how students began to generalize from the facts, and became more critical of subjective claims by recognizing ways societal factors may have influenced the author's perspective.

Similarly, 24 out of 26 students identified societal factors in their individual KEEP posters. However, students' group posters presented more in-depth analyses of potential societal influences, which accompanied changes in the way they were synthesizing their thoughts and evaluating the information.

Ozzie's individual KEEP poster While utilizing corn to create ethanol seems like a good idea for the US because of its large amount of maize crops, the same doesn't hold true for the rest of the world. For example, the Chinese recognized the threat to their food supplies... The European Union (EU) began to recognize the dangers to rainforests and the risk of forcing up food prices... I believe that, while fuel alternatives to gasoline must be found quickly, we still have a long way to go before any actual fuel will be ready for mass consumption. It seems that for each biofuel we are using, there is a side effect that negates any beneficial aspects of its use.

Team Biofuel's KEEP poster Economic and geopolitical factors (high oil prices, environmental concerns, and supply instability) have been prompting policy-makers to put added emphasis on renewable energy sources... (Stephanopoulos, 2007). The U.S. Department of Energy has set a goal of replacing 30 percent of gasoline used in the United States with fuels from renewable biological sources by 2030, and President Bush has made ethanol production a priority (Savage, 2007)... biotech startup companies are positioning themselves to take advantage of an anticipated booming market for biofuels (Savage, 2007). A 2008 Swiss government study determined that

biofuels were worse than fossil fuels in terms of total environmental impact, because cultivation of biofuels was driving the destruction of natural ecosystems for agriculture (Atkisson, 2008)... While utilizing corn to create ethanol seems like a good idea for the US because of its large amount of maize crops, the same doesn't hold true for the rest of the world... The Chinese recognized the threat to their food supplies, and put a halt to new corn ethanol projects... The European Union (EU)... announced that they would be issuing a certification scheme and promised a "clampdown on biodiesel from palm oil which is leading to forest destruction in Indonesia" (Rapier, 2008)... Unlike fossil fuels, which are limited resources, biofuels such as ethanol can get renewably brewed from biological material such as sugar. However, ethanol's energy content is just two-thirds that of gasoline by volume. In addition, ethanol can corrode metal and plastic, damaging car parts and gas pumps (Choi, 2008)... The topic of biofuels is important because economic and energy constraints are forcing scientists to try to develop cheaper and more efficient forms of renewable energy sources. Gasoline is becoming very expensive and scarce; therefore other methods of fuel are a necessity. On the political side, America and other free nations have a dangerous dependence on foreign oil. We depend on the Middle East, specifically Saudi Arabia, for much of our domestic oil needs. Many believe with a new fuel source, we can stop being so dependant on other nations and therefore be a stronger nation ourselves. Fossil fuels are a finite fuel source and we cannot indefinitely continue to consume oil and coal at our current rate. Environmentalists are also interested in biofuels due to the greenhouse gases emitted but by our gasoline burning cars, planes, and other forms of transportation. Biofuels may hold the key to finding a better balance between humanity and nature... *After examining the information, we gathered about biofuels, we have also come to the conclusion that biofuels, at this point, are an ineffective source of energy. They are too expensive and costly in both money and energy. They are also not nearly as efficient as regular fossil fuel... This does not mean however, that exploring biofuels is not a wise investment. We as a country and as a planet need to find alternate sources of energy and with new technology and advancements; it is possible that biofuels could one day be the solution.*

Although both research posters' contents have been abbreviated, this example shows several differences between Ozzie and the Team Biofuel poster. For instance, it is apparent that Team Biofuel extended the number of referenced societal factors. Both underlined sections show that students' were synthesizing their thoughts based upon their proximal knowledge⁵⁸ of the need to find alternative energy sources. However, there was a difference in how students' were using their prior knowledge to reason. In Ozzie's case, he focused on his personal interest; while Team Biofuel extended their reasoning to discuss economic and political issues. The bold and italicized text have highlighted the difference in the way Ozzie and Team Biofuel evaluated their

⁵⁸ A individual's proximal knowledge of the NOS can be developed from personal experiences such as engaging in television, radio, and newspapers as well as learning from family, friends, formal education, and life experiences (Schommer-Aikins, 2002; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006).

topic. Although Ozzie's response indicated he did attempt to analyze the information he read while researching his topic, he did not acknowledge that any alternate source of energy would have positive and negative ramifications. Further, Ozzie's discussion of the different types of biofuel indicated his knowledge about this alternative energy source was incomplete. Conversely, even though Team Biofuel reached the same negative conclusion about this alternative energy source, they acknowledged the potential of this alternative energy source. Team Biofuel also more thoroughly researched the different types of fuels made from plants and other forms of biomass.

Additionally, students' lab quiz showed all 26 participants recognized some connection to societal factors when asked to "Discuss the relationships/connections of science and human endeavors?"

Science greatly impacts human endeavors because it provides potential ways for improving society. Likewise, human endeavors affect what is researched in science because individuals want to research things that will be profitable. For example, discoveries of microbes that can produce ethanol are now used to support the human endeavor of finding alternate fuel sources.... I have also learned that the human endeavor in science requires individuals to be extremely critical. For example, when we write our post labs there are always things in our experiment that we could have done better or factors that we did not control for that may have affected our results... I have also learned that individuals achieve different results when they conduct experiments which is why it is so important to compare results with other individuals. For example, when we did our micro arrays, different groups got different colors and intensities on their slides. Had we formulated interpretations just on our own results, we would have come to incorrect conclusions.

In this case, the student recognized that scientists' efforts are often motivated by the desire to improve society as well as driven by the needs of society. Additionally, this student's response has also exemplified the way participants began to recognize that science is subject to human interpretation and limited by experimental design.

The end of the semester lab quiz also supported that students' learned more about how the nature of scientific discovery differs from other ways of knowing.

Taken as a whole, a comparison of the data from early and late student KEEP research posters and article exercise responses as well as the lab quiz, have suggested that undergraduates' understanding of the nature of scientific discovery developed.

The Nature of Scientific Processes

Sandoval (2003) has argued that there are several reasons why it is important to teach science inquiry in a way that fosters an epistemic understanding of how scientists ask and experimentally test questions. Specifically, he has pointed out that 1) analyzing evidence and data are goals of the national science reforms (AAAS, 1992; NRC, 1996), 2) students' conceptually based formal knowledge of the NOS can influence their ability to conduct science, and 3) few studies have attempted to understand how scientific practices influence students' beliefs about the nature of scientific processes. Lederman, Abd-El-Khalick, Bell, and Schwartz (2002, p. 501), as well as others have also pointed out that one of the most widely held misconceptions about science is the existence of the scientific method, the belief that there is a recipe-like stepwise procedure scientists follow during experiments (Carey & Smith, 1993; McComas, 1998; Wong, Hodson, Kwan, & Yung, 2008). Consequently, researchers have acknowledged the importance of teaching science in a manner that does not equate functional solutions with absolute conclusive knowledge and portray experimentation as a single sequence of activities.

An analysis of the data from this study indicated that exploring SSI through hands-on experimentation strengthened participants' understanding of the nature of scientific processes. For instance, the first lab that the students had to fully design was Lab 7, Ice Nucleation. Inductive analyses of the data revealed that 70% of the

students who completed their lab write-up believed they had answered their testable question. The 6 students who concluded that they had not answered their testable question attributed their inconclusive results to a procedural experimental error. During this lab, no students demonstrated a comprehensive understanding that most elaborate experimental protocols have uncontrolled variables, which prevents absolute conclusions. However, by their last experimental lab all 22 students who completed their lab write-up realized that their testable question could not be definitively proven. Rather undergraduates acknowledged that their data could be used to support an experimental hypothesis they could test further. [Table 7](#) has provides examples of how students' reflection on factors that influence scientific results developed.

Table 7. Summary Showing Students' Evolving Ability to Interpret the Limits of Their Experimental Designs

Instances the testable question was:	Answered	NOT Answered
Lab 7 Ice Nucleation	14 (70%)	6 (30%)
Lab 10 Hand Washing 1	11 (48%)	12 (52%)
Lab 11 Hand Washing 2	6 (26%)	17 (74%)
Lab 13 Antimicrobial Substances	0 (0%)	22 (100%)

Lab 7 Ice Nucleation

Example: Testable question answered

Testable question: Does *Pseudomonas syringae* (Ps) or *Escherichia coli* (E. coli) nucleate ice and which one does so the fastest?

Response: We needed to know first if they nucleated ice before we could time them because if one did and the other didn't, our experiment would have to be changed. It turned out that both of our questions were answered. Yes, they both nucleated ice, and in fact soil nucleated ice the fastest.

Example: Testable question **NOT** answered

Testable question: Will ice nucleation using *Pseudomonas syringae* (Ps) occur at different rates when varying amounts of *Escherichia coli* (E. coli) are added?

Response: I don't think our testable question was answered fully. We had some problems because one of the tubes of super cooled water was faulty, so we didn't gather enough data. Also, the negative control didn't do what we expected. I think the data we gathered was incomplete and our protocol could have been better, but our results still gave us pretty good evidence that Ps does nucleate at varying rates depending upon the amount of E. coli that is added.

Lab 13 Antimicrobial Substances

Example: Testable question **NOT** answered

Testable question: How do the household remedies of Listerine, Basitracen, Bactine, garlic, Purell, Betadine, iodine, and antifungal cream compare to the antibiotics of penicillin, streptomycin, and tetracycline (with respect to killing the bacteria *Bacillus subtilis* and *Escherichia coli*) .

Response: Our testable question was not answered. Unfortunately, we cannot conclusively state which of the substances is the best anti-microbial because there is an element of human error in our, as well as every other experiment... I believe that human error affected our results by: not having an exact equal amount of each substance on each disc, often the discs growth inhibition circles merged, making it hard to tell which was which, etc. I believe that we should try to be more precise with the amount of each substance cultured, as well as the distance in between each disc... Additionally, we only have a small amount of data and are technologically limited in our data analysis. However, the data that we have indicates that iodine is the best growth inhibitor.

This table exemplifies the types of simple questions students designed for two of their laboratory experiments and the conclusions they reached with respect to whether they answered their testable question. This table also illustrates the linear progression the class made as a whole, over 4 labs, in realizing that data cannot definitively prove an event; rather data are used to support conclusions (hypothesis or theories) that attempt to predict future events.

The results from students' end of the semester lab quiz strengthened the analysis of their lab write-up. For example, when asked to "Explain whether the scientific process is linear or circular. Justify your answer with a specific example." All 26 students claimed the scientific process was more circular and that results can always be tested further. All 26 participants also referenced their laboratory experiences where they had an opportunity to design and redesign their experiment based upon their first protocol's results as a specific example.

The scientific process is circular. A testable question allows one to create a hypothesis that predicts a possible answer to this question. Experiments can then be conducted to test the hypothesis... The conclusions reached by analyzing the results often lead to additional questions, thus beginning the cycle again. A specific example of the circularity of the scientific process is the Hand Washing experiment I conducted during BSCI122 lab this semester. My testable question was: "Does washing your hands with soap and warm water for 30 seconds kill or decrease the number of microbes on your hands more than washing for 10 seconds does?"... I

found that my results stimulated me to create another testable question: “Are there microbes on the paper towels we used to dry our hands after washing them?” I hypothesized that there are microbes on the paper towel, based on my observations of the results of my first experiment. I designed a new experiment to test this... At the start of this course, I would have said that the scientific process is linear because that was the way it was presented to me during high-school, and I therefore believed that every experiment that was appropriately designed to answer a testable question would provide a definite “yes” or “no” answer.

Additionally, 16 students also acknowledged this was not their original perception, but an evolved understanding based upon the experiences they had in lab. These experiences included designing experiments and explicit discussions exemplifying the scientific process as a non-linear series of steps. Of the remaining 10 students, 3 claimed to have had some prior exposure to science courses that prompted reflection upon the circular process of scientific experimentation; while the other 7 students did not comment upon the impact this course may have had upon their understanding.

The Nature of Scientific Justification

Science educational research has shown that viewing lack of data as a weakness for a claim was a skill that most students have not demonstrated (Sandoval, 2003). It has also been found that although students may demonstrate an awareness of the tentativeness of science, they have not use this knowledge when reasoning their positions to others (Walker & Zeidler, 2007). Yet, proponents of the SSI movement have asserted that learning environments using this structure can facilitate students’ reasoning such that the tenacious and social aspects of science are considered (Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005).

The findings from this study have suggested that students learned to recognize a lack of data as a weakness for a claim and used this knowledge when reasoning their point of view to others. For example, at the start of the semester no students’ lab

write-ups demonstrated a comprehensive understanding that even the most elaborate experimental protocols have uncontrollable variables. Although 6 students did recognize they had not answered their testable question because of a procedural experimental error, the context of students' responses did not indicate an understanding that lack of data weaken a claim in any experimental design. By the last experimental lab all 22 students who completed their lab write-up realized that their testable question could not be definitively proven and identified variables that needed further testing. Additionally, all undergraduates specifically referenced a lack of data as one reason for needing further validation.

Freya Lab 7, did not identify lack of data as a weakness: My testable question was answered because the addition of *P. syringae* does seem to affect the ice nucleation process because for Trial 1 and 2, the water did not freeze all the way or took longer than with just the Ps.

Freya Lab 13, identifies lack of data as a weakness: Our testable question was not really answered because of the variation between the two trials. In my trial, there was less growth with the anti-bacterial soap, but in Rui's trial there was less growth with the anti-microbial soap. There is not enough evidence to say whether one is more effective than the other. In the future, maybe more trials will give us an answer because there will be more results to look at and compare.

The start of the semester article exercise also indicated only 30% of students evaluated the theoretical claims in their article, as the remaining students restated the text in their article in response to the 6 questions. However, students' final article exercise indicated that 95% were asking questions about tenacious characteristics of scientific interpretations that were being made based upon the limitations of human interpretation.

Karina's first response Gordon and his colleague, Fredrik Backhed, conducted an experiment in which they compared two groups of mice, one that lived in the sterile bubbles with no gut microbes, and one that contained normal gut microbes... Relman discovered that each human's gut flora is strikingly different... Gordon and Ruth Ley... studied genetically mutated mice, to figure out if the gene or the microbes were causing weight gain...

Karina's final response (similar sections of text to the student's first response have been underlined) Before analyzing the multiple perspectives and points of view that are brought up in this article, I must first critically analyze a part of this article that seems somewhat contradictory to me. At the beginning of the article, the author states that these mice are "germ free" and

completely “sterile,” but later in the article the author states that an infant “gets its first major bacterial inoculation as it slides down the birth canal.” This contradiction makes me question how these mice are “germ free.” To exist they had to have been born and therefore have been exposed to their mother’s microbes in the birth canal. In addition, this article reads that all of the food and water that the mice are receiving are also “untainted by bacteria.” I question how this is true. Are there not natural microbes within the food that will then be present in the gut flora of the mice? The first perspective comes from Gordon and his colleague, Fredrik Backhed, who conducted an experiment in which they compared two groups of mice, one that lived in the sterile bubbles with no gut microbes, and one that contained normal gut microbes... Coming to the conclusion that gut microbes play an integral role in weight gain, seems reasonable, but there also could have been underlying variables that caused these mice to gain weight when microbes were introduced into their systems. There are many questions that should be considered. Could different mice have been affected in different ways? What if different microbes were added? Could the genetics of the mice also play a role in how they gain weight? I think that Gordon came to his conclusion and claim very quickly. More testing needs to be done to better support his statements... Relman studied the gut flora in three adults... discovered that each human’s gut flora is strikingly different... Gordon and Ruth Ley, genetically mutated mice to study if the gene or the microbes were causing weight gain... Although I agree with the perspectives of these scientists, I still have doubt that their data are conclusive. It seems that they are coming to conclusions too fast. Not enough data have been collected, nor have enough experimental tests been conducted. I think that the most important thing that I learned from the lab section of this class is that scientific experiments do not prove anything, rather they support a claim. These experiments do seem to support the claim that gut microbes do play an integral role in obesity and fat storage, but they do not prove anything.

These results have not suggested that students were able to read scientific papers written for the professional community and realize limits to data reported. However, the results have shown that students’ progressive awareness that data support, not definitively predict, observed phenomena.

Development of Undergraduates Proximal Knowledge of the NOS

Considering the majority of data presented thus far from a contextual constructivist perspective⁵⁹, an argument could be made that perhaps students’ NOS conceptualizations did not evolve over the semester. Rather, undergraduates’ developed an understanding of how to respond to course assignments based upon the explicit feedback they received over the semester. If this were the case, then the

⁵⁹ A contextual constructivist model is often associated with examining student learning and understanding with respect to the social or environmental structures forming the educational experience (Finkelstein & Pollock, 2005 pg 6; Hammer & Elby, 2002). That is, the cognitive structures determining a student’s understanding and processes for learning are circumstantial in nature (diSessa, 1993).

reasoning students' used in their research and lab activities would not necessarily correlated with their beliefs about the NOS.

There is a debate among science education researchers about how a person's informal reasoning is affected by distal and proximal knowledge of the NOS (e.g., Bell & Lederman, 2003; Hogan, 2000; Sadler, Chambers, & Zeidler, 2004). Bell and Lederman (2003), among other science education researchers, have proposed that social/political issues, ethical considerations, and personal beliefs dominate over formal NOS conceptualizations when making decisions (Grace & Ratcliffe, 2002; Ratcliffe, 1997). Others have contended that students dichotomize personal beliefs and their formal knowledge about the epistemology of professional science when informally reasoning (Sadler, Chambers, & Zeidler, 2004; Walker & Zeidler, 2007). Still others have asserted that there is an interaction between formal knowledge of the NOS and people's beliefs, which influences their learning and reasoning about science (Hogan, 2000; Smith & Wenk, 2006; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006; Yang, 2005).

More specifically, Hogan (2000) and others have stated that students' proximal knowledge may eventually be generalized to distal knowledge (Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006). Conversely, students' distal knowledge may help frame how they reflect on their science experiences, especially if students are engaging in authentic scientific processes (Hogan, 2000; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006). Recently, Vhurumuku, Holtman, Mikalsen, & Kolsto (2006) have shown how analyzing participants' written responses to NOS questions in conjunction with their laboratory work can provide insights into students' proximal

and distal images of the NOS. In this investigation, data from students' anonymous end of the semester evaluation, lab quiz, journals, lab write-ups, and writing exercise provided both belief-based and formal knowledge insights of participants' epistemological concepts of science. It was found that undergraduates' distal and proximal knowledge of the NOS interacted.

The discussion of students' responses to the lab quiz in the nature of scientific discovery and processes sections have illustrates this epistemological interaction. For example, as mentioned in the nature of scientific discovery section, all 26 undergraduates' responses to the question about ways scientific knowledge differs from other ways of knowing, indicated they were reflecting upon their beliefs. It was determined that students' proximal and distal knowledge of the NOS were correlated.

What I have learned from testing my own experiments is that you can never be too specific in conducting the experiments. Every detail and possibility needs to be looked at. For instance, there needs to be enough controls to perform the experiment. For me I believe what distinguishes scientific knowledge from other ways of knowing is that it is constantly questioned and perfected. This thus expands our knowledge because we think and question every aspect of the experiment. For instance, in the hand-washing experiment, ones conclusions might claim cold water with antibacterial soap kills more microbes than hot water and antibacterial soap. However, the cleanliness of the person's hands, the types of soap and temperature of the water... etc. are all factors that need to be further questioned...

The findings reported in the nature of scientific processes section on undergraduates' response to the lab quiz question "Explain whether the scientific process is linear or circular", again supported an interaction between participants' distal and proximal knowledge of the NOS. Results indicated that students not only demonstrated the ability to conceptually explain the cyclical aspects of scientific experimentation, but that their personal knowledge from this class influenced their thinking. The majority of undergraduates reflected that prior to this course their exposure to science resulted

in their belief that the scientific process was linear. However, students' laboratory experiences designing questions and interpreting their results helped develop their conceptual understanding that the scientific process has a more cyclical orientation.

Another example of how students' distal knowledge of the NOS interacted with their science experience based beliefs came from the end of the semester anonymous evaluation. It was found that undergraduates' self-assurance of their ability to evaluate scientific information increased. For example, when asked if "I am more confident in my ability to read scientific information. Explain your response." All 22 students who answered the question agreed and short answer explanations included some credit to their enhanced epistemological conceptions.

"Knowing that theories can not be proven has helped in making me more critical..."

Similarly, 95% of the students felt they were more confident in their ability to find and discuss scientific information. Students' also referenced NOS conceptualizations in their short answer explanations of their developed ability to discuss science.

I feel more confident in discussing scientific information because I have first hand experience in making interpretations and drawing conclusions... This has helped me to realize that not everything I read is fact and that the explanations given by scientists are just one of many possible explanations...

Undergraduates' final journal further supported these findings as all students recognized how their skill to be able to research, interpret, and/or reason microbiology issues improved over the semester. Additionally, 23 out of 26 students discussed how their initial beliefs about microbiology had changed because of their acquired knowledge, which also included a discussion of the values, assumptions, and/or processes inherent to scientific knowledge. The remaining students recognized

an enhanced understanding of microbiology issues, which they perceived as supporting their initial opinion(s). However, these students also credited an enhanced understanding of epistemological conceptions of science in their answers.

Evolved belief: In looking back at my initial scientific interest I realize that I still am very interested in the role of microbes in health and nutrition. However, through learning more about microbes my interests have also expanded...I have learned a great deal about my initial scientific interest because this was the topic I focused on for both the individual and group projects. I learned that microbes do help digestion and help in the absorption of nutrients. I also learned that it is important to have a balanced micro flora in your intestine... I still have questions about how effective probiotics taken as supplements are in maintaining a healthy intestine... There are many theories about how the relationships of microbes in the gut actually function and I want to know if new research has supported one theory more than another... My initial opinion about this topic was that it was important because it would help me lead a long and healthy life. I still feel that knowing how microbes affect health and nutrition is important. I now know that microbes and bacteria impact health more than I previously would have expected... After understanding more about probiotics I find myself disagreeing with my initial beliefs because at first I was in favor of all probiotics. Now I know that probiotics can have a negative effects and much of the research on probiotics is new and unproven.

Confirmed belief: My interest in science initially was founded in the same things I am interested in now, but this class has helped me see some of the things I care about in a different light, or from a different perspective. Looking back at my initial interest, I realize that... I knew very little about this topic. Being in this class has helped me learn how to make scientific information more accessible. I feel more confident about being able to learn and understand scientific information on my own... After understanding more about science, how we know what we know, and how that knowledge affects society, I find myself agreeing with my original assumption that society, government and politics, and microbiology are all linked and are relevant to one another.

Further, the nature of scientific justification section discussed how the start of the semester article exercise indicated that only 30% of students evaluated the theoretical claims in their article; but by the end of 15-weeks, 95% were asking questions about tenacious characteristics of scientific interpretations. Embedded in students' final article exercise response were findings that also showed undergraduates were using proximal knowledge when reasoning.

I initially agreed with the belief that SunEthanol would successfully use the Q microbe to commercially produce cellulosic ethanol on a commercial level because society currently needs a solution to the rising gas prices and dependency on foreign oil and biofuels are a popular solution... However after further analysis I no longer feel certain in SunEthanol's success. Much of the support given to research on the Q microbe is based on the belief that biofuels will solve our dependence on foreign oil and lower gas prices. Even though Q microbes are likely to be the cheapest method of producing ethanol because they do not require genetic engineering, producing ethanol remains an extremely expensive process requiring large amounts of energy...

After re-reading this article I realize that many questions remain unanswered such as how practical are biofuels for the average American? How will the use of ethanol affect the carbon cycle? And how will the use of ethanol affect other aspects of the economy?... Very little information is given on the other methods of producing cellulosic ethanol in this article, therefore it is difficult to assess how the Q microbe compares to its competition.

This student was among the majority who did not initially demonstrate an understanding of the tenacious characteristics of scientific interpretations.

Consequently, this example has illustrated how a student's conceptual knowledge of the scientific justification influenced a change in her belief-based understanding.

In general, results from this study have shown several ways undergraduates developed distal and proximal knowledge of the NOS interacted. The data have also been used to show how participants' enhanced epistemological conceptualizations of science influenced their ability to make more informed judgments about science.

Although these findings have differed from other science education researchers (e.g., Bell & Lederman, 2003; Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002), this may be explained by the instrumental design and SSI-based learning environment of this study.

Considering epistemological theoretical frameworks (Buehl & Alexander, 2001; Hammer & Elby, 2002), it is quite possible that this SSI-based curriculum and the instruments used in this investigation affected undergraduates' responses in a domain-specific manner. A domain-specific response would suggest that a student's scientific thinking would only be characterizable within the context of this course and the instruments used (Hammer & Elby, 2002). For example, students' journal at the end of the semester explicitly asked participants to reflect upon their initial interest(s) and opinion(s) in the context of this course. Despite undergraduates' discussion of their increased content knowledge and epistemological conceptions of science, the

data discussed thus far have not measured if and how students applied this knowledge in their everyday world. Although, several students made claims in their journals that:

This class has definitely given me a new perspective on many aspects of life. Mostly, it has taught me not to settle for convenient answers, but rather to question everything. For example, my friend was talking to me about something she had read in a magazine about losing weight by drinking soup. Normally I would just say, "cool," and take her word for it. But this time I started asking her a lot of questions about the theory, including who claims this? Is the person qualified in the nutrition field? What studies have they done to come to this conclusion? Etc. It seems that I have become much more skeptical of credentials and the researching process.

Overall I think that I have learned to enjoy science...(I have also) realized that learning how (science) affects our everyday lives does not have to take place in a classroom, but can take place in our world.

Even though I am still not planning on making science my career, this course has added greatly to my understanding of the world around me, and this is something I can carry with me for the rest of my life. When my kids ask me how they got chicken pox or why the milk went bad, I will be happy to have my microbial answer at hand.

This study did not seek to verify these statements. However, it has also been argued that domain-specific experiences have been recognized as essential to developing students' ability to reason in SSI-based frameworks (Zeidler, Sadler, Applebaum, & Callahan, 2009). Consequently, the data from this investigation have not disproved the findings of others, suggesting social/political issues, ethical considerations, and personal values dominate over NOS conceptualizations when a person informally reasons (Bell & Lederman, 2003; Grace & Ratcliffe, 2002; Ratcliffe, 1997). It may be possible that different situations cause students to dichotomize their personal beliefs and understanding of epistemology of science (Sadler, Chambers, & Zeidler, 2004; Walker & Zeidler, 2007; Zeidler, Walker, Ackett, & Simmons, 2002). Rather, the data from this investigation have been used to affirm that NOS conceptualizations significantly influence undergraduates' ability to informally reason, which influenced students' beliefs about current science issues affecting their life.

Summary

It was found in this study that undergraduates who had the opportunity to investigate SSI as well as design and test laboratory experiments developed their conceptually based formal knowledge about the epistemology of professional science. Students' began to use their expanded formal understanding of NOS conceptualizations when informally reasoning. Further, an analyses of the data indicated that students' distal knowledge of the NOS was interacting with their belief-based comprehension.

With respect to the nature of scientific discovery, the analyses of undergraduates' research projects and article exercise supported the finding that the majority of students developed the skill of distinguishing different theoretical points of view from opinions and summary statements. Analyses of the data from these instruments also indicated that the majority of undergraduates developed an ability to cite relevant facts to support higher-ordered epistemological evaluations of scientific issues. Further, students' lab quiz results have also suggested students recognized, over the course of the semester, how personal opinions differ from scientific knowledge.

With respect to students' ability to identify social factors influencing scientific discovery, it was found that all participants in this study were able to identify ways that society influences scientific discovery. However, data from undergraduates' KEEP poster and article exercise indicated that by the end of the semester the majority of students began to question how these societal influences might have affected the subjectivity of the claims made by the author(s).

It was determined that undergraduates' conceptual understanding of the epistemological characteristics of the scientific processes also matured. The data have supported providing participants with opportunities to design socially relevant experiments in conjunction with explicit discussion and reflection on the NOS, which could distal and proximal knowledge of scientific processes. For instance, undergraduates' lab write-ups demonstrated that all participants developed an awareness of ways scientific discovery was limited by instrumentation, experimental design, and data interpretations, which prevents absolute conclusions. Students' end of the semester lab quiz further supported undergraduates' knowledge of the NOS developed from their hands-on lab experiences and explicit discussions. For example, the Maryland Voluntary State Curriculum 5-E Pedagogical Model (Maryland State Department of Education, 1997) was used to explicitly discuss how the scientific process was more circular in nature. Consequently, all students articulated ways in which the scientific process was more circular rather than a defined set of steps that proceed in a linear manner. Additionally, students attributed their evolved understanding to their laboratory experiences and discussions.

With respect to the nature of scientific justification, the findings from this study suggested that students learned to recognize a lack of data as a weakness for a claim and used this knowledge when reasoning their point of view to others. For example, at the start of the semester no students' lab write-ups demonstrated a comprehensive understanding that even the most elaborate experimental protocols have uncontrollable variables. Having several opportunities to design and test their own experiments and discuss their data analyses, students learned to be more critical

of their experimental procedures and conclusions. By the last lab, all students recognized that their testable question could not be definitively proven and could identify variables that needed further testing. Undergraduates specifically referenced a lack of data as one reason for needing further validation. Additionally, the article exercise indicated that by the end of the semester, students were asking questions about the author's claims by referencing tenacious limitations of experimental designs and human interpretation of data.

With respect to undergraduates' proximal knowledge of the NOS, the data showed how students' beliefs matured with their distal knowledge of the NOS. For example, participants' response to "In what ways is scientific knowledge different from other ways of knowing?" and "Explain whether the scientific process is linear or circular" indicated students were able to formally articulate methods and goals of professional science. Students' responses also indicated that they related their distal knowledge of the NOS to their beliefs, which were originally formed by their prior experiences. Further support for this claim came from the end of the semester anonymous evaluation and students' journaling. It was found that undergraduates' credited their enhanced epistemological conceptions as one reason they felt more confident in finding, interpreting, and discussing scientific information. Students' final journal also included reflections on how their initial beliefs about microbiology had changed because of their knowledge of the values, assumptions, and/or processes inherent to the methods and goals of professional science.

Limits of the Data Analyses

As discussed in [Chapter 4](#), although the data from this SSI-based curriculum suggested that a group of non-science majors' became more scientifically literate about issues related to microbiology, any inferential claims that are drawn from these data must be subjected to further investigation. For example, it was found that students' formal conceptual understanding of professional science influenced their beliefs about science as a way of knowing. This finding has supported Hogan (2000) and others contention that an individual's formal knowledge and his/her beliefs about the NOS interact, which in turn influences one's reasoning (Smith & Wenk, 2006; Yang, 2005). However, an argument can be made that students' responses may be domain specific. How subjects participated, responded, and internalized the learning activities may not be consistent with how they reason SSI outside of this structured environment. Further examinations of participants' NOS conceptualizations in other educational and non-educational settings would strengthen the reported findings of students' distal and proximal scientific knowledge interacting. This is also one of the long-range objectives of [Project Nexus](#) (Project Nexus, 2005).

It was also previously mentioned, in [Chapter 4](#), that students' conceptual understanding of microbiology might have influenced their ability to evaluate scientific information. Similarly, the data from this study did not address how students' conceptual knowledge of microbiology might have affected their ability to 1) interpret information to distinguish facts, inferences, theories, and opinions, 2) evaluate societal influences affecting the author(s)'s perspective, as well as 3) design experiments and analyze data.

A question can also be asked about what function the SSI framework played in developing students' proximal and distal knowledge of the NOS to improve their reasoning about everyday science issues affecting society. That is, could another learning environment, such as an inquiry-based or Science-Technology-Society (STS) educational setting have promoted a similar outcome? Given that the setting of this case-study was limited to this SSI-based curricular intervention, the data from this investigation cannot answer whether other learning environments could promote similar outcomes. However, the findings support an important aspect of developing participants' proximal knowledge of the NOS was their personal connections to the science issues. A more complete discussion of these limitations and questions can be found in [Chapter 6](#).

Foreshadowing Emerging Insights

This study has suggested that the SSI-based curriculum implemented in this study is a promising framework for promoting functional scientific literacy. Our changing society accentuates the need to empower people with the skills to research and interpret alternative interpretations of scientific issues to make more informed decisions. Consequently, this SSI-based curriculum has a general application to educators interested in developing educational settings that promote a functional understanding of how scientific knowledge can be used to answer questions in today's world.

Specifically, it was determined that undergraduates' developed their ability to recognize and evaluate multiple perspectives as well as factual data when making informed evidence based positions. Interpretation of the data also suggested that SSI

can be used to develop an individual's formal knowledge of the NOS in a way that promotes pragmatic internal reflection and reevaluation of one's initial beliefs about scientific knowledge. The ability to understand NOS concepts, reevaluate personal beliefs, and make well-reasoned judgments about scientific issues are fundamental objectives to achieving scientific literacy (Roberts, 2007).

With respect to the nature of scientific processes, researchers have acknowledged the importance of teaching science in a manner that does not equate functional solutions with absolute conclusive knowledge and portray experimentation as a single sequence of activities (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Sandoval, 2003). It has been suggested that opportunities that give students hands-on experience designing experiments and analyzing scientific data may be useful in helping students to formally conceptualize the NOS (e. g., Ford, 2008; Smith & Wenk, 2006; Zeidler, Walker, Ackett, & Simmons, 2002). However, there is also evidence that has suggested simply engaging in scientific processes is not enough to bring about sophisticated understandings of the NOS (Bell, Blair, Crawford, & Lederman, 2003). Rather the empirical data have supported these inquiry-based activities should include explicit and reflective opportunities, such as journaling and discussions, upon the NOS (Khishfe & Abd-El-Khalick, 2002; Schwartz, Lederman, & Crawford, 2004). This study found that providing opportunities to design socially relevant experiments in conjunction with explicit discussion and reflection on the NOS, fostered participants' awareness of ways scientific discovery is limited by instrumentation, experimental design, and data interpretation.

With respect to the nature of scientific justification, science educational research has shown that viewing lack of data as a weakness for a claim was a skill that most students did not demonstrate (Sandoval, 2003). The findings from this study showed that students learned to recognize a lack of data as a weakness for a claim and used this knowledge when reasoning their point of view to others. Interpretation of the data have suggested that the opportunities undergraduates had designing and testing their own experiments and discussing their data analyses helped students become more critical of their own and others experimental procedures and conclusions.

It has also been found that although students may demonstrate an awareness of the tentativeness of science, they did not use this knowledge when reasoning their positions to others (Walker & Zeidler, 2007). The article exercise indicated that by the end of the semester, students were asking questions about the author's claims by referencing tenacious limitations of experimental designs and human interpretation of data.

Finally, given the debate among science education researchers about how formal conceptual knowledge of the NOS and personal beliefs have influenced people's ability to informally reason (e.g., Bell & Lederman, 2003; Hogan, 2000; Zeidler, Walker, Ackett, & Simmons, 2002), the findings from this dissertation are significant. The results from this investigation have supported the recent findings by Vhurumuku, Holtman, Mikalsen, and Kolsto (2006), on high-school students. It was found that students' formal knowledge about the epistemology of professional science and their belief-based knowledge of the NOS interacted.

In this chapter, I have more closely examined the effects this curricular and pedagogical intervention had on undergraduates' epistemological conceptualizations. Consequently, the data in this chapter have been used to further the insights from [Chapter 4](#), discussing how this curricular and pedagogical framework developed participants' ability to evaluate scientific information. In both [Chapter 4](#) and [5](#) I have discussed several significant findings with respect to science education research. However, I have also identified several questions that still need to be addressed with respect to understanding the impact of this student interest SSI-based curricular and pedagogical intervention. For example, in this chapter I raised the question of whether other learning environments, such as an inquiry-based or Science-Technology-Society (STS) educational setting could promote similar outcomes. In [Chapter 4](#), I asked how universal this curricular framework is to other science disciplines and grade levels. In [Chapter 4](#), I also raised the issue that teachers may not be prepared to implement a student interest SSI-based curriculum. The resultant discussion in [Chapter 6](#) combines the emerging insights that have come out of both [Chapter 4](#) and [5](#). The goal is to further establish the implications of this doctoral dissertation to the science education research community. I also use [Chapter 6](#) to more completely address the questions and limitations I have raised in [Chapters 4](#) and [5](#).

CHAPTER 6: Discussion and Future Research

Overview

In [Chapter 1](#), I introduced the focus of this doctoral dissertation. I used [Chapter 2](#) to review the literature to defend my claim that there is a need to know more about student interest SSI-based curricular and pedagogical interventions. [Chapter 3](#) I detailed the theoretical framework and the methodology I used to collect and analyze the data. [Chapters 4](#) and [5](#) discussed the results from my data analyses with respect to my two sub-research questions. In each chapter summary, I highlighted the significance of this doctoral dissertation, which served to foreshadow the discussion in this chapter. Consequently, [Chapter 6](#) serves to further establish the implications of this study to the science education research community.

The first section of this chapter discusses implications related to the emerging insights that were mentioned in [Chapters 4](#) and [5](#). Following this discussion, I address the limitations that I raised in [Chapters 1](#), [4](#), and [5](#). This section is followed by implications of reported findings that require future research. I then conclude my study by arguing for the significance of this work.

Overview of Emerging Finding Implications

Data from this investigation focused upon two principle research questions. The first of these was “What effects did this curricular and pedagogical intervention have on undergraduates’ evaluations of socio-scientific information (SSI)?” The other question proposed was “What effects did this curricular and pedagogical intervention have on undergraduates’ Nature of Science (NOS) conceptualizations?” In this section of [Chapter 6](#), I combine the discussion of the emerging findings from

[Chapters 4](#) and [5](#) to further establish the implications of this doctoral dissertation to the science education research community. First, I discuss the significant findings using the heuristic framework of the findings chapters. Consequently, I concentrate on the implications of the student interest aspect of this curricular and pedagogical intervention with respect to undergraduates' ability to evaluate scientific information. Next, I have revisited significant findings related to how participants' NOS conceptualizations developed, which influenced their ability to informally reason. Throughout these discussions, I reference the significance of the data with respect to students' epistemological beliefs⁶⁰. In the findings reported in [Chapters 4](#) and [5](#), I also discussed ways my pedagogical practices may have affected the reported outcomes. I acknowledge that my assessment of this factor was limited to my practitioner researcher journal and a few anonymous survey questions, but may have significantly affected my results. As a result, I have added [Appendix E](#) to discuss these potential implications more completely. I conclude my discussion by summarizing the general contributions to the education research community.

Implications of Students' Interest(s) and Ability to Evaluate Scientific Information

One of the rationales behind the SSI movement is that popular science issues can promote scientific literacy by connecting to people's lives and promoting critical evaluation of scientific data and information (Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). However, Sadler, Chambers, and Zeidler

⁶⁰ Epistemological beliefs have been defined as an individual's perceptions about knowledge, the nature and justification of knowledge, as well as beliefs about intelligence and learning (Hofer & Pintrich, 2002; Maggioni, Riconscente, & Alexander, 2006). Epistemological beliefs can also include open-mindedness (Toplak & Stanovich, 2003; Zeidler, Walker, Ackett, & Simmons, 2002), motivation and persistence to learn (Buehl & Alexander, 2005; DeCorte, Op't-Eynde, & Verschaffel, 2002;

(2004) and others have also shown that although SSI are believed to connect to a person's life, the use of SSI does not necessarily ensure students make personal connections to the science content (Zeidler, Walker, Ackett, & Simmons, 2002). In fact, Sadler (2004a, p. 531) has argued that SSI-based curricula need to begin including approaches that specifically focus on science experiences students' identify as relevant to their life. Currently, there is a gap in the research literature examining how meaningful personal connections can be integrated into SSI-based curricula to foster scientific literacy (Sadler, 2004a).

In [Chapter 4](#), four students were used to illustrate the diversity of students' interests and experiences with science. One aspect of this chapter discussed how the student interest aspect of this curricular and pedagogical intervention motivated undergraduates' to become better at evaluating scientific information. These data included examples of the ways students' skills developed as well as their epistemological belief-based insights.

For example, Brandi, Rui, and Wesesa's data were used to illustrate specific ways the majority of undergraduates began the course with low self-confidence with respect to learning science. At the start of the semester, these students demonstrated difficulties in 1) differentiating facts, theories, and opinions, 2) researching and interpreting scientific information, 3) identifying and analyzing different perspectives related to a socio-scientific issue, and 4) supporting their claims with relevant information.

Tolhurst, 2007; Tsai & Kuo, 2008), and self-confidence (DeCorte, Op't-Eynde, & Verschaffel, 2002; Paulsen & Feldman, 2005; Schommer-Aikins, Duell, & Hutter, 2005).

Conversely, Gannon's data depicted the minority of undergraduates who acknowledged and demonstrated an interest in science as well as the ability to understand scientific information at the start of the semester. However, this is not to say that Gannon and the other undergraduates did not benefit from this student interest SSI-based curriculum. In fact, Gannon's story was used to exemplify why it is important to offer learners more chances to influence their educational environment. For instance, Gannon used his opportunities to shape his learning by furthering his knowledge of a microbial issue that has affected his life, HIV. Resultantly, Gannon chose to advance his skills of researching, interpreting, and discussing scientific information so that he could more critically evaluate articles written for a scientific audience.

It was found that Brandi, Rui, Wesesa, and the majority of undergraduates also chose to research areas of microbiology that they recognized as influential to their life. This finding accompanied all undergraduates improved ability to research, interpret, and discuss scientific information. Although, unlike Gannon and a few other undergraduates, most students advanced their skills for researching, interpreting, and discussing science articles written for the popular press.

What strengthened my interpretation of Gannon, Brandi, Rui, Wesesa, and the other participants' skills at evaluating scientific information were the rich epistemological belief-based insights they disclosed in their journaling, anonymous evaluations, and lab quiz. For instance, it was found that all students revealed enthusiasm towards the student interest aspect of the curriculum. Undergraduates also reflected upon ways they had advanced their 1) self-confidence to find, interpret,

and discuss scientific information, 2) motivation to learn about science, and 3) prior knowledge of science over the course of the semester. This discussion in [Chapter 4](#) can be found in the finding section where I focused on the motivational effectiveness of this curriculum on students' personal growth.

Summary

Resultantly, the findings from [Chapter 4](#) extended the research on SSI-based curricular interventions in several ways. First, this study has expanded what is known about ways to ensure that students' interests are integrated in a SSI-based curriculum. Given that, over 80% of the participants began the semester with negative science experiences and apprehensions about their ability to understand science. These findings are significant. Specifically, participants not only demonstrated enthusiasm towards this student interest SSI-based curricular framework but they also had a general increased interest in how science affects their lives. For example, it was also found that all undergraduates demonstrated engagement and persistence towards learning over the semester, resulting in each student successfully passing the course. More explicitly, it was found that 16 of the 21 undergraduates who claimed to be insecure in their science ability or had never found science interesting achieved an above average score (B or better) and no student's final grade was lower than average (C). Perhaps even more important was the data showing students' opportunities to evaluate social issues in science that affecting them accompanied changes in their initial beliefs. Consequently, the findings discussed in [Chapter 4](#) offered several significant insights with respect to

providing students' with engaging and pragmatic opportunities to build functional scientific literacy skills.

Implications of Findings Related to NOS Conceptualizations and Informal Reasoning

Unlike [Chapter 4](#), in [Chapter 5](#) I discussed the findings of participants' data in a more general sense. That is, I represented the data using general statistics and quotes taken from several different participants' data. However, in my [Chapter 4](#) discussion of students' interest and ability to evaluate scientific information I also included aspects of Gannon, Brandi, Rui, and Wesesa's NOS conceptualizations. Specifically, I used their lab write-ups and quiz data to show how students' epistemological understanding of science improved their ability to evaluate scientific information over the semester. Thus far, I have not mentioned this part of the [Chapter 4](#) data. As a result, in addition to my discussion of the general findings from [Chapter 5](#) I have included insights on how Gannon, Brandi, Rui, and Wesesa's NOS conceptualizations can be used to strengthen my claims.

The NOS has been explicitly emphasized in recent reform movements as an essential component in achieving scientific literacy (AAAS, 1989, 1993; NRC, 1996). Educators and researchers who have advocated for the use of SSI-based interventions have contended that social, tentative, and empirical aspects of science are learned in this type of educational setting, which in turn can promote more informed reasoning about scientific issues in an everyday context (Sadler, 2004a). Although the few instances where participants' NOS conceptualizations were explicitly examined in a SSI-based curricular intervention, the findings failed to conclusively support this claim (Khishfe & Lederman, 2006; Walker & Zeidler, 2007; Wong, 2008). For

example, Walker and Zeidler (2007) found that high-school students' responses to questions based on the Views on Science-Technology-Society Survey (VOSTS) (Aikenhead & Ryan, 1992) indicated that participants developed a conceptual understanding of the tentative, creative, subjective, and social aspects of science. Yet, when given the opportunity to utilize this knowledge in decision making contexts learners failed to draw upon their conceptual knowledge of the NOS. Rather, Walker and Zeidler (2007) found that students reasoning about a global warming issue focused on factual-based evidence, which disclosed science content misconceptions.

Another example was the work of Wong, Hodson, Kwan, and Yung (2008). Wong, Hodson, Kwan, and Yung (2008) created and assessed the effects of a 4-hour instructional experience about the severe acute respiratory syndrome (SARS) on student-teachers' understanding of the NOS. In this study, participants were asked to respond to selected questions from the Views of Nature of Science Questionnaire (VNOS-C) (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Additionally, participants spent 2 hours in a reflective workshop, where they created a 'mind map' of NOS characteristics in groups. Similar to Walker and Zeidler (2007), Wong, Hodson, Kwan, and Yung (2008) found that some students developed more mature epistemological conceptions of science. However, these participants failed to demonstrate conceptual knowledge of the NOS during the 2-hour reflective workshop. Wong, Hodson, Kwan, and Yung (2008) recognized that participants found this activity to be confusing. Unlike Walker and Zeidler (2007), this investigation did not ask participants to use their understanding of the epistemology of science in a decision-making context. Further, although several selected interview

quotes included some epistemological belief-based insights, Wong, Hodson, Kwan, and Yung (2008) did not seek to examine how learners' distal⁶¹ and proximal⁶² knowledge of the NOS may have interacted.

Hogan (2000) and others have acknowledged that if the goal of understanding NOS conceptualizations is to help enrich students' lives to make better informed decisions, then it is important to examine both students' distal and proximal knowledge of the NOS (Hand, Lawrence, & Yore, 1999; Hogan, 2000; Yang, 2004; Zeidler, 1997). However, Bell and Lederman (2003, p. 353) have acknowledged that most studies examining participants' NOS conceptualizations have been decontextualized with respect to understanding how people's formal epistemological conceptualizations of science affect their personal belief-based decisions.

[Chapter 5](#) explicitly discussed ways students' nature of science discovery, processes, justification, as well as their personal epistemological conceptions of the NOS developed over the semester. In general, the data have shown giving undergraduates opportunities to research SSI in the literature as well as in a hands-on laboratory setting developed students' distal and proximal knowledge of the NOS.

The Nature of Scientific Discovery

One example of how Gannon, Brandi, Rui, and Wesesa's data can also be used to illustrate how undergraduates developed their conceptual understanding of the

⁶¹ Distal knowledge of the NOS has been defined as a person's formal definitions about the methods and goals of professional science (Hogan, 2000, p. 57). An example of an individual's distal knowledge of the NOS would be distinguishing an observation from an inference and a scientific law from a theory.

⁶² Proximal knowledge of the NOS has been defined as an individual's beliefs, commitments, or personal theories about scientific epistemological conceptualizations. A person's beliefs about the NOS can be developed from personal experiences such as engaging in television, radio, and

nature of scientific discovery came from their KEEP research projects and article exercise. Brandi and Rui's data illustrated how both students had trouble identifying different theoretical perspectives and conflated theories and opinions at the start of the semester. Wesesa on the other hand, had difficulty differentiating facts from theories. However, these students did not demonstrate difficulty distinguishing these concepts by the end of the semester. Conversely, Gannon and a minority of undergraduates demonstrated the ability to distinguish a testable question, hypothesis, theory, fact, inference, and opinion as well as critically evaluate science articles written by the popular press early in the semester. [Chapter 5](#) discussed these findings using general statistics and qualitative data from other students. I also connected these reported statistics to the educational research that has found high-school and college age students may not possess the ability to differentiate theories, conclusions, hypotheses, and conjectures from opinions (Zeidler, Walker, Ackett, & Simmons, 2002). Consequently, the improvement seen by the majority of undergraduates has supported the use of this student interest SSI-based curricular and pedagogical intervention with respect to developing participants' nature of scientific discovery understanding.

Further, I connected my nature of scientific discovery discussion in [Chapter 5](#) to ways societal factors influence science. It was found that the majority of students were able to identify ways that societal factors have influenced scientific discovery early in the semester. This result paralleled what others have found (Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002). However, I

newspapers as well as learning from family, friends, formal education, and life experiences

gave several examples that illustrated how undergraduates had developed skills that allowed them to be more critical of how these factors may have affected an author's claims by the end of the semester. Similarly, Brandi, Rui, and Wesesa's data from [Chapter 4](#) further support this interpretation. Specifically, I exemplified ways in which each of these students were more critical of how these factors may have influenced the author(s)' perspective by the end of the semester. The finding that participants in this study developed the skill to be more critical of how societal factor's influence scientific discovery is significant to science education research (Kolsto, 2001a, b; Kolsto, et al., 2006). For example, Kolsto (2001b) and Kolsto, et al. (2006) have found that high-school and collegiate students have dealt with SSI by accepting knowledge claims and information as authoritative.

The Nature of Scientific Processes

With respect to the nature of scientific processes, it was determined that all participants' distal and proximal knowledge of the NOS developed. [Table 3](#) in [Chapter 4](#) and [Table 7](#) in [Chapter 5](#), illustrating participants' lab write-up data, showed how hands-on experimentation strengthened participants' understanding of the nature of scientific processes. For instance, the first lab that students had to fully design was Lab 7, Ice Nucleation. Inductive analyses of the data revealed that no students recognized that even the most elaborate experimental protocols have uncontrolled variables, which in turn prevents absolute conclusions. However, by their last experimental lab all students realized that their testable question could not

(Schommer-Aikins, 2002; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006).

be definitively proven. Rather, undergraduates acknowledged that their data could be used to support an experimental hypothesis they could test further.

Students' end of the semester lab quiz data in [Chapters 4](#) and [5](#) further supported that undergraduates' knowledge of the nature of scientific processes developed over the semester. For example, the Maryland Voluntary State Curriculum 5-E Pedagogical Model (Maryland State Department of Education, 1997) was used to describe how the scientific process was more circular in nature. The laboratory write-up data in [Chapter 4](#) specifically referenced Gannon, Brandi, Rui, and Wesesa's response to the question "Explain whether the scientific process is linear or circular. Justify your answer with a specific example." Another undergraduate's response was chosen for [Chapter 5](#). It was found that all students articulated ways in which the scientific process was more circular rather than a defined set of steps that proceed in a linear manner. Additionally, all students' responses included belief-based insights where they attributed their evolved understanding to their laboratory experiences and discussions. These findings are significant in light of Sandoval's (2003) argument. He has claimed that 1) analyzing evidence and data are goals of the national science reforms (AAAS, 1992; NRC, 1996), 2) students' conceptually based formal knowledge of the NOS can influence their ability to conduct science, and 3) few studies have attempted to understand how scientific practices influence students' beliefs about the nature of scientific processes (Sandoval, 2003). The data was also related to the claim that one of the most widely held misconceptions about science is the existence of the scientific method, the belief that there is a recipe-like stepwise procedure scientists follow during experiments (Carey & Smith, 1993; Lederman,

Abd-El-Khalick, Bell, & Schwartz, 2002; McComas, 1998; Wong, Hodson, Kwan, & Yung, 2008).

The Nature of Scientific Justification

The discussion in [Chapter 5](#) expanded what was I said about the nature of scientific discovery and processes. Specifically, data were used to show how students began to use their knowledge of the tentativeness of science when evaluating claims and reasoning their positions to others. For instance, [Table 3](#) in [Chapter 4](#) and another student's quote in [Chapter 5](#) were used to illustrate how students began to use their knowledge of uncontrollable variables that accompany all experimental protocols when informally reasoning. The data from students' final article exercise were another example that showed how students began reasoning with an awareness of the tenacious characteristics associated with scientific interpretations.

I related the significance of these findings to the research literature that has shown that viewing lack of data as a weakness in claim is a skill that most students have not demonstrated (Sandoval, 2003). It has also been found that although students may demonstrate an awareness of the tentativeness of science, they do not use this knowledge when reasoning their positions to others (Walker & Zeidler, 2007). By the end of the semester, undergraduates' in this study began to question the reported conclusions of others based upon limits of the data described. It was also determined that students were informally reasoning their point of view by acknowledging the constraints of their own experimental results.

Development of Undergraduates Proximal Knowledge of the NOS

Another significant finding discussed in [Chapter 5](#) was the debate among science education researchers about how a person's informal reasoning is affected by their distal and proximal knowledge of the NOS. Specifically, Bell and Lederman (2003), among other science education researchers, have proposed that social/political issues, ethical considerations, and personal beliefs dominate over formal NOS conceptualizations when making decisions (Grace & Ratcliffe, 2002; Ratcliffe, 1997). Others have contended that students dichotomize personal beliefs and their formal knowledge about the epistemology of professional science when informally reasoning (Sadler, Chambers, & Zeidler, 2004; Walker & Zeidler, 2007). Still others have asserted that there is an interaction between formal knowledge of the NOS and people's beliefs, which has influenced their learning and reasoning about science (Hogan, 2000; Smith & Wenk, 2006; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006; Yang, 2005).

The findings from this study supported participants' conceptual knowledge about the epistemology of professional science interacting with their belief-based insights. The data used to support this claim came from the lab quiz, article exercise, anonymous survey, and participants' journaling. One example of the way undergraduates demonstrated their distal and proximal knowledge of the NOS was interacting came from lab quiz data. Specifically, students' lab quiz response to the question of whether they viewed the scientific process as linear or circular. Gannon, Brandi, Rui, and Wesesa's response in [Chapter 4](#), the student's quote from [Chapter 5](#), as well as all other undergraduates acknowledged that the scientific process is more circular in nature. All undergraduates also referenced an instance from their

laboratory experience (belief-based knowledge) as an illustration that supported their understanding.

Other examples in [Chapter 5](#) included students' lab quiz response to the question "in what ways does scientific knowledge differ from other ways of knowing?" Participants' responses indicated that they recognized how scientific knowledge seeks to be objective and is empirically based, yet also influenced by underlying epistemological assumptions. Explicitly discussed in all undergraduates' answers were belief-based insights they had gained as a result of laboratory activities.

Another illustration of students' distal and belief-based epistemological knowledge of science interacting came from the article exercise. As previously mentioned, it was found that by the end of the semester undergraduates connected their experiential knowledge of uncontrollable variables accompanying all experimental protocols to their conceptual understanding of the tenacious characteristics of scientific interpretations.

[Chapter 5](#) also included belief-based insights from undergraduates' anonymous evaluation and journaling that were correlated to their epistemological conceptualizations. For instance, students' journaling revealed ways their initial beliefs about microbiology had changed. Included in participants reflections were discussion of the values, assumptions, and/or processes inherent to scientific knowledge.

Summary

In general, the data on undergraduates' NOS conceptualizations with respect to their ability to informally reason have provided several significant insights to the

educational research community. For instance, it was determined that this SSI-based curricular and pedagogical intervention helped participants develop their nature of scientific discovery, processes, and justification understanding. Given that education researchers have found that collegiate students may not possess the ability to differentiate theories, conclusions, hypotheses, and conjectures from opinions (Zeidler, Walker, Ackett, & Simmons, 2002), it was important to find undergraduates developed their knowledge of scientific discovery. Considering the arguments for teaching science in a way that foster an epistemic understanding of how scientists ask and experimentally test questions (Carey & Smith, 1993; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; McComas, 1998; Sandoval, 2003; Wong, Hodson, Kwan, & Yung, 2008), the data that supported students had developed an understanding of scientific processes is of value. Acknowledging that researchers have found subjects do not reason using the tentative characteristics of scientific justification (Sandoval, 2003; Walker & Zeidler, 2007), the growth undergraduates showed when reasoning their point of view to others is also significant. Further, the results from this study have suggested that undergraduates developed their conceptual knowledge of epistemological aspects of science, which influenced their beliefs about issues that affect their life. Consequently, the findings discussed in [Chapter 4](#) and [5](#) have several implications to science educational researchers interested in developing curricula that give learners practice at becoming functional scientifically literate citizens.

General Implications to the Education Research Community

One of the rationales behind the SSI movement is that popular science issues can promote scientific literacy by connecting to people's lives and promoting critical

evaluation of scientific data and information (Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). Scientific literacy has been broadly defined as a functional understanding of science knowledge to answer questions about everyday life not just theoretical science (DeBoer 1991, p. 174). Scientific literacy can be evidenced through the ability to identify problems for investigation, formulate hypotheses, design and conduct research, as well as evaluate evidence and conclusions (Korpan, Bisanz, Bisanz, & Henderson, 1997; Roberts, 1995). However, scientific literacy can also be indicated by a person's open-mindedness, thirst for more information, ability to identify bias, and reflect critically (Kolsto, 2006; Oulton, Dillon, & Grace, 2004).

It has been argued that a person's beliefs about knowledge and knowing⁶³ influence one's learning, reasoning, and interest (Hammer & Elby, 2002; Hofer, 2002; Schommer-Aikins, 2002). This is significant to pursuits of scientific literacy, as researchers have shown how people's beliefs influence how they informally reason science issues (e.g., Toplak & Stanovich, 2003; Zeidler, 1997; Zeidler, Walker, Ackett, & Simmons, 2002), and understand science concepts (Chu, Treagust, & Chandrasegaran, 2008; May & Etkina, 2002; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006). It has been shown that individuals' beliefs influence their open-mindedness towards science (Toplak & Stanovich, 2003; Zeidler, Walker, Ackett, & Simmons, 2002), motivation and persistence to learn (Buehl & Alexander, 2005; DeCorte, Op't-Eynde, & Verschaffel, 2002; Tolhurst, 2007; Tsai & Kuo, 2008), and

⁶³ Hofer (2002, p. 3) has defined personal epistemology as the beliefs an individual holds about knowledge and knowing. Those epistemic cognitive processes that are activated as a person engages in learning and knowing.

academic self-confidence (DeCorte, Op't-Eynde, & Verschaffel, 2002; Paulsen & Feldman, 2005; Schommer-Aikins, Duell, & Hutter, 2005).

Resultantly, it has been argued that assessing an individual's scientific literacy should not only examine one's understanding of scientific concepts but also the learner's epistemological beliefs (Hofer, 2002; Hogan, 2000; Schommer-Aikins, 2002). Epistemological beliefs have been defined as an individual epistemic cognition about how knowledge is acquired and how he/she learns (Hofer, 2002). Epistemological beliefs can also include self-efficacy and motivational aspects related to learning and knowledge (Schommer-Atkins, 2002).

Educators and researchers who have advocated for the use of SSI-based interventions believe that 1) skills to critically examine scientific information, 2) NOS conceptualization, 3) knowledge of science content, and 4) the ability to skillfully support one's position can be learned in this type of educational setting (Sadler, 2004a; Zeidler, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2008; Zeidler, Sadler, Simmons, & Howes, 2005). These advocates have also contended that the SSI-based framework offers learners opportunities to examine and develop their epistemological beliefs about science, which in combination with the former will promote a functional understanding of scientific knowledge (McGinnis, 2003; Zeidler, Sadler, Applebaum, & Callahan, 2008; Zeidler, Sadler, Simmons, & Howes, 2005).

There is substantial literature that has documented the need to include societal, ethical, epistemological, conceptual, and technological orientations to foster the public's scientific literacy. However, the design, implementation, and

examination of SSI-based curricular frameworks is a relatively new area of research (Sadler, 2004a; Zeidler, Sadler, Applebaum, & Callahan, 2009). Those studies, discussed in [Chapter 2](#), that have been identified as SSI interventions have mainly examined primary and secondary student learners and have varied in scope and effectiveness (e.g., Barab, et al., 2007; Walker & Zeidler, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009). Consequently, there is a need to understand more about the affects of SSI-based curricular interventions on post-secondary learners.

Additionally, Zeidler and Sadler (2008) and others have claimed that there are several characteristics that distinguish a SSI learning model from other science teaching approaches. These distinguishing aspects include examining alternative scientific and societal viewpoints related to real-world issues. Further, students' examination of these issues should be done in a way that facilitates social and personal reflection upon an individual's science content and informal (belief-based) knowledge domains (Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009). Yet, the diversity and early stages of SSI-based curricular models have shown differing affects on developing students' scientific literacy (Jimenez-Aleixandre & Pereiro-Munoz, 2002; Walker & Zeidler, 2007). More research is needed to identify the differences between SSI-based interventions and those most salient characteristics of successful SSI-based curricular designs.

One such aspect of the SSI framework that still needs to be understood is how to ensure students make personal connections to the science issues (Sadler, Chambers, and Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002). Sadler, Chambers, and Zeidler (2004) and others have also shown that although SSI are

believed to connect to a person's life, the use of SSI does not necessarily ensure students engage with the scientific and social implications of issues that are affecting the world (Zeidler, Walker, Ackett, & Simmons, 2002). In fact, Sadler (2004a, p. 531) has argued that SSI-based curricular research has yet to fully consider how students' experiences can be enhanced to ensure learners see the relevance of science to their life. Currently, there is a gap in the research literature examining how meaningful personal connections can be integrated into SSI-based curricula to foster scientific literacy (Sadler, 2004a).

Consequently, this research study has several important contributions to offer the educational research community. Zeidler, Sadler, Applebaum, and Callahan (2009) have acknowledged that more work needs to be done that directly examine NOS orientations under an SSI framework. In this study data were collected on participants' ability to critically evaluate scientific information, which included an evaluation of students NOS conceptualizations. Another important aspect of the data discussed in this doctoral dissertation is the findings that provided insights into undergraduates' epistemological beliefs. It has been argued that far too often research examining an individual's scientific literacy fails to consider the complexity and influence of a learner's epistemological beliefs in data analyses (Hammer & Elby, 2002; Hofer, 2002; Hogan, 2000; Schommer-Aikins, 2002). The present study notably does not fail to consider the complexity and influence of learners' epistemological beliefs in its data analysis. Additionally, this SSI framework has extended what is known about post-secondary SSI-based curricular frameworks. Currently, the majority of studies identified as SSI-based curricular interventions

have examined primary and secondary learners (e.g., Khishfe & Lederman, 2006; Jimenez-Aleixandre & Pereiro-Munoz, 2002; Patronis, Potari, & Spiliotopoulou, 1999). Finally, this investigation has addressed the gap in the literature related to ways of stimulating a diverse group of collegiate students' interest in science. In general, interpretation of the data have supported this student interest SSI-based curriculum can advance students' functional scientific literacy by enhancing their skills to informally reason.

Limitations

In this section, I dissect the limitations of this doctoral dissertation methodology into 4 different aspects. First, I discuss the limits related to the convenient sampling of undergraduates and the confines that accompany a case-study. Next, I focus on how the case-study setting and instrumental design have limited my data analyses. I then discuss the implications related to the defined focus of this investigation. Finally, I disclose ways that my data analyses have limited what is known about undergraduates' ability to informally reason.

Convenient Sampling and Sample Size

In [Chapter 1](#), I mentioned several limitations related to the construction of this case-study. One limit applies to the convenient sampling of participants enrolled in this undergraduate microbiology course during the spring 2008 semester. It is important to recognize that the 26 participants, although diverse with respect to ethnicity, culture, prior science experiences, and gender may not be a representative population of undergraduate non-science majors. Consequently, it is possible that this group of undergraduates was particularly motivated to succeed, which has

inflated the positive outcomes reported. However, given that the results from the pilot study in 2007 have shown similar gains with respect to the level of student engagement and enhanced knowledge of the NOS (Marbach-Ad, et al., 2008), the findings from this doctoral dissertation support transferability to a population of undergraduate non-science majors. That is, it can be argued that the findings from this student interest SSI-based learning environment have offered important insights to researchers and educators interested in developing curricula that engage students' interest and promote scientific literacy.

Case-Study Setting and Instrumental Design

Another limit of this investigation, mentioned in [Chapters 1, 4, and 5](#), is related to the 15-week timeframe, instrumental design, and controlled setting. For example, in [Chapter 5](#) it was determined that undergraduates developed distal and proximal knowledge of the NOS. It was also found that these two knowledge-domains of students' NOS conceptualizations were interacting and affected how participants informally reasoned. Although this finding was significant given the debate about how a person's informal reasoning is affected by their epistemological knowledge of science (e.g., Bell & Lederman, 2003; Hogan, 2000; Sadler, Chambers, & Zeidler, 2004), I also acknowledged that this finding did not disprove other research claims. For example, Bell and Lederman (2003) and others have found that political, ethical, and personal beliefs dominate over formal NOS conceptualizations when a person makes decisions (Grace & Ratcliffe, 2002; Ratcliffe, 1997). Others have contended that students dichotomize personal beliefs and their formal knowledge about the epistemology of professional science when informally reasoning

(Sadler, Chambers, & Zeidler, 2004; Walker & Zeidler, 2007). The fact that the data from this student interest SSI-based curricular and pedagogical intervention varied from other reports may be explained by differences in the instrumental design and controlled setting.

It has been argued that students' can respond to questions and situations in a domain-specific manner⁶⁴. Consequently, the data from [Chapter 5](#), repeatedly showing how students' distal and proximal knowledge of the NOS were interacting and affected how participants informally reasoned may have been influenced by this study design. Given that the data from this investigation was limited to the controlled context of this course, no data was gathered on how students applied this knowledge in their everyday world. It may be found that in other educational or non-educational settings students' responses to prompts eliciting their epistemological conceptualizations of science may not show a similar interaction.

Hammer and Elby (2002) have argued that a person's epistemological reasoning framework is sensitive to context. Consequently, one of the problems with comparing different reports about how people's NOS conceptualizations affect their ability to reason is the significant variation in experimental design and data collection. For instance, Bell and Lederman (2003) asked a group of adults to informally reason how they felt about a variety of science and technology scenarios related real-world issues that citizens might face. In one specific example, subjects were asked whether they would support banning smoking in public places because of the alleged dangers of passive cigarette smoke and cancer. Although this

investigation used SSI, participants in this study were not in a classroom context nor prompted to explicitly evaluate their NOS conceptualizations. In this study, undergraduates were asked over the course of the semester to reflect upon their initial beliefs about SSI and NOS concepts as they formally learned about epistemological characteristics of science.

Whether the findings from this student interest SSI-based curricular and pedagogical intervention are domain-specific or general, it has also been argued that domain-specific experiences are essential to developing students' ability to reason in real world science issues (Zeidler, Sadler, Applebaum, & Callahan, 2009). Consequently, although the data from this study must be subjected to further validation in other educational and non-educational settings, the findings still offer valuable insights into ways to promote learners scientific literacy.

Defined Focus of Case-Study

Further, the instruments and defined focus of this study have limited my inferential claims. For example, in [Chapters 4](#) and [5](#) I mentioned that students' conceptual understanding of microbiology might have influenced their ability to evaluate scientific information and NOS conceptualizations. Several studies have shown that the quality participants' reasoning is significantly influenced by their science content knowledge (e.g., Sadler & Zeidler, 2005; Tytler, Duggan, & Gott 2001; Zeidler & Schafer, 1984). However, it has also been argued that people may not reason using their formal knowledge of science (e.g., Bell & Lederman, 2003; Grace & Ratcliffe, 2002; Walker & Zeidler, 2007). Still others have proposed that a

⁶⁴ Domain-specific responses suggest that students' scientific thinking would only be characterizable

student's ability to informally reason is reflective of their knowledge threshold (Sadler & Donnelly, 2006; Sadler & Fowler, 2006). A person's knowledge threshold is a point where one has a sufficient conceptual understanding of the science content to demonstrate correct use and reference of the subject matter to support his/her claims (Sadler & Donnelly, 2006; Sadler & Fowler, 2006).

This investigation did not focus on how participants' content knowledge may have affected their ability to evaluate scientific information or NOS conceptualizations. Therefore, the reported findings are limited by the defined focus of this case-study. It is quite possible that undergraduates' understanding of microbiology concepts influenced their ability to reason. Further research is needed to more completely assess other significant variables, such as content knowledge, that may have been affected by this student interest SSI-based curricular and pedagogical intervention. However, the need to extend this research does not negate the significant findings that have been reported.

Data Analyses

Finally, my involvement as a curricular reformer and the limits of my own knowledge has undoubtedly biased my data analyses. Despite the fact that I was critical of my conclusions and sought external validity of my data analyses, it is impossible to escape my human nature. That is, this investigation has focused upon how people critically evaluate scientific information and their understanding of the NOS. A salient characteristic of scientific knowledge is that human perspectives, experiences, and understandings of the data limit interpretations. This is perhaps

within the context of this course and the instruments used (Hammer & Elby, 2002).

even more significant in social science research. Therefore, even though I sought to reinforce my analyses through several triangulation techniques, such as member-checking and inter-rater reliability, the reported findings are still limited by the instruments, defined boundaries of the research, and interpreters' knowledge.

I have already mentioned several ways the methodology of this study could have been expanded, such as examining more undergraduates, varying the setting, and extending the delimited components of informal reasoning. I also feel it is important to acknowledge that my own perspectives, experiences, and knowledge of the data have undoubtedly limited what I have reported about students' skills, understandings, and beliefs. That is not to say that my data interpretations were not credible, as the participants of this study, graduate, and education researchers have confirmed my analyses. Rather, I am recognizing that the guiding research question of this study has not only affected my methods of data collection and analyses, but has also influenced my conceptual understanding of issues that affect how learners' become more scientifically literate. For instance, from discussing my data with several people, I have recognized that the richness of students' academic products as well as their evaluative and journaling insights could have been assessed through many different analytical lenses in addition to the SSI theoretical framework chosen for this dissertation. Consequently, the same SSI perspective that has helped me to focus and explain several important implications of this student interest curricular and pedagogical intervention has also limited the insights that could have been gleaned from the data. Even given this limitation, the findings from this study have still

contributed significantly to what is known about undergraduates' interests in science and educational settings that promote scientific literacy.

Implications for Future Research

Given the limitations just discussed, this case-study has also raised several questions that require further research. In this section, I address the implications of reported findings that still need to be investigated. Specifically, I discuss ways to further validate the results from this investigation. Next, I focus on the need to understand more about the most salient characteristics of SSI-based curricular frameworks. Embedded in this discussion I include the issue of investigating the universality of this student interest SSI-based curriculum in other science disciplines and grade levels. Finally, I recognize the need to further research implications associated with implementing a student interest SSI-based curriculum with respect to teacher preparation.

Implications of Further Validating Reported Findings

It was mentioned in the limitations section that more research is needed to understand how conceptual knowledge and domain-specific responses may have affected the reported findings. One way to have addressed whether participants' conceptual understanding of microbiology influenced their ability to informally reason would have been to have correlated the reported data with participants' lecture examinations. Additionally, Dr. Benson administered a pre/post conceptual knowledge instrument during the course of this investigation. Data from these sources would have extended the inferences that could have been drawn from this

study with respect to how participants' conceptual understanding of microbiology affected their informal reasoning.

One way to have assessed whether undergraduates' improved skills to informally reason were domain-specific or general would have been to investigate if and how students applied their knowledge of the NOS and skills to evaluate scientific information in other educational and non-educational settings. However, data from the larger NSF supported project aimed at recruiting and training future upper elementary/middle school science teachers may offer insights to address this shortcoming (Marbach-Ad, et al., 2008; Project Nexus, 2005). Questions from the Views on Science-Technology-Society (VOSTS) (Aikenhead & Ryan, 1992) instrument have been used in this longitudinal project to probe students' epistemological concepts of science. Resultantly, tracking elementary interns responses to the VOSTS questions during their science methods course and in their teaching environments would serve to further extend the findings reported from this doctoral dissertation.

Implications of Further Characterizing SSI-based Curricular Frameworks

In addition to understanding how conceptual knowledge and domain-specific responses may have affected the reported findings, questions can be asked about which aspects of this curricular and pedagogical intervention were most salient in developing students' skills to informally reason. That is, could another learning environment, such as an inquiry-based or Science-Technology-Society (STS) educational setting have promoted a similar outcome?

Empirical studies have shown that an understanding of the NOS can develop from explicit and reflective⁶⁵ inquiry-based opportunities (Akerson & Hanuscin, 2007; Khishfe & Abd-El-Khalick, 2002; Schwartz, Lederman, & Crawford, 2004; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006). However, Bell and Lederman (2003, p. 353) have acknowledged that most studies examining participants' NOS conceptualizations have been decontextualized with respect to understanding how people use their epistemological conceptualizations in decision-making contexts.

Considering the theoretical perspective that people's epistemological beliefs play a role in their learning, reasoning, and interest (Hammer & Elby, 2002; Hofer, 2002; Hogan, 2000), only examining how participants distal knowledge of the NOS develops limits what is known about people's reasoning of scientific issues.

Similarly, examining a student's proximal and distal knowledge in a laboratory setting that removes the learner from making decisions and arriving at conclusions about science issues that affect their life, arguably limits what is known about students scientific literacy.

Contextualized instruction has been proposed as a means to support learning by providing a cognitive framework onto which students can connect or "anchor" ideas (Rivet & Krajcik, 2008). Researchers have also acknowledged that meaningful real-world problems provide learners with more readily available cognitive connections to their prior knowledge and experiences (Bell & Matkins, 2003; Khishfe & Lederman, 2006; Rivet & Krajcik, 2008; Zeidler, Sadler, Applebaum, & Callahan,

⁶⁵ Khishfe and Abd-El-Khalick (2002, p. 555) define an explicit teaching of the NOS as emphasizing student awareness of certain epistemological concepts in relationship to the science-based activities in which they are engaged. The term reflective refers to providing students with opportunities to analyze

2009). Rivet and Krajcik (2008) have argued that contextualized instruction results in more learning by these students. Resultantly, contextualizing instruction so that learners have opportunities to reason science issues that they are interested in and recognize as relevant to their life may promote students' formal understanding of the NOS (Khishfe & Lederman, 2006). It is also possible that the direct connection to learners' prior experiences and knowledge also encourage reflection and reevaluation of students' initial beliefs.

Researchers have shown how the SSI framework facilitates contextualized learning to develop both formal and informal (belief-based) domain knowledge (e.g., Walker & Zeidler, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zohar & Nemet, 2002). In fact, Zeidler (2003) and others have argued that this is what distinguishes the SSI model from other ways of learning science (Barab, et al., 2007; Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009). Given the setting of this case-study was limited to this SSI-based curricular intervention, the data have not answered whether other learning environments could promote similar outcomes. However, the findings have supported an important aspect of developing participants' proximal knowledge of the NOS came from the personal connections they had identified by choosing science issues that affected their life.

It can be argued that the salient characteristics of the SSI-based learning environments remain ill defined. Unlike the literature, that has documented the need to include societal, ethical, epistemological, conceptual, and technological

various perspectives of the NOS by making connections between their activities and ones undertaken

orientations to foster the public's scientific literacy, the design, implementation, and examination of SSI-based curricular frameworks is a relatively new area of research (Sadler, 2004a; Zeidler, Sadler, Applebaum, & Callahan, 2009). In general, those studies that have been identified as SSI-based interventions have varied in scope and effectiveness (e.g., Barab, et al., 2007; Keselman, Kaufman, Kramer, & Patel, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009).

For instance, Jimenez-Aleixandre and Pereiro-Munoz (2002) showed that a 2 month, 16-session, real-life environmental socio-scientific issue could promote students' use of relevant conceptual knowledge. Their results have suggested that students developed the skills to analyze different dimensions of data. They also found that participants demonstrated the ability to integrate their conceptual knowledge when synthesizing and evaluating potential solutions. However, Walker and Zeidler (2007) reported that participants, at the end of a 7-week SSI-based learning exercise, incorrectly used factual-based knowledge in their reasoning. These authors found that although students possessed an understanding of the tentative and social aspects of scientific discovery; participants only justified their reasons with their factual-based knowledge, disclosing their lack of conceptual understanding (Walker & Zeidler, 2007). Both studies used Toulmin's (1958) model of argumentation to assess students' arguments and warrants. However, Walker and Zeidler (2007) used the Web-based Science Environment (WISE)⁶⁶ to develop students' Nature of Science (NOS) conceptualizations by designing internet-based

by scientists.

⁶⁶ WISE educational activities were designed to include alternative perspectives of scientific phenomena (Linn, Clark, & Slotta, 2003; Walker & Zeidler, 2007).

activities centered on the socio-scientific issue of genetically modified foods.

Jimenez-Aleixandre and Pereiro-Munoz's (2002) SSI curricular intervention was a real-life environmental issue that provided authentic problem solving activities performed by experts in the field.

These findings have suggested that further research is needed to identify those characteristics that are central to successful SSI-based curricula. Jimenez-Aleixandre and Pereiro-Munoz's (2002) have claimed that the real-world context of their learning activity, which included acknowledgement of a variety of experts and expertise, was a cornerstone for developing students' scientific literacy. Walker and Zeidler (2007) acknowledged that their socio-scientific issues approach lacked the opportunities for students to apply their NOS conceptualizations in a decision-making context.

This student interest SSI-based curriculum, found that having opportunities to influence one's learning was a significant aspect in motivating learners to develop their scientific literacy. Although Jimenez-Aleixandre and Pereiro-Munoz's (2002) claimed that their real world problem motivated students, they did not indicate if or how this was measured. Similarly, Walker and Zeidler (2007) claimed that they optimized students' engagement towards the web-based activities by pairing subjects on reading ability and learning motivation levels (Bell, 1999). However, as with Jimenez-Aleixandre and Pereiro-Munoz's (2002), Walker and Zeidler (2007) did not indicate if or how motivation was measured. Consequently, it can be argued that the complexities of SSI-based interventions have not fully assessed the variables that contribute to the differing success between learners. Although this investigation has

contributed valuable insights about the significance of students' interest, more research is needed to understand which aspects of SSI-based curricula are most salient in developing learners' scientific literacy.

Implications of Testing the Universality of This Student Interest SSI-Based Curriculum

The key components of this student interest SSI-based curricular scaffold identified from the data analyses were 1) presenting science content with a focus on real-world applications by using SSI; 2) providing choices to more closely examine those real-world issues students associated to their life; and 3) creating experimental activities where learners discovered by influencing the protocol design. However, more research is needed to understand how generalizable this student interest SSI-based framework is at fostering students' functional scientific literacy. Consequently, another issue that has yet to be researched is whether this student interest SSI-based curricular framework is universal to other science disciplines and grade levels.

Although biology is associated with many social issues, SSI exists in other scientific disciplines (Ekborg, Ottander, & Ideland, n.d.; Hobson, 1995; Murphy, Lunn, & Jones, 2006; Marks, Bertram, & Eilks, 2008; Weiss, 1979; White, Brown, & Johnston, 2005). The positive findings from this study support investigating the transferability of this curricular and pedagogical framework to other science fields such as physics and chemistry.

Further, researchers have also shown that students do not inherently develop the ability to critically evaluate scientific information (Kolsto, et al., 2006; Kortland, 1996; Wu & Tsai, 2007). At what age is it beneficial to learners to begin to examine

different perspectives relating to popular science issues? At what age are learners able and/or interested in identifying an area within a science discipline that affects their life? Barab, et al. (2007) showed that they were able to develop a meaningful socio-scientific inquiry framework for 4th graders. In their study, a virtual aquatic habitat simulation was combined with a socio-scientific narrative to teach students about NOS conceptualizations and water quality. However, Barab, et al. (2007) also acknowledged several implications in developing an appropriate SSI-based scaffold that considered the developmental needs of diverse learners. Designing and testing the affects of student interest SSI-based curricula during different stages in learners' development would also provide more insights into the universality of this educational framework in fostering scientific literacy.

Implications of Implementing a Student Interest SSI-Based Curriculum

Along with designing and testing the affects of student interest SSI-based curricula in other science disciplines and grade levels, raises questions about preparing teachers to implement a student interest SSI-based curriculum. McGinnis and Simmons (1999) have suggested that one of the problems with implementing science, technology, and society (STS) pedagogical interventions was that teachers felt ill prepared to deal with the science discussions that encompassed personal beliefs and cultural values with fear of losing their job or the local community not being receptive. Similarly, Hart (2002) and others have acknowledged that traditional examination regimes can also overturn attempts to introduce a more progressive curriculum (Lyons, 2006; Volkman, 2000). According to Hart, in order for successful transformation of science curricula to be widely implemented,

assessment strategies, curricular content, and pedagogical approaches need to reflect the same educational philosophy.

These are issues that have yet to be fully addressed in the implementation of SSI-based curricular interventions. Recently, Sadler, Barab, and Scott (2007) have tried to address some of these concerns by addressing the question “what students gain by engaging in socio-scientific inquiry?” In this paper, the authors have attempted to address ways the SSI framework can develop students’ content knowledge as well as understandings of the nature of science. Resultantly, they have introduced socio-scientific reasoning as a construct to further advance the SSI model as a meaningful and assessable educational framework. They claim that this construct can be used to guide educators to begin to operationalize SSI-based practices as they approach plan, and implement science lessons. Specifically, Sadler, Barab, and Scott (2007) have characterized the socio-scientific reasoning construct as 1) recognizing the inherent complexity of SSI, 2) examining issues from multiple perspectives, 3) appreciating that SSI are subject to ongoing inquiry, and 4) exhibiting skepticism when presented potentially biased information.

Consequently, it can be argued that investigating which aspects of student interest SSI-based curricular framework are most salient in developing learners’ scientific literacy as well as if this framework is effective in other science disciplines and grade levels is only the first step. Understanding more about preparing teachers to implement a student interest SSI-based curriculum is undoubtedly an area of research that will need to be examined further if the SSI framework promoted by Zeidler,

Sadler, and others is to become widely implemented (Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005).

Summary

Today's world is more science and technologically driven than ever before and society continues to influence as well as evolve with our changing times. There are over 2.7 billion searches performed on Google each month (Fisch, 2007; Sullivan, 2006). The amount of technical information is doubling every 2 years (Oblinger, 2007). It is predicted that a supercomputer will be built that exceeds the computations capability of the human brain by 2013 (Col. Day, 2007; LTG Croom, 2007). Thus, our youth are not in need of facts, but the tools to access and discern information to make more educated decisions tomorrow. How do we help students become more scientifically literate 21st century learners? What are effective strategies for introducing students to the exponentially growing amount of scientific information? How do we empower learners to resolve questions about science issues that influence their lives? These are undoubtedly major challenges science education reformers face today.

This study does not resolve these dilemmas. However, this study has served to further what is known about ways to help students become more scientifically literate 21st century learners. Specifically, the data from this investigation have been used to address a gap in the science education literature pertaining to effective learning environments focused on fostering diverse undergraduates' interest and understanding of science (Palmer, 2005; Sadler, 2004a). Although the SSI initiative has been suggested to promote skills to evaluate scientific information and make

school science more relevant to people's lives (Sadler & Zeidler, 2004; Zeidler, 2003; Zeidler, Sadler, Simmons, & Howes, 2005), until now researchers had not examined how meaningful personal connections could be integrated into SSI-based curricula (Sadler, 2004a). In fact, studies that have been identified as SSI-based curricula (e.g., Keselman, Kaufman, Kramer, & Patel, 2007; Khishfe & Lederman, 2006; Patronis, Potari, & Spiliotopoulou, 1999) have primarily examined primary and secondary learners. As well, motivational factors that are known to engage students have rarely focused on postsecondary educational environments (e.g., Basu & Barton, 2007; Palmer, 2005; Rivet & Krajcik, 2008). Consequently, this study has expanded the SSI-based framework by showing that personalized hands-on SSI-based labs and research opportunities were effective at fostering undergraduates' scientific literacy.

It has been suggested that one way to help students become more scientifically literate 21st century learners is to rethink the way science content is acquired and encourage students to search independently for information and then evaluate it (Solomon, 2000). Solomon (2000) has contended that this type of approach to science can help to motivate learners who are more interested in the exploration of their self-identity than of the sciences. The findings from this investigation have supported Solomon's (2000) contention. It was found that students' personal beliefs were reassessed and their skills to evaluate scientific information improved after having opportunities to influence their learning. Specifically, infusing opportunities for students' to choose popular science issues they recognized as relevant to their life, proved to be a motivating tactic for promoting learners' critical evaluation of information, awareness of the NOS, and the

re-examination of prior beliefs. Giving learners the chance to design and test their own experimental procedures on pragmatic SSI also established engagement and literacy towards science.

In general, this research has shown that the SSI-based curriculum and pedagogical intervention implemented in this study was a useful framework for promoting functional scientific literacy. Our changing society accentuates the need to empower people with the skills to research and interpret alternative interpretations of scientific issues to make better-informed decisions. Consequently, this student interest SSI-based curriculum and pedagogical intervention has a general application to educators interested in developing educational settings that promote a functional understanding of how scientific knowledge can be used to answer questions in today's world.

APPENDICES

Appendix A. Lab Syllabus

<p>Microbes and Society BSCI222 Spring 2008 Lab Activity Schedule (Labs Meet 3:30 or 4:30) TuTh..... 2:00pm- 3:15pm (KEB 1110) TuTh..... 3:30pm- 4:30pm (MCB 1206) Lab or (EDU 0304) Computer Lab when indicated TuTh..... 4:30pm- 5:30pm (MCB 1206) Lab or (EDU 0304) Computer Lab when indicated Each week you need to print, read, and save your weekly labs posted in your ELMS readings. Please note this Lab Syllabus is subject to change based upon snow days or to benefit student learning Any changes that need to be made to the Lab Syllabus will be posted on the ELMS Announcements Page</p>		
Week 1	31-Jan.	ELMS Scavenger Hunt and KEEP orientations Meets in EDU 0304 Computer Lab ELMS hunt tasks: Bios Pick a topic of interest KEEP poster Read Lab Safety
Week 2	5-Feb	Lab Safety & Microscopy Read Microscope-lab-students_08 Bring lab coat and note book
	7-Feb	Do the lab task due Tuesday February 12th before 6:00 am Read Isolation-lab-students-08
Week 3	12-Feb	Lab Media & Isolation Decide on a individual topic of interest question
	14-Feb	Post Lab results on discussion board due Tuesday February 19th before 6:00 am Read Yogart-lab-students-08
Week 4	19-Feb	Lab Yogurt Post Lab results on discussion board due Tuesday February 26th before 6:00 pm
	21-Feb	Make any needed changes to your individual topic of interest question Part of lab will give you time to work on your individual projects... so bring you lap tops to lab MCB 1206 Read IndividualProject-lab-08
Week 5	26-Feb	Lab Individual Project & Graphic Art Meets in EDU 0304 Computer Lab create KEEP banners and subtitles
	28-Feb	1st draft of Individual Project due Tuesday March 4th before 6:00 pm Read IndividualProject-lab-08 Do the PreLab task due before Tuesday March 4th before 2 pm.
Week 6	4-Mar	Lab Micro Array Work on your individual project

Week 6	6-Mar		Post Lab results on discussion board due Tuesday March 11th before 6:00 am. Read Ice-nucleation-lab-Student-08 Complete the PreLab in the discussion board with Group Project Team due Tuesday March 11th before 2:00 pm.
Week 7	11-Mar	Lab Ice Nucleation	
	13-Mar		Post Lab results on discussion board due Tuesday March 25th before 6:00 pm Remember... Your Individual Project is due Thursday March 27th before 6:00 am
Week 8	18-Mar	Spring Break No Lab... Enjoy the Rest	
	20-Mar		
Week 9	25-Mar	Museum Week	
			Visit the museum with your Group Project Team Members... Talk about your group project while you explore the museum
	27-Mar		Your Individual Project is due Thursday March 27th before 6:00 am Complete the task due Tuesday due April 1st before 6:00 am Read HandWashing1-lab-Students-08 Complete the PreLab outline in the discussion board with your lab partners due Tuesday April 1st before 2:00 pm
Week 10	1-Apr	Lab Hand Washing 1... No foolin' hand washing is really important	
	3-Apr		Post Lab results on discussion board due Tuesday April 8th before 6:00 am Read HandWashing2-lab-Students-08 Complete the PreLab outline in the discussion board with your lab partners due Tuesday April 8th before 2:00 pm
Week 11	8-Apr	Lab Hand Washing 2	
	10-Apr		Post Lab results on discussion board due Tuesday April 15th before 6:00 am Read HandWashing2-lab-Students-08 1st draft of the Group Project due Tuesday April 15th before 6:00 am
Week 12	15-Apr	Lab Group Project & Graphic Art Meets in EDU 0304 Computer Lab	
	17-Apr		Read AntimicrobialSubstances-lab-Students-08 Lab Quiz
Week 13	22-Apr	Lab Antimicrobial Substances	
	24-Apr		Post Lab results on discussion board due Tuesday April 29th before 6:00 am
Week 14	29-Apr	Lab Group Projects Meets in EDU 0304 Computer Lab and in a Lecture Hall to be announced	
			Time used for finalizing your group project due Thursday May 1st before 6:00 am
	1-May		Group Project Presentations Evaluate your peers
Week 15	6-May	Lab Group Projects and Lab Cleanup Meets in a Lecture Hall to be announced & MCB1206	
			Group Project Presentations Evaluate your peers
	8-Apr		Lab Cleanup KEEP poster

Appendix B. Instrumentation

End of the Semester Article Exercise

Begin re-reading the short scientific article you chose at the start of the semester.

1) Diet and Nutrition

Slimming for slackers

01 October 2005

NewScientist.com news service

Bijal Trivedi

<http://www.newscientist.com/channel/being-human/mg18825191.900-slimming-for-slackers.html>

2) Health and Disease

Confusion in the joints: If the immune system becomes confused, it can turn against the body's own tissues, causing destructive diseases such as rheumatoid arthritis. Are bacteria to blame?

04 May 1991

From New Scientist

Julie Clayton

<http://www.newscientist.com/article/mg13017675.700-confusion-in-the-joints-if-the-immune-system-becomesconfused-it-can-turn-against-the-bodys-own-tissues-causing-destructivediseases-such-as-rheumatoid-arthritis-are-bacteria-to-blame.html>

3) DNA / Genetics

Transgene Escape! - But No One Has Called Out the Guards

By Doug Gurian-Sherman of the Centre for Food Safety

Chemistry World

<http://www.bioscienceresource.org/commentaries/dgs1.php>

4) Your Environment

In Microbe, Vast Power For Biofuel

By Steven Mufson

Thursday, October 18, 2007; Page D01

The Washington Post

<http://www.washingtonpost.com/wp-dyn/content/article/2007/10/17/AR2007101702216.html>

After carefully rereading the article you chose in February, write 1000-1200 words to address the following points including **if your initial response has changed or remained the same.**

Start by summarizing the article e.g. what is the science issue/question that is being addressed?

Then...

1. Describe the author's perspective(s), is there more than one point of view presented?
2. How are the various perspective(s) supported?
3. Are data used to support the perspective(s)? If so, describe the data and how they are used?
4. How might societal factors have influenced the perspective(s), explain?
5. What is/are the conclusion(s) of the article, how accepted are they among the scientific community?
6. Do you agree with one or more of the perspectives, if so which one and why. If not also explain why not.

Original Questions from the Sadler, Chambers, and Zeidler (2004) Study

1. Are data used to support either position? If so, describe the data and how they are used?
2. Do societal factors (issues not directly related to science) influence either position? If so, describe how these factors influence each argument. If not, describe why these factors would not influence each argument.
3. Why do the two articles, which are both written by scientists discussing the same material, have such different conclusions?
4. Which article is more convincing? Please explain your response.

5. Which article has more scientific merit? Please explain your response.

Laboratory Experiments

Lab 1	This lab is to introduce students to ELMS and KEEP through a scavenger hunt
Introduction	1 st KEEP journal entry is the product
Lab 2	Safety & Microscopy
Lab 3	Media & Isolation
Lab 4	Yogurt
Lab 5	Individual Project & Graphic Art
Lab 6	Micro Array
Lab 7	Ice Nucleation
No Lab	Spring Break
Lab 9	Museum Week
Lab 10	Hand Washing 1
Lab 11	Hand Washing 2
Lab 12	Group Project & Graphic Art
Lab 13	Antimicrobial Substances
Lab 14	Group Presentations
Lab 15	Group Presentations & Clean up

Student Lab Quiz

This lab quiz is to test your understanding of what it means to look at life through a scientific lens. We have talked about how scientific knowledge distinguishes itself from other ways of knowing through its empirical standards, logical arguments, skepticism, and subjectivity to change as new evidence becomes available. We have also discussed the human endeavor of science, which encompasses the value peer review, truthful reporting about the methods and outcomes of investigations, as well as being influenced by society, culture, and personal beliefs. Based upon **what you have learned in this course** respond to the following questions:

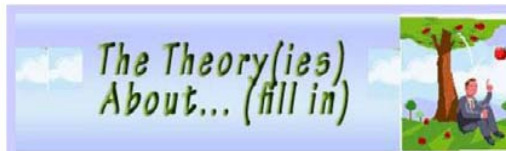
1. Explain whether the scientific process is linear or circular? Justify your answer with a specific example.
2. In what ways is scientific knowledge different from other ways of knowing?
3. Discuss the relationships/connections of science and human endeavors?

Individual Project Instrument



Define a question / problem to address (3pts)...

This is your testable question you want to know more about. This question must relate to microbes and some phenomena that you find interesting. This question must not have too many variables (only one or two underlying causes).



Define the current **scientific theory (theories)** surrounding this topic of interest (3pts)...

Theories and facts are not the same. Theories describe, explain, or model observable physical phenomena (facts). Theories have the characteristics of being tentative and subject to corrections, but are not just opinions or personal beliefs. Theories are validated by their ability to predict physical events; where as opinions or beliefs need not fit this criterion.



Summarize / make conclusions about your assimilated knowledge (3pts)

What stance do you take and



Discuss the current knowledge = facts / physical phenomena (3pts)...

Facts are observable physical phenomena, objective, and verifiable by multiple observers.



Describe the opinions and beliefs that surround the unknown variables of your question (3pts)...

Describe two alternative views about your identified question. These are peoples' opinions or beliefs about the interpretation of the observable phenomena



References... you will be required to have several references to get any research project points

Group Project Instrument


Microbes & Society Group Project on



Our Question

Our Question

Here you need to describe the "proposed question" that is the focus of your project




Our Answer

Your Answer to the Proposed Question

In this section briefly describe/explain your answer to the topic question including:

1. a clear indication of your position on the question
2. support for your position
3. alternative points of view and any limitations



We Would Teach This Material


How I would Teach this Material

In this section do the following:

Describe which upper elementary to high school grade (e.g. grades 5-10) that your learning exercise / experiment materials have been developed for.

Explain or describe how you would address each of 5-Es components:

- . Engagement
- . Exploration
- . Explanation
- . Extension
- . Evaluation



Why it is important...

Why it is important


Here you need to explain why this is an important/relevant question



Additional Resources

Additional Resources

Here provide a list of resource for individuals who would like to further explore the proposed question.



Background Information

Background Information

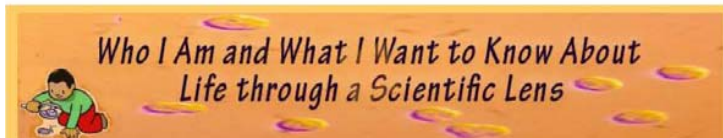
Background Information including knowledge = facts / physical phenomena

References...

References

Cite your references here and throughout your poster.

Student Journal Instrument



I come from a family...
My culture plays (a role or no role) in...
I am aspiring to be (or I am not sure what I am aspiring to be but I am interested in)...
I have always found science to be... because...
I have an interest in what scientists know about (with relationship to microbes)...
This is relevant to my life because...



In looking back at my initial scientific interest I realize...
I have learned... about my initial scientific interest
I still have questions about...
My initial opinion about this topic was...
After understanding more about... I find myself (agreeing or disagreeing) with my initial beliefs because...

Anonymous Mid-Semester Evaluation on Study Techniques Instrument

Question 1	On average how long do you spend reviewing your class notes after each lecture?				
I do not review my notes	Less than 30 minutes	30 minutes – 1 hour	1 – 2 hours	More than 2 hours	
Question 2	For exam 1 how long did you study/review for the exam by yourself?				
I did not review/study for exam 1	Less than one hour	1 – 2 hours	3 – 4 hours	5 – 6 hours	More than 6 hours
Question 3	For exam 1 how much time did you study/review in a study-group?				
I did not study/review in a group for exam 1	Less than one hour	1 – 2 hours	3 – 4 hours	5 – 6 hours	More than 6 hours
Question 4	If you studied in a group who was in your study group?				
Question 5	Please describe your study strategy for exam 1				
Question 6	What was your initial score on exam 1 (score before the retest).				
A (90 or above)	B (80-89)	C (70-79)	D (60-69)	F (less than 60)	
Question 7	For exam 2 how long did you study/review for the exam by yourself?				
I did not study in a group for exam 3	Less than one hour	1 – 2 hours	3 – 4 hours	5 – 6 hours	More than 6 hour
Question 8	For exam 2 how much time did you study/review in a study-group?				
I did not study in a group for exam 3	Less than one hour	1 – 2 hours	3 – 4 hours	5 – 6 hours	More than 6 hour
Question 9	If you studied in a group who was in your study group?				
Question 10	Describe your study strategy for exam 2				
Question 11	What was your initial score on exam 2 (score before the retest).				
A (90 or above)	B (80-89)	C (70-79)	D (60-69)	F (less than 60)	
Question 12	For exam 3 how long did you study/review for the exam by yourself?				
I did not study in a group for exam 3	Less than one hour	1 – 2 hours	3 – 4 hours	5 – 6 hours	More than 6 hour
Question 13	For exam 3 how much time did you study/review in a study-group?				
I did not study in a group for exam 3	Less than one hour	1 – 2 hours	3 – 4 hours	5 – 6 hours	More than 6 hour
Question 14	If you studied in a group who was in your study group?				
Question 15	Describe your study strategy for exam 3				
Question 16	What do you think your score will be on exam 3				
A (90 or above)	B (80-89)	C (70-79)	D (60-69)	F (less than 60)	
Question 17	Tell us one aspect of the course that helps you to understand and learn the material.				
Question 18	Tell us one thing we might change that would help you to better understand/learn the material.				

*Anonymous End of the Semester Evaluation on Laboratory Experience
Instrument*

Question 1	I am more confident in my ability to read scientific information
strongly agree	agree somewhat agree disagree strongly disagree
Question 2	Explain your response above
Question 3	I am more confident in my ability to find information about popular scientific issues
strongly agree	agree somewhat agree disagree strongly disagree
Question 4	Explain your response above
Question 5	I am more confident in my ability to discuss popular scientific issues
strongly agree	agree somewhat agree disagree strongly disagree
Question 6	Explain your response above
Question 7	The individual project helped me to learn more about how science relates to my life.
strongly agree	agree somewhat agree disagree strongly disagree
Question 8	Explain your response above
Question 9	The individual project engaged my interest
strongly agree	agree somewhat agree disagree strongly disagree
Question 10	Explain your response above
Question 11	The group project helped me to learn more about how science relates to my life.
strongly agree	agree somewhat agree disagree strongly disagree
Question 12	Explain your response above
Question 13	The group project engaged my interest.
strongly agree	agree somewhat agree disagree strongly disagree
Question 14	Explain your response above
Question 15	What laboratory activity did you learn the most in?
Question 16	Why?
Question 17	What laboratory activity did you enjoy the most?
Question 18	Why?
Question 19	The laboratory activities increased my interest in science.
Question 20	Explain your response above using a specific example.
Question 21	What laboratory activity did you enjoy the least?
Question 22	Why?
Question 23	This course gave my opportunities to reflect upon my own values and belief about popular scientific issues
strongly agree	agree somewhat agree disagree strongly disagree
Question 24	Explain your response above
Question 25	Would you recommend this class to others?
strongly agree	agree somewhat agree disagree strongly disagree
Question 26	Why or why not?

Practitioner Researcher Self-reflective Journal Outline Instrument

Area	Post-Lesson Instructor Reflection				Date: 00 - 00-08
Lab title					
Brief general description of lab activities					
Did the activity promote	Sensitivity to SSI	Problem solving in groups	Problem solving in individually	Interest	
Brief description of lab assignments					
Instructional preparation and Dr. Benson's mentoring insights					
NOS conceptualizations					
Content knowledge					
Evaluation of scientific information					
Interactions with students in ELMS					
Interactions with students in lab					
Any observable differences between education and other non-science majors'					
Other Comments					

Appendix C. Original Institutional Review Board Application & Consent Form

Accepted January 9th, 2008
 Application number 07-0686
 UNIVERSITY OF MARYLAND, COLLEGE PARK
 Institutional Review Board

Initial Application for Research Involving Human Subjects

Name of Principal Investigator (PI) or Project Faculty Advisor Dr. J. Randy McGinnis **Tel. No** 301-405-6234
 Department or Unit Administering the Project EDCI

E-Mail Address jmcginni@umd.edu
 Where should the IRB send the approval letter? Dr. J. Randy McGinnis; College of Education; 2226 Benjamin Building; Science Teaching Center; University of Maryland

Name of Student Investigator Kelly Schalk **Tel.** 301-405-
 E-Mail Address of Student Investigator schalk@umd.edu

Check here if this is a student master's thesis or a dissertation research project

Project Duration (mo/yr – mo/yr) 1/08 -- 8/09

Project Title A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning

Sponsored Project Data	Funding Agency <u>N/A</u>	ORAA Proposal <u>N/A</u>
-------------------------------	---------------------------	---------------------------------

Vulnerable Populations: The proposed research will involve the following (Check all that apply):
 pregnant women , human fetuses , neonates , minors/children ,
 prisoners , students , individuals with mental disabilities , individuals with physical

Exempt or Nonexempt (Optional): You may recommend your research for exemption or nonexemption by completing the appropriate box below. For exempt recommendation, list the numbers for the exempt **Exempt** --- List Exemption Category Or **Non-Exempt**

If exempt, briefly describe the reason(s) for exemption. Your notation is a suggestion to the IRB Manager and IRB Co-Chairs.

This proposed research will take place in the established BCSI122 Microbes and Society educational settings. This undergraduate microbial biology curriculum meets the approval of the College of Life Sciences and Chemistry standards for non-science majors. This proposed investigation has an interest in understanding the affects of the current educational practices in this course. Specifically, this proposed investigation desires to examine the effectiveness of the curricular intervention and instructional techniques on non-science majors' informal reasoning.

Most of the data for this study will come from education products of the curriculum. However, there is an additional voluntary on-line, anonymous survey in ELMS, which will take students approximately fifteen minutes at the end of the semester to complete. This anonymous survey may also result in a few additional questions if it is necessary to clarify subjects' responses. If there is a need for additional questioning then ELMS will again serve as an anonymous communicative interface.

Subjects will be informed that participation in the study is voluntary and should any persons initially agree to participate they have the right to withdraw from the study at any time without penalty.

The graduate teaching assistant and practitioner researcher, Kelly Schalk, is also a subject of this study. Ms. Schalk will be keeping self-reflective journals on her pedagogical practices over the semester. Ms. Schalk's participation is also voluntary as she realizes her participation will enhance her own scholarly practices for a future career in higher academia.

Data collection includes procedures that enable human subjects' identification. However, providing students consent to disclosing their responses for educational purposes, all data will protect the subjects' identities. Arbitrary identifiers will allow the disclosure of research findings without revealing participants name or any other personal information. Any disclosure of data from this study will be used strictly for educational purposes to benefit future undergraduates' science experiences.

This study does not involve children, elect / appointed public officials, or candidates for public office. The subjects of this study will be those University of Maryland undergraduates who register for BCSI122 Microbes and Society in the Spring 2008.

Date **Signature of Principal Investigator or Faculty Advisor** *(PLEASE NOTE: Person signing above accepts responsibility for the research even when data collection is performed by*

Date **Signature of Co-Principal Investigator**

Date **Signature of Student Investigator**

Date **REQUIRED** Departmental Signature
Name _____,
Title _____
(Please also print name of person signing above)

(PLEASE NOTE: The Departmental signature block should not be signed by the investigator or the student investigator's advisor.)

***PLEASE ATTACH THIS COVER PAGE TO EACH SET OF COPIES**

Original Institutional Review Board Application for Researching Human Subjects

1. Abstract

Title of the study: A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning

The purpose of this case study is to understand if this socio-scientific issues (SSI) based curriculum fosters student interest in science and develops skills to insightfully reason scientific issues important to society. The central research question for this study is: *How does a SSI curricular and pedagogical intervention, including a student interest-focus, affect undergraduates in education and other non-science majors' ability to informally reason?* A student interest-SSI framework guides this research by allowing students to choose socially controversial scientific issues they find interesting. Examination of subjects will be in their curriculum environment, which meets the College of Life Sciences and Chemistry requirements for non-science majors. Data for this study mainly come from subjects' educational products such as journals, individual and group projects. However, there is an additional voluntary confidential survey in ELMS. This confidential survey does not ask, require, or desire subjects to include their names or UID numbers if they choose to complete the survey. Subject will be informed participation in this study is optional and any participation or lack of participation will not affect the evaluation of students' academic performance. Participants also will be informed should they agree to participate they have the right to withdraw from the study at any time without penalty. Furthermore, several fail-safes will ensure student confidentiality in any resulting publications of this investigation.

2. Subject Selection

a. Subjects for this project are students who enroll in BSCI122 General Microbes and Society for the spring 2008. The only potential advertisement for this course is a flyer; see Appendix A for a copy of the 2007 version. Use of this flyer is contingent upon low enrollment in January 2008. Should enrollment of BSCI122 prove to be low prior to January 28th, 2008 (the start of the 2008 spring semester) Dr. Spencer Benson will update the 2007 flyer with minor changes. Consequently, circulation of the flyer will only be for a few weeks in January until February 8th, the last day of late course registration. This flyer circulates within the College of Education, Chemistry and Life Science, and throughout campus.

b. This investigation takes place in an undergraduate microbiology course, BSCI122 Microbes and Society. A transformation of this course began in the spring of 2007. This transformation was partly the influence of Project Nexus, a Maryland upper elementary/middle school science teacher professional continuum model, which the National Science Foundation

supports as part of their Teacher Professional Continuum Programs (Project Nexus, 2005). Consequently, this study will examine the effectiveness of two aspects of this new curriculum. The first aspect involves a student interest focus, where students have an influence on their learning. This focus stems in part from the desire Project Nexus has in recruiting future upper elementary and middle school science teachers. Consequently, this student interest focus has the objective of exciting undergraduates about science through projects relevant to the diversity of the University of Maryland's student body. The other aspect of this curriculum connects to the former by offering potential teachers a chance to reflect and develop ways to teach science. By asking students to develop learning activities / experiments education majors not only get practice with planning science activities they also learn about the Maryland voluntary state curriculum 5-E model (Maryland State Department of Education, 1997). However, non-education majors can also benefit from such opportunities by further developing their communicative skills, knowledge of microbial biology, and in some cases parenting skills.

Consequently, this non-major's microbiology course is for future K-8 teachers and students with a general interest in how science plays into their everyday lives. Students who enroll in this course do not typically see themselves in future science careers. However, subjects are not chosen for this investigation, rather this study seeks to understand the needs of students who select this course based upon personal choice. Although students from the College of Education may be more likely to hear of this course because of its scaffold design for prospective K-8 teachers, this course is open to all University of Maryland undergraduates. Consequently, there are no specific selective characteristics for this study such as age, sex, race, ethnic origin, religion, or any social or economic qualifications. The only requirement to enroll in BCSI122 Microbes and Society is being a University of Maryland student. Student profiles range from freshman to senior status, with a variety of ethnic backgrounds. The population of males to females is mixed and is not predictable.

Finally, Kelly Schalk, the graduate practitioner researcher of this dissertation study is also a subject of investigation. Ms. Schalk is a returning teaching assistant from the spring 2007, and will assist Dr. Benson in the implementation of the BSCI122 curriculum. However, Ms. Schalk will also investigate her own pedagogical practices over the course of the semester through reflective journals, thus she is also a subject in this study.

d. The total number of students enrolling in this undergraduate microbial course can vary, but is typically around thirty students. Likewise, although this course has the additional goal of engaging potential future teachers, the number of general non-science majors to education interns is variable. Both general non-science and education undergraduates can have diverse majors. For instance, non-science majors may have an interest in journalism, sociology, theater, music, government and policy, while education majors may have a special, pre-K, or elementary focus.

3. Procedures

Background of Curricular Environment

The purpose of this case study is to gain insight into whether this socio-scientific issues (SSI) based curriculum fosters student interest in science as well as develops skills to insightfully reason scientific issues important to society. By definition, SSI describes social dilemmas with conceptual ties to science (Sadler & Zeidler, 2004, p. 5; Sadler, Chambers, & Zeidler, 2004, p. 387). Informal reasoning is the process of considering a claim where the reasoner weighs and synthesizes benefits and disadvantages to arrive at the best sound judgment (Perkins, 1985, p. 562; Mean & Voss, 1996, p. 140). Sadler (2004, p. 515) relates informal reasoning to socio-scientific research through four primary themes: 1) socio-scientific argumentation, 2) Nature of Science (NOS)⁶⁷ conceptualizations, 3) conceptual understanding of science content, and 4) evaluation of scientific information. This research is delimited by the latter three themes. Data suggest SSI based curricular frameworks are a way to promote curiosity, open-mindedness, and informed skepticism in addition to building students' contextual knowledge of science (Jimenez-Aleixandre & Pereiro-Munoz, 2002; Zohar & Nemet, 2002). However, data also reveal that SSI do not necessarily promote students' connections to science (Zeidler, et al., 2002; Sadler, et al., 2004). A student interest-SSI framework guides this dissertation study, by allowing students to choose socially controversial scientific issues they find interesting.

Examination of subjects will take place in their curricular environment, which meets the approval of the College of Life Sciences and Chemistry educational standards for non-science majors. Most of the data form this study will come from subjects' educational products such as journals, individual and group projects, as well as pre and post-evaluative tests all currently part of the course curriculum. These curricular activities, in Appendix B, are the product of Dr. Benson, Dr. McGinnis, the Project Nexus Research Team, and Ms. Schalk's transformation of this undergraduate microbiology course, beginning in the fall of 2006. A brief outline of this 2008 General Microbes and Society curriculum follows.

In the first week of classes, students start to examine their interests by journaling about an issue in science that connects with their lives. Students also journal three more times over the course of the semester on the knowledge and perspectives they have about science after exposure this microbiology curriculum. Over the course of the semester, the lab scaffold fosters refinement of the initial journal until students identify two opposing scientific perspectives with a limited number of variables. This first journal

⁶⁷ The NOS, also known as epistemology of science, or science as a way of knowing, defines values and assumptions inherent to scientific knowledge. NOS values and assumptions include such concepts as tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (theory laden), partly the product of human inference, imagination, and creativity (involves the invention of explanation), socially and culturally embedded, and involves a combination of observation and inferences (Bell & Lederman, 2003, p. 353; Bell, Lederman, & Abd-El-Khalick, 2000, p. 564).

evolves into students' individual research posters, which use the University of Maryland's KEEP toolkit as the medium of expression (Knowledge Media Lab at the Carnegie Foundation for the Advancement of Teaching, 2002). This individual work establishes groups of similar interest to refine students' reflections, informal reasoning, and knowledge through social learning. A team effort also creates a KEEP poster that discloses two opposing views on a popular socio-scientific issue the students determine interesting. Finally, there is an additional conceptual knowledge test that Dr. Benson uses as a measure of students' gains in microbiology understanding over the semester.

There are also changes in the Lecture and Laboratory Structure for spring 2008. The piloting of this curriculum, in the spring 2007, shows positive changes in facilitating student learning. Consequently, most of the student activities such as journaling, individual and group projects are carrying over to spring 2008. However, there are some modifications in response to student feedback. These changes include fewer journaling exercises. The students' journals are no longer after each lab, but after each learning unit reducing the journals by more than half. Additionally, there are some modifications to the wording of the remaining journal instructions to elicit more elaboration on students' conceptual knowledge. Finally, there is a start and end of the semester learning activity that focuses on helping students to reflect upon their understanding of microbiology and informal reasoning. This activity requires students to read one (at the start of the semester) or two articles (at the end of the semester) written for the popular press. Students summarize their interpretations of these articles as well as respond to six or seven open-ended questions prompting reflection of their beliefs. In alignment with the first journal and projects, students select a controversial socio-scientific issue they find interesting. At the end of the semester, after students have time to develop their skills to find reliable sources of scientific information, they find one article supporting each of the opposing sides they summarized at start of the fifteen weeks. They also respond to similar open-ended questions, again fostering reflection upon their understanding of microbiology and informal reasoning.

This investigation will examine the effects of this curriculum mainly through the educational products of students not available to the public. Consequently, several fail-safes will ensure student confidentiality. First, the summation of results will use a numeric coding scheme to protect all subjects' identities. Second, pseudonyms will replace student names if it becomes necessary to reference direct quotes for educational or data analyses purposes. Finally, no person beyond the research team will have access to student information such as name, social security number, and any other personal identification information.

Investigative Procedures on Human Subjects

Although this course takes place in a lecture hall and microbiology laboratory, this course also uses the University of Maryland's online learning environment, the Enterprise Learning Management System (ELMS), as a way of storage course materials and encouraging communication (Blackboard Inc.,

2006). The University of Maryland's database will store the data from this study. Any additional data analyses products will also be secured by using locked Project Nexus file cabinets in Cole Field house, 0108L.

The investigative procedure involving human subjects involves a confidential survey, administered voluntarily in the discussion board of ELMS. This confidential survey is an additional means of assessing students' beliefs and opinions. However, subjects will not be asked to include their names or UID numbers on the survey. This survey will have no negative affect upon any students' grades or result in any negative assessments of students' performances over the semester. This end-of-the-semester questionnaire will take students approximately fifteen minutes to complete, and students will have at least a three-day window to complete these six questions. Appendix C contains this questionnaire. This survey instrument will provide students a chance to express how they feel about their learning experiences and if they would recommend this educational setting to others. However, participation is voluntary and will have no negative affect upon any students' grades, or result in any negative assessments of students' performances over the semester. Consequently, subjects will be informed that participation in the study is voluntary and should any persons initially agree to participate they have the right to withdraw from the study at any time without penalty.

Furthermore, it may be necessary for Ms. Schalk to confirm her interpretations of students' responses through additional confidential questions in ELMS. These questions will not require students' participation but will provide an opportunity for communication between the practitioner researcher, Ms. Schalk, and students in a non-threatening manner. Should further correspondence be useful for clarification of students' replies, questions will be short and students' responses do not need to be lengthy or take more than ten minutes to complete. Again, subjects will not be asked to include their names or UID numbers on the survey. As with the survey, students will have several days to respond to any additional questions. An example question could be "Thank you for responding to: Give an example of how the laboratory activities have or have not increased your interest in science. However, most of your responses only talk about a laboratory activity you liked or disliked, with no comments about increasing, not affecting, or decreasing your interest in science. It would be helpful if you could expand on your initial responses by more explicitly discussing the affects of labs on your interest in science." As with the confidential survey, any additional confidential questions will be voluntary, have no negative affect upon any students' grades or result in any negative assessments of students' performances over the semester, and students will be informed of the right they have not to respond or withdraw from the study.

Ms. Schalk will also study her own pedagogical practices through journaling. Appendix C also contains the journal template Ms. Schalk will use. Ms. Schalk's responses towards her actions and thoughts will vary in length depending upon the curricular preparation or events that transpire when

interacting with students in class or through ELMS. Ms. Schalk's participation in this study is also voluntary, thus there is no required level of effort. Ms. Schalk also has the right to not respond or withdraw from the study should she feel an irresolvable conflict between her graduate teaching responsibilities and data collection.

4. Risks and Benefits

Participation in the project may potentially create psychological risks. Involving students in any type of educational experience can cause students to experience emotional anxieties in relationship to performance, previous or current events in their life, and future aspirations. However, the risks from this study should not be any greater than what students experience from enrolling in any University of Maryland course, as participation in this study is optional. Furthermore, the confidential ELMS survey will not have any negative influence on students' grades and should not adversely affect students' engagements in the course activities. Any additional questioning through the discussion board in ELMS is also optional and again will not have any negative impact on students' grades or students' participations.

However, there are benefits associated with participating in this investigation. For example, it offers students a chance to voice their satisfaction or dissatisfaction with their undergraduate microbes and society educational experience as well as share ideas to improve the course for future undergraduates. Participation in ELMS should decrease any anxiety that could be associated with interviews especially considering the practitioner researcher, Ms. Schalk, would facilitate that dialogue.

Additionally, subjects are free at any time to withdraw from the study without repercussions. Subjects may choose at anytime to refuse to respond to any question. Subjects are also invited to ask questions throughout the study should they feel uncomfortable or inquisitive. In no way will participating, refusing to participate, or withdrawing from the study affect the subjects' grades or participations in the course.

Any psychological risks with respect to Ms. Schalk's reflective journals should be no greater than the emotional growth that is associated with perusing a doctorate of philosophy degree in Education. Ms. Schalk's participation is also voluntary and she can choose to withdraw from this study without repercussions. However, in no way is Ms. Schalk's decision to withdraw from this investigation associated with her obligations as a teaching assistant to Dr. Benson and the students enrolled in BCSI122, General Microbes and Society.

Any social risks to student subjects will be reduced by confidentially handling students' responses for the ELMS survey. Consequently, subjects will not be asked to include their names or UID numbers on the survey. Furthermore, Ms. Schalk's role in the course should not vary from her spring 2007 teaching assistantship experience. Consequently, she should not experience any increase in social risks from teaching this course.

Legally, Ms. Schalk will be at risk to make sure her contact with students is appropriate and aligns with the requirements of the IRB. For example, Ms. Schalk will need to make sure she obtains student consent, and respects the wishes of students should they choose not to partake in any aspect of this study. However, students are not at any legal risks by participating, or not participating, in this investigation.

There are no known financial or physical risks known for either student or practitioner researcher in this study.

5. Confidentiality

A subject is not at risk of a confidentiality violation during or after this study is complete. Although this investigation will examine the effects of this curriculum mainly through the educational products of students not available to the public, several fail-safes will ensure student confidentiality. First, the summation of results will use a numeric coding scheme to protect all subjects' identities. Any use of data for analyses or summation purposes will be at the class level. For example, descriptions of findings at a class level include "undergraduates enrolled in a microbes and society course at a major university in the northeast". If it is necessary to share the data of individual students for data analyses or scholarly publications then arbitrary pseudonyms will replace subjects' names.

No persons other than the researchers named on this IRB application shall have access to confidential student information. The principal investigator is Dr. McGinnis and Ms. Schalk is the student investigator. Survey responses and educational products will only be accessible by the course instructors Dr. Benson and Ms. Schalk through ELMS and KEEP, as both ELMS and KEEP operate under the security of University of Maryland databases. Upon completion of this study, the data will be archived within ELMS and KEEP for two years. After these two years all electronic data will be destroyed. Any paper products resulting from data analyses will be safe in private and locked Project Nexus filing cabinets in Cole Field house, 0108L, until the study is complete. At the completion of this study all data will be archived in the Department of Curriculum and Instruction's Science Teaching Center for five years. After these five years all data will be destroyed.

When we write a report or article about this research project, students' identities will be protected to the maximum extent possible. However, students' information may be shared with representatives of the University of Maryland, College Park or governmental authorities if subjects are in danger or if we are required to do so by law.

6. Information and Consent Forms

At the beginning of the BSCI122, General Microbes and Society, the instructors of the course (Dr. Benson and Ms. Schalk) will inform students of the intent to research how this course affects subjects' interests in science and informal reasoning processes. A description of informal reasoning will include the process of considering a claim where the pros and cons influence a

person's judgment, however positions can change as additional information becomes available and by pondering causes, consequences, and alternatives.

Since this study involves an existing, standard curriculum, no treatments are being investigated, thus subject deception is not necessary. Consequently, disclosure of the purpose of this study and requests for students' consents will occur at the start of the semester. The introduction of this study will also include an explanation of why this study is important to future undergraduates' science education and depends upon voluntary student participation. Students will be aware that any data resulting from this study will protect their identities should they agree to participate in this study. Should students opt to not participate in the confidential survey their data will not be included in the data analyses and there will be no negative ramifications upon their grades or participation in class activities. It will also be explained to the students that if they choose to participate, their choice to discontinue participation at any time is possible without any penalty.

Students who consent to participate in this study will also be informed that they are allowing their curricular products to be evaluated with respect to the central research question of this investigation (how does this learning experience affect aspects of students' informal reasoning?). However, the research evaluation of students' educational products will in no way connect to students' performances assessments, in this undergraduate microbes and society course. Consequently, whether students participate in this research study or not, there will be no negative affect on students' grades. At the conclusion of this study's introduction students will be given the opportunity to voluntarily sign the informed consent form (see Appendix D).

7. Conflict of Interest

There is a potential conflict of interest in this study as the practitioner researcher Ms. Schalk has a dual research and teaching relationship with the students. Consequently, there is the potential for Ms. Schalk to enforce students' compliances with the confidential survey. However, Ms. Schalk is aware that such actions can potentially bias data and students responses. Additionally, the confidential format of this survey protects students from such a conflict of interest by protecting their identities and keeping Ms. Schalk from knowing which students may choose not to respond.

There is also a potential conflict of interest in Ms. Schalk wanting to see changes over the course of the semester in students' products, thus bias her grading of students' efforts over the course of the semester. To minimize this conflict of interest several steps will be taken. For example, Ms. Schalk is aware that the less bias her data analyses are, the more significant her contribution is to any scholarly research community. Consequently, Ms. Schalk has several methods for protecting students from any potential conflict of interest when evaluating data for research purposes and assessing students' academic performances for her teaching obligation. For instance, Ms. Schalk will keep a self reflective journal, enforcing critical evaluation of her student-teacher interactions and instructional practices, which will be reviewed by her

dissertation committee throughout the semester (arbitrary pseudonyms will replace subjects' names). These faculty are Dr. Randy McGinnis, Dr. Ann Smith, Dr. Hanney Mawhinney, and Dr. William Holliday all of whom are not associated with the instruction of this course. In addition, Ms. Schalk has several assessment rubrics that she will use to measure students' effort; Appendix E includes several of these rubrics. Similar rubric designs will assist Ms. Schalk assessing all assignments. Finally, Ms. Schalk's evaluations of students' efforts are subject to Dr. Benson's review and approval, further minimizing any potential conflict of interest she may have when evaluating students' performances as a teacher. Finally, should Ms. Schalk feel unable to resolve a conflict between her teaching and research role in this study, Ms. Schalk may withdraw from her research obligations.

8. HIPAA Compliance

Not applicable

9. Research Outside of the United States

Not applicable

10. Research Involving Prisoners

Not applicable

Selected references

Blackboard Inc. (2006). Enterprise learning management system (ELMS).
from <https://bb.rhsmith.umd.edu>

Jime'nez-Aleixandre, M., Pereiro-Munoz, C., (2002). Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *International Journal of Science Education*, 24(11), 1171-1190.

Knowledge Media Lab at the Carnegie Foundation for the Advancement of Teaching. (2002). The KEEP toolkit. 2007, from <http://www.keep.umd.edu/>

Perkins, D. N. (1985). Post-Primary Education Has Little Impact on Informal Reasoning. *Journal of Educational Psychology*, 77(5), 562-571.

Project Nexus. (2005). The Maryland upper elementary/middle school science teacher professional continuum model 2007, from <http://projectnexus.umd.edu/>

Maryland State Department of Education. (1997). Maryland voluntary state curriculum. Retrieved October 10, 2007, from <http://mdk12.org/instruction/curriculum/index.html>

- Means, M. L., & Voss, J. F. (1996). Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels. *Cognition and Instruction*, 14, 139 – 178.
- Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, 41(5), 513-536.
- Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education*, 26(4), 387-409.
- Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education*, 88(1), 4-27.
- Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, 86(3), 343-367.
- Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, 39(1), 35-62.

Original Participant Informed Consent Form

Identification of Project/Title	A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning
Statement of Age of Subject	I state that I am 18 years of age or older and wish to participate in a program of research being conducted by Dr. J. Randy McGinnis and Ms. Kelly Schalk in the Department of Curriculum and Instruction at the University of Maryland, College Park.
Why is this research being done?	<p>The purpose of this case study is to understand if this ‘socio-scientific issues’ (SSI) based curriculum fosters student interest in science and develops skills to insightfully reason scientific issues important to society. The central research question for this study is: <i>How does a SSI curricular and pedagogical intervention, including a student interest-focus, affect undergraduates in education and other non-science majors’ ability to informally reason?</i> The delimited components of informal reasoning measured were undergraduates’ 1) Nature of Science (NOS) conceptualizations, 2) conceptual understanding of science content, and 3) the evaluation of scientific information.</p>
What will I be asked to do?	<p>The subjects for this research study include all students who enroll in BSCI122 General Microbes and Society for the spring 2008, are 18 years of age or older, and consent to participate. Students who agree to participate in this study will voluntarily complete a fifteen-minute confidential survey in ELMS near the end of the semester. However, subjects will not be asked to include their names or UID numbers on the survey. This evaluation will have no negative affect upon any students’ grades or result in any negative assessments of students’ performances over the semester. However, participation in the study will greatly benefit interested persons’ understandings of how effective this curricular design is at improving future non-science majors’ interests in science and informal reasoning.</p> <p>It may also be necessary for Ms. Schalk to clarify students’ responses by asking additional confidential follow-up questions in ELMS. These questions will provide an opportunity for correct interpretations of students’ responses in a non-threatening manner. Should further dialog be useful for clarification of initial responses, questions will be short and student responses do not need to be lengthy or take more than ten minutes to complete. Again, subjects will not be asked to include their names or UID numbers on the survey. This evaluation will have no negative affect upon any students’ grades or result in any negative assessments of students’ performances over the semester. As with the confidential survey, any additional questions will be voluntary, have no negative affect upon any students’ grades or result in any negative assessments of students’ performances over the semester. Subjects are also invited to ask questions throughout the study should they feel uncomfortable or inquisitive. Additionally, should any participant choose to no longer participate in this research study, he /she has the right to withdraw from this investigation without any penalty.</p> <p>Ms. Schalk, the practitioner researcher, will also be a subject of this study through analyses of self-reflective journals on her pedagogical practices. Analyses of these journal entries will be subject to the review of her dissertation committee throughout this study.</p> <p>Students who consent to participate in this study will also be allowing their curricular products to be evaluated with respect to the central research question of this investigation (how does this learning experience affect aspects of</p>

	<p>students' informal reasoning?). However, the research evaluation of students' educational products will in no way connect to students' performances assessments, in this undergraduate microbes and society course. Consequently, whether students participate in this research study or not, there will be no negative affect on students' grades.</p>
<p>What about confidentiality?</p>	<p>We will keep subjects personal information confidential. To help protect subjects' confidentiality, the survey will not ask subjects to include their names or UID numbers and be collected confidentially through ELMS. Additionally, survey responses and educational products will only be accessible to the course instructors Dr. Benson and Ms. Schalk through ELMS and KEEP, both of which operate under the security of University of Maryland's databases. Should it be necessary to share data from this study for analytical purposes, there will be no reference to subjects' identities. For the most part data will be analyzed at the class level, resulting in descriptions of findings at a class level. An example of such a description includes "undergraduates enrolled in a microbes and society course at a major university in the northeast". Should it be necessary to reference specific example of students' responses arbitrary subject pseudonyms will replace all names and only the researchers will be able to link subjects' identities to their data.</p> <p>Upon completion of this study, the data will be archived within ELMS and KEEP for two years. After these two years all electronic data will be destroyed. Any paper products resulting from data analyses will be safe in private and locked Project Nexus filing cabinets in Cole Field house, 0108L, until the study is complete. At the completion of this study all data will be archived in the Department of Curriculum and Instruction's Science Teaching Center for five years. After these five years all data will be destroyed.</p> <p>If we write a report or article about this research project, students' identities will be protected to the maximum extent possible. However, students' information may be shared with representatives of the University of Maryland, College Park or governmental authorities if subjects are in danger or if we are required to do so by law.</p>
<p>Identification of Project/Title</p>	<p>A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning</p>
<p>What are the risks of this research?</p>	<p>Participation in the project may potentially create psychological risks. Involving students in any type of educational experience can cause students to experience emotional anxieties in relationship to performance, previous or current events in their life, and future aspirations. However, the risks from this study should not be any greater than what students' experience from enrolling in any University of Maryland course. Should any student attribute their anxiety to their voluntary</p>

	<p>participation in this study that student may withdraw their involvement without any repercussions. Furthermore, the confidential ELMS survey will not influence students' grades or involvement in the course. Any additional correspondence through the discussion board in ELMS is also optional and again will not have any negative affect on students' grades.</p>
<p>What are the benefits of this research? Benefits, Freedom to Withdraw, & Ability to Ask Questions</p>	<p>The benefits associated with participating in this investigation include opportunities for students to voice there satisfaction or dissatisfaction with there educational experience as well as ideas to improve the course for future undergraduates. Participation in ELMS should decrease any anxiety that could be associated with interviews, especially considering the practitioner researcher would facilitate such dialogue. We hope that, in the future, other people might benefit from this study through improved understanding of curricular frameworks that engage non-science majors in learning about science and develop undergraduates' informal reasoning skills. Understanding more about how to successfully develop educational settings that foster interest and understanding of science is important as society advances into this new technologically advanced era.</p>
<p>Do I have to be in this research? May I stop participating at any time?</p>	<p>Subjects' participations in this research are completely voluntary. Students may choose not to take part at all. If a student decides to participate in this research, they may stop participating at any time. If students decide not to participate in this study or if subjects stop participating at any time, there will be no penalty or loss of any benefits to which subjects would otherwise qualify. Subjects also have the right to participate but opt at times not to respond to any question. This level of participation is acceptable and will not result in any penalty or loss of any benefits to which subjects would otherwise qualify.</p>
<p>What if I have questions?</p>	<p>Subjects are also invited to ask questions throughout the study should they feel uncomfortable or inquisitive. This research is being conducted by Dr. Randy McGinnis (is the Primary Investigator), and Ms. Schalk (is the student-investigator) at the University of Maryland, College Park. If students have any questions about the research study itself, please contact Dr. Randy McGinnis at: jmcginni@umd.edu, (telephone) 301-405-6234 or Kelly Schalk at: schalk@umd.edu, (telephone) 301-405-3155</p> <p>If students have questions about their rights as research subjects or wish to report a research-related injuries, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; (e-mail) irb@deans.umd.edu; (telephone) 301-405-0678</p> <p>This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.</p>
<p>Contact Information of Investigators</p>	<p>Dr. J. Randy McGinnis and Ms. Kelly Schalk Department of Curriculum & Instruction Room 2234 Benjamin University of Maryland, College Park College Park, MD 20742 Telephone numbers: 301-405-3133; 301-405-6234; 301-405-3152 Email addresses: jmcginni@umd.edu; schalk@umd.edu</p>
<p>Subject Consent</p>	<p>Your signature indicates that: you are at least 18 years of age; the research has been explained to you; your questions have been fully answered; and you freely and voluntarily choose to participate in this research project.</p> <p>Name of participant _____</p> <p>Signature of participant _____</p> <p>Date _____</p>

Renewal Institutional Review Board Application & New Consent Form

Accepted January 8th, 2009

Application number 07-0686

UNIVERSITY OF MARYLAND, COLLEGE PARK

Institutional Review Board

Renewal Application for Research Involving Human Subjects

Name, Department and E-mail Address of Principal Investigator or Faculty Advisor:

Dr. J. Randy McGinnis; Department of Curriculum & Instruction Room 2226 Benjamin; jmcginni@umd.edu

Name, Department and E-mail Address of Co-Investigator(s) (if applicable):

N/A

Name and E-mail Address of Student Investigator(s) (if applicable):

Kelly Schalk; schalk@umd.edu

Project Title:

A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning

IRB Application Number:

07-0686

Date IRB Approval Expires:

January 09, 2009

Name and Address of Person to Receive the Approval Documents

Dr. J. Randy McGinnis; Science Teaching Center,
Department of Curriculum & Instruction Room 2226
Benjamin

SIGNATURE SECTION

The Principal Investigator, Co-Investigator, and Student Investigator, in signing this renewal application, certify that they have conducted research in accordance with the IRB-approved protocol and that any consent forms used in connection with the project have been retained by the Principal Investigator unless otherwise indicated in this renewal application.

Principal Investigator or Faculty Advisor Date

Co-Investigator (if applicable) Date

Student Investigator (if applicable) Date

Who Must Renew?

Please indicate YES or NO for each of the following questions. This will determine whether you need to submit a renewal application.

1. Will future research activities involve obtaining data through intervention or interaction with human subjects?
YES NO
2. Will future research activities involve obtaining identifiable private information about living individuals? (Information is identifiable if subjects can be identified directly or through identifiers linked to the subjects.)
YES NO
3. Will future research activities include analyzing **identifiable** private information about living individuals?
YES NO

Project Description:

The purpose of this case study is to understand if this socio-scientific issues (SSI) based curriculum fosters student interest in science and develops skills to insightfully reason scientific issues important to society. The central research question for this study is: *How does a SSI curricular and pedagogical intervention, including a student interest-focus, affect undergraduates in education and other non-science majors' ability to informally reason?* A student interest-SSI framework guides this research by allowing students to choose socially controversial scientific issues they find interesting. The delimited component of informal reasoning assessed were students ability to evaluate scientific information and their nature of science (NOS) conceptualizations. The NOS, also the epistemology of science or science as a way of knowing, defines processes, values, and assumptions inherent to scientific knowledge (Bell & Lederman, 2003, p. 353).

Specifically, this research has focused on the educational experience of 26 students who were enrolled in BCSI122 Microbes and Society during the spring of 2008. The data collection has focused on understanding the affects of the educational practices offered to students. Most of the data from this study has come from undergraduates' education academic products such as lab write-ups and research projects. However, there was an additional voluntary on-line, anonymous survey in ELMS, which took students approximately fifteen minutes to complete. Undergraduates were asked to complete this survey at the end of the semester.

Subjects were informed that their participation in the study was voluntary and at any time, any persons had the right to withdraw from the study without penalty to their course grade or class participation. Subjects were also asked if they would consent to allowing any resulting data collected be disclosed for educational purposes providing their identities have been protected. All students consented to participating in this study and to allowing their responses be disclosed for educational purposes providing their identities have been protected. Consequently, pseudonyms and arbitrary identifiers have been used throughout the data analyses to disclose any significant research findings without revealing participants name or any other personal information. The data from this investigation is being used for strictly for educational purposes. Specifically, a doctoral dissertation and educational publications are being written to disclose significant findings from this study, to benefit future undergraduates' science experiences.

The graduate teaching assistant and practitioner researcher, Kelly Schalk, was also a subject of this study. Ms. Schalk took self-reflective journals on her pedagogical practices over the semester. Ms. Schalk's participation was also voluntary and she was aware of her right to withdrawal from the investigation.

This study does not involve children, elect / appointed public officials, or candidates for public office. The subjects of this study were those University of Maryland undergraduates who registered for BCSI122 Microbes and Society in the spring 2008. No additional subjects are being recruited for this IRB renewal request.

Bell, R. L., & Lederman, N.G. (2003). Understandings of the nature of science and decision-making on science and technology based issues. *Science Education*, 87(3), 352-377.

Investigator Information:

The Principal Investigator, Dr. J. Randy McGinnis, has remained the same and no additional investigators have been added.

Project History:

This study examined 26 non-major undergraduates, the majority of whom insecure about their ability to understand scientific information. It was found that when given a chance to choose what topics they could learn more about, the majority of students frequently selected microbiology issues relevant to their life. The data have also indicated that this curriculum encouraged students to engage with science despite many having negative prior experiences with science.

Further, interpretation of the data show undergraduates developed skills to evaluate scientific information and their NOS conceptualizations. For example, students' individual and group projects suggested improvement in subjects' ability to research and discern scientific information, which in turn helped them re-evaluate prior beliefs about science. Data from the writing exercise showed most undergraduates began to synthesize and evaluate the data, opinions, and societal factors that were presented in their article. Students' lab write-ups and lab quiz indicated participants' NOS conceptualization improved their evaluation of scientific information over the semester. Undergraduates also learned to recognize a lack of data as a weakness for a claim and used this knowledge when reasoning their point of view to others. The data from undergraduates' journaling and anonymous evaluation have been used to support the coding of subjects

academic products. These instruments have also provided insights into students' epistemological beliefs about science. In general, this student interest SSI-based curriculum appears to motivate diverse learners to develop their skills of finding, interpreting, and discussing scientific information. Consequently, the findings from this study offer several valuable insights to the science education community concerned with promoting diverse learners interest and understanding of science.

Problem History:

There have not been any adverse events and any unanticipated problems involving risks to subjects. No subjects have asked to withdrawal from the research or complained about participating in this research or about the research in any general sense since the last IRB review.

Additional Information:

The purpose of this case study is to gain insight into whether this socio-scientific issues (SSI) based curriculum fosters student interest in science as well as develops skills to insightfully reason scientific issues important to society. By definition, SSI describes social dilemmas with conceptual ties to science (Sadler & Zeidler, 2004, p. 5; Sadler, Chambers, & Zeidler, 2004, p. 387). Informal reasoning is the process of considering a claim where the reasoner weighs and synthesizes benefits and disadvantages to arrive at the best sound judgment (Perkins, 1985, p. 562; Mean & Voss, 1996, p. 140). Sadler (2004, p. 515) relates informal reasoning to socio-scientific research through four primary themes: 1) evaluation of scientific information, 2) Nature of Science (NOS) conceptualizations, 3) conceptual understanding of science content, and 4) socio-scientific argumentation. This research is delimited by the first two themes. Data suggest SSI based curricular frameworks are a way to promote curiosity, open-mindedness, and informed skepticism in addition to building students' contextual knowledge of science (Jimenez-Aleixandre & Pereiro-Munoz, 2002; Zohar & Nemet, 2002). However, data also reveal that SSI do not necessarily promote students' connections to science (Zeidler, et al., 2002; Sadler, et al., 2004). A student interest-SSI framework guides this dissertation study, by allowing students to choose socially controversial scientific issues they find interesting.

Selected references

Jiménez-Aleixandre, M., Pereiro-Munoz, C., (2002). Knowledge producers or knowledge consumers? Argumentation and decision making about

environmental management. *International Journal of Science Education*, 24(11), 1171-1190.

Perkins, D. N. (1985). Post-Primary Education Has Little Impact on Informal Reasoning. *Journal of Educational Psychology*, 77(5), 562-571.

Means, M. L., & Voss, J. F. (1996). Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels. *Cognition and Instruction*, 14, 139 – 178.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, 41(5), 513-536.

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education*, 26(4), 387-409.

Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education*, 88(1), 4-27.

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, 86(3), 343-367.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, 39(1), 35-62.

Approved Changes:

There have been no prior addendums filed. Consequently, the IRB has not been asked to approve any modifications in recruiting procedures, study procedures, types or number of subjects, or the consent process since the previous annual IRB approval.

Changes Implemented without IRB Approval:

There have been no amendments or modifications since the last review that the IRB did not approve.

Request for approval of new changes:

We would like to request one modification to this study's procedures.

Rationale for the change:

For our project we would like to request the ability to membercheck data from a few selected participants. There are 2 aspects to member-checking

1. Participants see a selection of their raw data and confirm we have accurately reported.

2. Participants are asked to read and comment on the researcher's interpretations of the participant's data.

In this case, the student researcher, Ms. Schalk, would like to contact a few subjects to request that they validate her interpretation of their data.

Ms. Schalk would also like to ask the subjects for permission to record their voices to verify their consent of accurate reporting. Consequently, the rationale behind this request is to confirm that we have accurately reported and interpreted the findings from this investigation.

Description of procedure:

Ms. Schalk is requesting students voluntarily be interviewed to reaffirm her data analyses. Ms. Schalk would also like to ask these subjects to have their voices recorded to verify their consent of accurate reporting.

The student researcher, Ms. Schalk, would like IRB consent to contact these students via email. An example of Ms. Schalk's email to these students has been drafted for your approval.

Dear (student 1 name),

(Student 1 name), I know you are busy with it being close to the end of the semester. However, I would like to ask you for your additional voluntary consent and time with respect to the BSCI122 study you participated in last spring 2008.

In looking over your class projects, lab quiz, lab write-ups, and journaling, you have given me some great insights into how BSCI122 gave you a chance to learn in ways that a scripted science class might have inhibited.

(Student 1 name), I would also like you to know that I have protected all the data I have collected so that all BSCI122 students' identity have not and will not be shared publicly. At the same time as you, know I am using all students' data to complete my dissertation. This data is also going to be written for journal publications and has been recently accepted to be presented at a national science education conference, the National Association of Research in Science Teaching (NARST) conference.

I have selected several of your quotes to represent how a minority of students took their learning opportunities to expand their understanding of microbes in ways that other science class might not have facilitated. For example, you pushed your knowledge to be able to read and find information written for a scientific audience. Conversely, I found that many of your peers showed growth with respect to reading information about science written for the popular press. You also articulated very nicely how your knowledge of science as a way of knowing grew over the semester. Consequently, I would like to use some of your quotes in a presentation I will be giving at NARST this spring. I would like to reiterate that I have masked your identity and that you do not have to consent to letting me use some of your quotes.

However, I believe the data I collected is important to share with other researchers who are interested in finding ways to promote learners knowledge of science in ways that are meaningful to their everyday life.

If you still agree to my use of your data for educational purposes, I would like to ask you for your additional voluntary time and assistance. I would like to ask that you verify my interpretation of your data. This would mean that I would ask you to read selected segments of comments you made over the semester, verify my analyses of your quotes, and allow me to record your voice as verification of your confirmed consent of my data analyses. The estimated time for this interview/recording session should take is 40-50 minutes.

(Student 1 name) if you agree I can meet you on campus at my office or another safe and secure place you prefer.

Should you agree to this request I will ask you to fill out another IRB consent forum to reiterate how this data will be used, what you are being asked to do, and any potential risks that might result from recording your voice or volunteering your time. At any time you can decide you no longer would like to participate in the interview/recording session and/or have your data withdrawn from further analyses as well as any resulting reports.

(Student 1 name), I want to thank you kindly for your time and consideration of this voluntary request.

With Gratitude,
Kelly

A similar email would be to other selected subjects. The time estimation for students' voluntary time is 40 to 50 minutes. Students will be asked to sign the new IRB consent forum (see attached document), which will allow Ms. Schalk to once again reaffirm selected subjects understand how this data is being used, what students are being asked to do, and any potential risks that might result from recording their voice or volunteering of their time. Ms. Schalk will also make clear that students can at anytime decide not to participate and/or have their data be reported. If students do not respond to this email, no further pursuit will be made to request subjects volunteer their time. The suggested place for interviewing students' is 2311 Benjamin Building. If students feel uncomfortable with this setting, an alternative safe and secure place may be arranged.

Risk to subjects:

The risks to these human subjects include emotional anxieties that result from educational experiences related to performance, previous or current events in their life, or undergraduates' future aspirations. However, given the nature of the positive findings of the data, this risk is reduced.

Additionally, subjects' desire or refusal to voluntarily offer their time to verify data interpretations is in no way jeopardizing their final course grade.

Should subjects identify emotional anxieties from revisiting some of their prior spring semester BSCI122 learning experiences as a result of this interview/recording session; subject will be informed once again of their right to end the interview/recording session, refuse to allow their data to be reported, and withdraw their data from further analyses. The risks to these selected human subjects are slightly greater than what other students' have already consented to when signing the original IRB consent form. For example, subjects may recognize emotions of embarrassment from prior academic performances when asked to revisit some of their academic efforts over the spring 2008 semester. Consequently, Ms. Schalk will honor the students' desire and right to refuse to finish the interview, have their voice recorded, and/or withdraw their data from this research investigation.

New IRB Consent Form:

Should this request be accepted, selected subjects will be asked to sign the new IRB consent form upon the meeting time and place arranged by Ms. Schalk and the students. Ms. Schalk will ask subjects to sign this form and reaffirm that students understand how this data is being used, what subjects are being asked to do, and any potential risks that might result from affirming Ms. Schalk's data analyses. Ms. Schalk will also make it clear to the students that they can at anytime decide not to: participate and/or have their data be reported. Students' willingness to volunteer in this additional request of time will be honored and no additional efforts beyond the first invitational email will be made.

The new IRB consent form is included in this IRB Renewal. The specific changes that have made to this new request has been bolded.

Data Location:

Per the University of Maryland policy on records retention and disposal, all data will be archived in the Department of Curriculum and Instruction's Science Teaching Center for 10 years. After 10 years, all data will be destroyed.

Consent Forms:

There is one new consent form for this IRB renewal. A copy of the previous approved consent form is included. All changes to the new changes to the original consent form have been bolded.

Health Insurance Portability and Accountability Act (HIPAA):

Not applicable

Conflict of Interest:

The risks to these selected human subjects are slightly greater than what other students' have already consented to when signing the original IRB consent form. For example, there is the potential conflict of interest of Ms. Schalk influencing subjects during the interview to agree with her data analyses. For example, Ms. Schalk may want students to confirm her analyses of subjects feeling more confident and comfortable finding, reading, and discussing scientific information. Such desires could cause human subjects emotional distress from feeling the need to comply with their former instructor's evaluation of their academic performance. Ms. Schalk is aware of the potential conflict of interest that comes with asking students to validate their quotes as well as her data analyses. Ms. Schalk also realizes that such actions would invalidate her data analyses and any reports that result from this investigation. Consequently, Ms. Schalk will take precautions to avoid leading students' responses. For instance, Ms. Schalk will ask students to comment upon their own reflection of a series of quotes before sharing her interpretation of the data. If Ms. Schalk does feel it important to disclose her data analyses, she will make it clear to the subject that the purpose of this interview was to validate her understanding, which may not be accurate.

Additionally, subjects interviewed may find revisiting their educational experiences stressful. Participation in the project may potentially create psychological risks. Asking students to revisit their educational experience can cause emotional anxieties with respect to performance, previous or current events in their life, and future aspirations. However, given the nature of the positive findings of the data, this risk is reduced.

Additionally, subjects' desire or refuse to voluntarily offer their time for additional verification of the data interpretations can no longer in anyway affect subjects' final course grade. Further, should subjects identify emotional anxieties from revisiting some of their prior spring semester BSCI122 learning experiences as a result of this interview/recording session; Ms. Schalk will inform subjects once again of their right to 1) end the interview/recording session, 2) refuse to allow their data to be reported, and 3) withdraw their data from further analyses.

Funding Source/Research Support:

Not applicable

New Participant Informed Consent Form

Identification of Project/Title	A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning
Statement of Age of Subject	I state that I am 18 years of age or older and wish to participate in a program of research being conducted by Dr. J. Randy McGinnis and Ms. Kelly Schalk in the Department of Curriculum and Instruction at the University of Maryland, College Park.
Why is this research being done?	The purpose of this case study is to understand if this 'socio-scientific issues' (SSI) based curriculum fosters student interest in science and develops skills to insightfully reason scientific issues important to society. The central research question for this study is: <i>How does a SSI curricular and pedagogical intervention, including a student interest-focus, affect undergraduates in education and other non-science majors' 3.ability to informally reason?</i> The delimited components of informal reasoning measured were undergraduates' Nature of Science (NOS) conceptualizations, and the evaluation of scientific information.
What will I be asked to do?	<p>The subjects for this research study include all students who enroll in BSCI122 General Microbes and Society for the spring 2008, are 18 years of age or older, and consent to participate. Students who agree to participate in this study will voluntarily complete a fifteen-minute confidential survey in ELMS near the end of the semester. However, subjects will not be asked to include their names or UID numbers on the survey. This evaluation will have no negative affect upon any students' grades or result in any negative assessments of students' performances over the semester.</p> <p>Additionally, a few subjects may be selected to voluntarily reaffirm the analyses of the data that results from their academic products. Subjects selected to reaffirm the interpretation of their data will also be asked to voluntarily read selected quotes for audio-recording. The selection of subjects and these voluntary requests will be made after participants have completed the spring course. Resulting, such follow requests of subjects' voluntary time will be made in the fall of 2008. These voluntary requests will be made by email. Subjects who are selected to verify the interpretation of their data and have their voices recorded will be informed that their participation is voluntary and that at any time they can chose to decide not to participate and/or have their data be reported. However, participation in the study will greatly benefit interested persons' understandings of how effective this curricular design is at improving future non-science majors' interests in science and informal reasoning.</p> <p>In any case, subjects' identity will be protected. Participation or a subjects' refusal to participate in any additional verification of the data interpretations will in no way affect any students' final grade or result in any negative assessments of students' performances.</p> <p>Subjects are also invited to ask questions throughout the study should they feel uncomfortable or inquisitive. Additionally, should any participant choose to no longer participate in this research study, he /she has the right to withdraw from this investigation without any penalty.</p> <p>Ms. Schalk, the practitioner researcher, will also be a subject of this</p>

Identification of Project/Title	A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning
	<p>study through analyses of self-reflective journals on her pedagogical practices. Analyses of these journal entries will be subject to the review of her dissertation committee throughout this study.</p> <p>Students who consent to participate in this study will also be allowing their curricular products to be evaluated with respect to the central research question of this investigation (how does this learning experience affect aspects of students' informal reasoning?). However, the research evaluation of students' educational products will in no way connect to students' performance assessments, in this undergraduate microbes and society course. Consequently, whether students participate in this research study or not, there will be no negative affect on students' grades.</p>
What about confidentiality?	<p>We will keep subjects personal information confidential. To help protect subjects' confidentiality, the survey will not ask subjects to include their names or UID numbers and be collected confidentially through ELMS. Additionally, survey responses and educational products will only be accessible to the course instructors Dr. Benson and Ms. Schalk through ELMS and KEEP, both of which operate under the security of University of Maryland's databases.</p> <p>Should it be necessary to share data from this study for analytical purposes, there will be no reference to subjects' identities. For the most part data will be analyzed at the class level, resulting in descriptions of findings at a class level. An example of such a description includes "undergraduates enrolled in a microbes and society course at a major university in the northeast". Should it be necessary to reference specific example of students' responses arbitrary subject pseudonyms will replace all names and only the researchers will be able to link subjects' identities to their data.</p> <p>If we write a report or article about this research project, students' identities will be protected to the maximum extent possible. However, students' information may be shared with representatives of the University of Maryland, College Park or governmental authorities if subjects are in danger or if we are required to do so by law.</p> <p>This research project also involves making audio-recordings of selected subjects. The purpose of the audio-recordings document subjects' validation of data analyses. To help protect subjects' confidentiality, the audio-recordings will only be accessible to the researchers involved in this investigation Dr. McGinnis and Ms. Schalk. These audio-recordings will be stored in for 10 years upon which time they will be destroyed. If there is a need to share clips from these audio-recordings for educational purposes, subjects' identifiable information will not be disclosed. Rather subjects will be referred to though pseudonyms.</p> <p><input type="checkbox"/> I agree to be audio-recorded during my participation in this study <input type="checkbox"/> I do not agree to be audio-recorded during my participation in this study</p>

Identification of Project/Title	A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning
	Any data resulting from this investigation will be safe in a private and locked filing cabinet in 2311 Benjamin Building, until the study is complete. At the completion of this study all data will be archived in the Department of Curriculum and Instruction's Science Teaching Center for 10 years. After these 10 years all data will be destroyed.
What are the risks of this research?	Participation in the project may potentially create psychological risks. Involving students in any type of educational experience can cause students to experience emotional anxieties in relationship to performance, previous or current events in their life, and future aspirations. Should any student attribute anxiety to their voluntary participation in this study that student may withdraw from this investigation without any repercussions. Furthermore, the confidential ELMS survey will not influence students' grades or involvement in the course. Any additional correspondence through the discussion board in ELMS is also optional and again will not have any negative affect on students' grades.
What are the benefits of this research? Benefits, Freedom to Withdraw, & Ability to Ask Questions	The benefits associated with participating in this investigation include opportunities for students to voice their satisfaction or dissatisfaction with their educational experience as well as ideas to improve the course for future undergraduates. Participation in ELMS should decrease any anxiety that could be associated with interviews, especially considering the practitioner researcher would facilitate such dialogue. We hope that, in the future, other people might benefit from this study through improved understanding of curricular frameworks that engage non-science majors in learning about science and develop undergraduates' informal reasoning skills. Understanding more about how to successfully develop educational settings that foster interest and understanding of science is important as society advances into this new technologically advanced era.
Do I have to be in this research? May I stop participating at any time?	Subjects' participations in this research are completely voluntary. Students may choose not to take part at all. If a student decides to participate in this research, they may stop participating at any time. If students decide not to participate in this study or if subjects stop participating at any time, there will be no penalty or loss of any benefits to which subjects would otherwise qualify. Subjects also have the right to participate but opt at times not to respond to any question. This level of participation is acceptable and will not result in any penalty or loss of any benefits to which subjects would otherwise qualify.
What if I have questions?	Subjects are also invited to ask questions throughout the study should they feel uncomfortable or inquisitive. This research is being conducted by Dr. Randy McGinnis (is the Primary Investigator), and Ms. Schalk (is the student-investigator) at the University of Maryland, College Park. If students have any questions about the research study itself, please contact Dr. Randy McGinnis at: jmcginni@umd.edu , (telephone) 301-405-6234 or Kelly Schalk at: schalk@umd.edu , (telephone) 301-405-3155 If students have questions about their rights as research subjects or wish to report a research-related injuries, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; (e-mail) irb@deans.umd.edu ; (telephone) 301-405-7326 This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.

Identification of Project/Title	A Case Study of a Socio-scientific Issues Curricular and Pedagogical Intervention in an Undergraduate Microbiology Course: A Focus on Informal Reasoning
Contact Information of Investigators	<p>Dr. J. Randy McGinnis and Ms. Kelly Schalk Department of Curriculum & Instruction Room 2234 Benjamin University of Maryland, College Park College Park, MD 20742 Telephone numbers: 301-405-3133; 301-405-6234; 301-405-3152 Email addresses: jmcginni@umd.edu; schalk@umd.edu</p>
Subject Consent	<p>Your signature indicates that: you are at least 18 years of age; the research has been explained to you; your questions have been fully answered; and you freely and voluntarily choose to participate in this research project.</p> <p>Name of participant _____</p> <p>Signature of participant _____</p> <p>Date _____</p>

Appendix D.

Table 1D. *Students' Individual and Group KEEP Projects Topics by Ethnicity, Student, and Connection to Interest.*

Ethnicity Student Connection to interest	Individual topic	Group topic	Similar	Related
African American Femi family history	Will Gardasil really guard me?	Comparing HIV & Ebola		X
African American Wesesa family history	Microbes, genetics, & diet/exercise influence on weight	Gene therapy		X
African American Juji personal	Microbes and how they affect global warming	Biofuels in modern society		X
African American Roble personal	Antimicrobial products & microbial resistance	Probiotics		X
Asian American Lei family history	Chocolate & microbes	Probiotics		X
Asian American Long family history	Lung cancer	Comparing HIV and Ebola Virus		X
Asian American Rui family history	Where did the insulin go? Diabetes today	Gene therapy		X
Asian American Tadao family history	Possible life on mars	Biofuels in modern society		X
Asian American Caitlin personal	Weight management	Weight & microbes: Causes of obesity	X	
European American Brandi career	Biological weapons & scientific censorship	Biological weapons & scientific censorship	X	
European American Hugh career	Antimicrobial use and the fatally ill	Biological weapons and scientific censorship		X
European American Reuben career	Gene therapy: A cure or curse?	Gene therapy	X	

European American Freya family history	Organic produce and Escherichia coli	Effects & pathways of E. coli contamination	X	
European American Cathy family history & personal	The role of organisms in weight regulation	Weight & microbes: Causes of obesity	X	
European American Debbie personal	Gut Microbes and Their Effects	Weight & microbes: Causes of obesity	X	
European American Emma personal	Obesity, your fault? Maybe not.	Weight & microbes: Causes of obesity	X	
European American Eilene personal	Botox: Harmful or Helpful?	Probiotics		X
European American Gannon personal	Anti-retroviral agents in treating HIV infection	Comparing HIV and Ebola	X	
European American Karina personal	Genetically mutated food crops: BT corn	Biofuels in modern society		X
European American Linnea personal	Rheumatoid arthritis	Biological weapons & scientific censorship		X
European American Liza personal	Listeria testing methods	Effects & pathways of E. coli contamination		X
European American Ozzie personal	Ways can microbes be used to create biofuels?	Biofuels in modern society	X	
European American Perla personal	Microbes and milk	Probiotics		X
European American Remington personal	The negative health effects of eating moldy bread	Effects & pathways of E. coli contamination		X
European American Susannah personal	H. Pylori and stomach cancer	Comparing HIV and Ebola		X
European American Tod personal	Possible danger in genetically modified foods	Biological weapons & scientific censorship		X

Appendix E.

Implications of Findings Related to Pedagogical Reflections

In this appendix, I discuss teaching practices that I employed over the semester that may have affected the findings reported in this doctoral dissertation. This section also includes implications of my pedagogical reflections with respect to what is known about effective science education pedagogy. Resultantly, I reference sections from [Chapters 4](#) and [5](#) where I previously discussed my teaching practices. Additionally, I include coded data from my practitioner journals that I have not mentioned earlier to strengthen my claims. This section concludes by discussing the implications related to my pedagogical practices. Specifically, I reflect upon my opinions about instructive techniques that are important in promoting academic success among learners.

[Chapter 4](#)

Embedded throughout [Chapter 4](#) were reflections on my pedagogical practices that may have affected my reported findings. Lee and Luykx (2007, p. 182) among others have suggested that teachers need to build their cultural experience and knowledge to understand how different learners approach science learning (Ladson-Billings, 1995a, 1995b; Moje, Collazo, Carillo, & Marx, 2001). Some researchers have argued that culturally relevant pedagogy can be used to equip teachers to help non-mainstream students⁶⁸ achieve academic success in science while simultaneously promoting their cultural integrity (Ladson-Billings, 1995a; Lee, 2002,

⁶⁸ Lee and Luykx (2007) have described non-mainstream students to have characteristics such as 1) acquiring English as a second language, 2) being of low socio-economic-status, 3) having parents who have not received much formal education, and 4) coming from a family/community that devalues formal education.

2003; Lee & Fradd, 1998). The role of the teacher has been argued to be an integral aspect to creating learning environments where students not only achieve academically but also feel their identity and culture are valued (Ladson-Billings, 1995a; Lee, 2002, 2003; Lee & Luykx, 2007). It has been suggested that inquiry based learning is one way to promote culturally relevant pedagogy (Ballenger, 1997; Rosebery, Warren, & Conant, 1992; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). It is believed that inquiry based environments allow teachers to identify and support non-mainstream learners' by giving teachers insights into how students are integrating their everyday knowledge with the Western science way of knowing (Ballenger, 1997; Rosebery, Warren, & Conant, 1992; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). Other researchers have contended that trusting and caring relationships between teachers and students is the key in helping students from diverse backgrounds take intellectual risks, which are necessary to develop deep understandings of science content and practices (Sconiers & Rosiek, 2000).

My coded practitioner journals indicated that giving students an opportunity to choose and investigate microbiology SSI, which affected their life was one way I could support students' identity and culture. One example was the way I introduced the KEEP research projects. Specifically, I shared with undergraduates' ways that prior students had used this learning opportunity to understand more about who they were by researching science issues that affected them.

I discussed how some students' were interested in tuberculosis because this disease had affected many people they were close to in their country. Another student chose the Mononucleosis Virus because it had affected him. One undergraduate identified an interest in

potential connections between Multiple Sclerosis and microbes because her parent was infected with this disease. Another student shared an interest in the relationship between microbes and food contamination because of his job in a bakery / deli.

This quote taken from my practitioner's journal has shown how I introduced this topic to stimulate students. I wanted students to realize how much they could learn from these pragmatic research projects. I found that all undergraduates identified SSI related to microbiology that affected their life and most (90%) chose to research their interest over the course of the semester. See [Appendix D](#) for a detailed table of the broad range of participants' individual and group projects by ethnicity, student, and connection to their topic or [Table 2](#) in [Chapter 4](#).

Having students identify personal areas of interest to them gave me several opportunities to interact with students at a level, which supported their identity and culture. For instance, I discussed in [Chapter 4](#) how Wesesa (an African American) and Rui (an Asian American) identified interests in illnesses that affected family members. In Wesesa's case, she also recognized how her interest in microbes, genetics, and diseases was related to her prior knowledge of health issues that have a higher risk of affecting African Americans.

I come from a family that is known for diabetes, high blood pressure, overweight, heart attacks and strokes for generations. My culture plays a big role in me wanting to find out more information because both high blood pressure and cholesterol are very high in my culture compared to most other cultures. Also heart attacks are very common among deaths in my culture.

Consequently, I also found that another important aspect of my pedagogical practice was establishing a trusting and caring relationships with the students. For instance, in [Chapter 4](#) I mentioned that my weekly interactions included 1) staying late after lab to give students individual attention, 2) facilitating study groups early in

the semester, and 3) responding to questions students had in the ELMS help thread. Scoring of my weekly practitioner journal indicated that I interacted with 20 out of the 26 students several times over the semester in two or more of these ways.

For instance, I recorded several times each African American student Robel, Femi, Juji, and Wesesa came to me often and ask me for advice or clarification on science concepts we were covering in lecture and lab. Reflected in my recorded dialog were several occasions where I worked with students to encourage them not to lose interest, as they all had acknowledged to me several times that they did not come from a strong science background. These students were also the impetus behind me facilitating study groups early in the semester. I purposely made sure these (and other weak science background) students could meet with those in the class who were demonstrating conceptual understanding of the material presented during lecture and lab. The emails and personal feedback from students I recorded weekly in my practitioner journal reaffirmed my interpretation that establishing a trusting and caring relationship benefits student learning.

Femi's last email: I apologize for leaving in such a rush. I meant to run back and give you a hung goodbye but because I was so upset about my grade on the exam and stressed out and confused that I didn't. I thought I would see you again. Anyway, I really appreciated everything you've done for me as a T.A. You went over and beyond the expectations I had for you in regards to helping me. Thank you so much again. I appreciated everything you've done for me.

Another example, of the way I established a trusting and caring relationship centered on students individual projects. In [Chapter 4](#) I gave an example of the feedback I gave Brandi, to help her conceptualize the differences between a testable question, hypothesis, theory, fact, inference, and opinion. However, I also made sure that I encouraged students' efforts throughout the entire research process. For instance, students turned in a draft for their individual project, which required them to

identify their testable question and at least two references discussing alternative scientific perspectives on their topic. Although I also offered students the opportunity to complete as much of the KEEP individual research project template, if they wanted more individual help. My comments to students not only focused on helping them to conceptualize alternative perspectives related to their socio-scientific issue and differences between facts, theories, inferences, and opinions, but I also sought to further develop a trusting and caring relationship with them.

Brandi: You have done an excellent job in finding a focused question that relates to microbes and has two alternative perspectives as well as relates to your interest! So I hope you enjoy exploring your topic more.

Rui: This is an EXCELLENT opening! It is attention grabbing as well as informative! In addition, I love the topic! Finally, it has several scientific perspectives, maybe to many... However, you have done some Great work thus far... Rui, I am also grateful that you have chosen a topic of interest to you!... Rui, this is also a topic with a lot of information so you should further refine your question. For example, are you interested in how microbes might cause *or* treat diabetes?

Wesesa: Let me begin by saying I love your topic (How much do we know about carbohydrates and their effects on intestinal diseases and autism)! However, in looking into the literature I am concerned about the alternative scientific perspectives that exist and how you will connect your topic to microbes... Wesesa, based upon our conversations after lab I am still not sure if your interest is more in carbohydrate diets, autism, or intestinal disease. In any case I am wondering what connection you are going to make to microbes?... For example, if you want to follow up on autism diets I did find a paper that reviewed research related to GI tract physiology of autistic children by summarizing what is known about: gross pathology, histopathology, and microbial abnormalities. See Erickson, C. A. (2005) Gastrointestinal Factors in Autistic Disorder: A Critical Review. *Journal of Autism and Developmental Disorders*, 35 (6) 713- 727... I looked closely at the focus on the microbial abnormalities, but this case (as well as for the research on gross pathology and histopathology) the authors came to the conclusion that lack of rigorous studies has resulted in no published rigorous data to support increased GI symptomatology in autistic children. That is, this literature review sought to determine if autism should be considered a neurodevelopmental disorder with abdominal features, but the research to date is lacking scientific rigor to make such claims... Wesesa, I believe you have several options at this point, but I am sorry that it seems as if scientists have not yet spent time looking into your specific interest of the benefits or consequences to different types of diets with relationship to microbes. If you are interested in diet and nutrition here are some topics that I know have alternative scientific perspectives...

Gannon: I have been inspired by your interest and enthusiasm to learn thus far... I also am excited to learn more from you about HIV... Gannon, each person in the class is at a different point in their life and at a different academic level. My comments to you are based upon your level of work and interest you have shown me after lab. If you feel these resources have too much scientific jargon to understand more about anti-retroviral medications to treat HIV infection, you do not need to use them. What I would like you to focus on are my comments about the differences between facts and theories in your final poster.

This feedback, I gave students on their individual poster drafts, illustrates how I approached each student on an individual needs basis. For example, in Brandi's case her draft only included her defined question and two related references. Consequently, my feedback to Brandi was more encouraging. Rui and Wesesa on the other hand had filled out some sections of the individual KEEP poster template so I could give them more feedback. My comments to Rui were meant to be both encouraging and to help her narrow her specific question. Wesesa, on the other hand, had not found a topic that fit within the criteria of the project. Therefore, rather than discourage Wesesa's initial research attempt I tried to offer her more explicit guidance to further her understanding of the project while still encouraging her engagement. Gannon had done a lot of work on benefits and negative side effects of using anti-retroviral medications to treat HIV infection. However, as described in [Chapter 4](#) he desired to learn more than what the literature written for the popular press had to offer. I recorded several occasions where I had talked to Gannon after lab about his topic, resources that would further his understanding, as well as approaches I have found to be helpful in understanding articles written for a scientific audience. My comments to Gannon's first individual KEEP project draft have reflected that it was not my expectation for Gannon to develop the skill to interpret scientific literature written for scientists. Yet, I did not want to discourage his motivation. Rather, I wanted to make sure he understood the different theoretical aspects of what he was reading from factual data.

Given the different perspectives science educational researchers hold about the most effective means to help all students achieve academic success while promoting

their cultural integrity (Ladson-Billings, 1995a; Lee, 2002, 2003; Sconiers & Rosiek, 2000; Warren, et al., 2001), this case-study has not resolved this debate. However, my practitioner journaling has supported one important aspect of this student interest SSI-based curricular and pedagogical intervention was offering students chances to research SSI that they related to their everyday life. This helped each student identify with the scientific knowledge. I have also recognized that I hold the opinion that learning opportunities fostering teacher-student trusting and caring relationships promote positive growth for both teacher-learner and student-learner. That is, my experiences interacting with students has developed my belief that trusting and caring relationship not only can enrich a student's understanding of scientific knowledge but also furthers a teacher's ability to impart learning. However, I also acknowledge that one limit of this case-study was not being able to compare my teaching practices to another's approach.

[Chapter 5](#)

I also discussed my pedagogical practices in [Chapter 5](#) with respect to helping students conceptualize the NOS. There is evidence that has suggested simply engaging in scientific processes is not enough to bring about sophisticated understandings of the NOS (Bell, Blair, Crawford, & Lederman, 2003; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006). Rather, the empirical data has supported these inquiry-based activities should include explicit and reflective⁶⁹ opportunities upon the NOS (Khishfe & Abd-El-Khalick, 2002; Schwartz, Lederman, & Crawford, 2004;

⁶⁹ Khishfe and Abd-El-Khalick (2002, p. 555) have defined explicit and reflective teaching of the NOS as emphasizing epistemological concepts related to science and providing opportunities to make connections between an individual's activities and ones undertaken by scientists.

Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006). In [Chapter 5](#), I included illustrations of the explicit instruction I gave on the epistemology of science.

For example, [Table 5](#), in [Chapter 5](#), provided one example of how I explicitly discussed NOS conceptualizations. Specifically, [Table 5](#) was used to show how I connected the Maryland Voluntary State Curriculum 5-E Pedagogical Model (Maryland State Department of Education, 1997) to the scientific process. This table also includes the definitions I used in class to define the differences between a fact, inference, scientific question, hypothesis, and theory. Resultantly, I acknowledged in [Chapter 5](#) that explicit discussions and reflective opportunities students had to conceptualize the NOS might have affected the positive trends seen in the data with respect to undergraduates' conceptual understanding of the scientific epistemologies.

Another example was the explicit discussions during lab and comments I made on students' early lab write-ups to help students conceptualize aspects of the scientific justification. For instance, I recorded that I made several remarks to each students' interpretation of data in their early lab write-ups.

My comment has been bolded: Our testable question was answered. We found water alone at different temperatures did make a difference in microbial growth. We found cold water with antibacterial soap was more effective at killing microbes than hot water with antibacterial soap. **How do you know that drying with a paper towels did not introduce contamination to your experiment? You did not have a negative control that showed paper towel alone do not cause microbial growth. How do you know that your hands were equally dirty when beginning your experiment? Again you did not have a positive control to show equal amounts of microbial growth. Given that you did a limited number of trials and another group got opposite results, how can you be certain of your data collection and interpretation?**

This comment reflects how I explicitly reinforced the idea that any experimental protocol has uncontrolled variables, which prevents absolute conclusions. It was found that many students acknowledged similar explicit discussions during lab when

responding to the lab quiz question “In what ways is scientific knowledge different from other ways of knowing?”

Gannon: I have learned that scientific knowledge distinguishes itself from other ways of learning by possessing an inherent skepticism not found in other forms of learning. Throughout elementary, middle, and high-school, I was always taught to accept my science teachers’ statements as absolute fact simply because the teacher said they were. I did not go through my 13 years of public school asking “why” or “how”... Through my experiments in the Microbes and Society laboratory, I have learned that science cannot exist without skepticism... In testing my experimental designs, I was grateful for the skepticism of Kelly and my classmates. Their questions about the conclusions I drew from my experimental results always prompted me to change my protocol and control for errors... This helped me to realize how scientific knowledge is supported by experimentation, which is advanced every day by doubt and questioning.

Tadao: Scientific knowledge is much more specific and valuable than anecdotal or other forms of knowledge. It is specific because the tests and experiments done are with the utmost care and thought. During our second self-designed experiments, we thought we were going to come to specific conclusions. However, Kelly quickly pointed our holes in our designs that basically negated any findings we made. I learned how carefully specific, controlled, and documented scientific findings are made and that their value is greater because of this...

Wesesa: Because I had the opportunity to test my own experimental designs, I have learned a lot about how scientific knowledge distinguishes itself from other ways... Scientific knowledge comes from the many tests/trials, errors/mistakes, and new findings of information. Some of the labs that my group and I have done in class gave me a better understanding of scientific knowledge. There were a few mistakes that we tended to not have noticed when coming up with our testable questions, until we actually tested it. Then we were amazed at why our results did not turn out as we had planned... The feedback that Kelly gave us in the lab allowed us to go back and try to understand our scientific data better... Little mistakes that we didn’t think mattered like time, played a big part in our results...

Hugh: I have learned that scientific knowledge is distinguished from other forms in that to say “I know” should be taboo for most scientists in most cases... The main thing I have gained from lab discussion and projects concerning the human endeavor of science is that it is really unending. Every new discovery or invention leads scientists to discover more and build more upon their work. A scientist’s job is never through because the question, “what’s next?” always remains.

Given that this study did not investigate the differences between implicit and explicit instruction, I cannot argue that the discussions and reflective opportunities students had were essential to developing their NOS conceptualization. That is, it is possible that similar findings would have resulted had I not explicitly guided students to consider and question processes, values, and assumptions inherent to scientific knowledge. However, the findings from this study have supported the success of other interventions that have provided inquiry-based learning opportunities

accompanied by discussion and reflections upon scientific epistemological conceptualizations (Khishfe & Abd-El-Khalick, 2002; Schwartz, Lederman, & Crawford, 2004; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006).

REFERENCES

- 125 Questions: What don't we know? (2005). *Science Magazine*, 309, 1 - 204.
- Retrieved February 11, 2008, from <http://www.sciencemag.org/sciext/125th/>.
- Abbott, A. (2002). Disbelief greets claim for creation of first human clone. *Nature*, 416(6881), 570-570.
- Abd-El-Khalick, F. (2003). Socioscientific issues in pre-college science classrooms
In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 41-62). Norwell, MA: Kluwer Academic Publishers.
- Abd-El-Khalick, F. (2005). Developing deeper understandings of nature of science: the impact of a philosophy of science course on preservice science teachers' views and instructional planning. *International Journal of Science Education*, 27(1), 15-42.
- Abd-El-Khalick, F., & Lederman, N. G. (2000a). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, 37(10), 1057-1095.
- Abd-El-Khalick, F., & Lederman, N. G. (2000b). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education*, 22(7), 665-701.
- Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, 82, 417-436.

- AIDS Treatment Data Network. (2006). Epivir is a nucleoside reverse transcriptase inhibitor. Retrieved October 2, 2008, from <http://www.atdn.org/simple/lami.html>.
- Aikenhead, G. S. (1997). Toward a first nations cross-cultural science and technology curriculum. *Science Education*, 81, 217–238.
- Aikenhead, G. S., & Ryan, A. G. (1992). The development of a new instrument: “Views on Science–Technology–Society” (VOSTS). *Science Education*, 76(477–491).
- Akerson, V. L., & Hanuscin, D. L. (2007). Teaching nature of science through inquiry: Results of a 3-year professional development program. *Journal of Research in Science Teaching*, 44(5), 653-680.
- Akerson, V. L., Buzzelli, C. A., & Donnelly, L. A. (2008). Early childhood teachers' views of nature of science: The influence of intellectual levels, cultural values, and explicit reflective teaching. *Journal of Research in Science Teaching*, 45(6), 748-770.
- Albe, V. (2008). When scientific knowledge, daily life experience, epistemological and social considerations intersect: Students' argumentation in group discussions on a socio-scientific issue. *Research in Science Education*, 38(1), 67-90.
- Altheide, D. L., & Johnson, J. M. (1994). Criteria for assessing interpretive validity in qualitative research. In N.K. Denzin & Y.S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 485-499). Thousand Oaks, CA: Sage.

- American Association for the Advancement of Science. (2006). *Project 2061*. Retrieved March, 2009, from <http://www.project2061.org/about/principles.htm>.
- American Association for the Advancement of Science. (1997). Resources for science literacy: Professional development. Project 2061: *National science education standards (NSES)*, 2008, from <http://www.project2061.org/publications/rsl/online/COMPARE/NRC/BSL2NRC/CH5/BSLCH5.HTM>.
- American Association for the Advancement of Science. (1989). *Science for all Americans*. New York: Oxford University Press.
- American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.
- American Society for Microbiology. (2006). Viruses. Retrieved October 4, 2008, from <http://www.microbeworld.org/microbes/virus/>.
- Anderson, A. (2001). Designing systems to support learning science with understanding for all: Developing dialogues among researchers, reformers, and developers . Retrieved October 18, 2007 from <http://www.project2061.org/events/meetings/textbook/science/anderson.htm>.
- Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching and assessing: A revision of Bloom's Taxonomy of educational objectives: Complete edition*. New York, NY: Longman.
- Andrew, R., Beswick, K., Swabey, K., Barrett, M., Bridge, D., Loudon, W., et al. (2005). Repertoires for diversity: Effective literacy and numeracy practice in

inclusive schools. Retrieved. from

http://www.dest.gov.au/NR/rdonlyres/FDD36FD9-2034-4756-8E10-60CB633ACD2F/12826/Repertoires_for_Diversity.pdf.

Atkinson, R. L. (2007). Viruses as an etiology of obesity. *Mayo Clinic Proceedings*, 82(10), 1192-1198.

Atkisson, A. (2008). Biofuels: Driving in the Wrong Direction? Retrieved March 26, 2008, from <http://www.worldchanging.com/archives/007862.html>.

Atwater, M. M. (1994). Research on cultural diversity in the classroom. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 558–576). New York: Macmillan.

Balanskat, A., & Kefala, S. (2006). Major education reforms in Norway . Insight Observatory for New Technologies and Education. Retrieved September, 2008 from http://insight.eun.org/ww/en/pub/insight/policy/policy_briefings/countryreport_norway.htm.

Ballenger, C. (1997). Social identities, moral narratives, scientific argumentation: Science talk in a bilingual classroom. *Language and Education*, 11(1), 1–14.

Barab, S. A., Sadler, T. D., Heiselt, C., Hickey, D. T., & Zuiker, S. (2007). Relating narrative, inquiry, and inscriptions: Supporting consequential play. *Journal of Science Education and Technology*, 16, 59 - 82.

Baram-Tsabari, A., & Yarden, A. (2007). Interest in biology: A developmental shift characterized using self-generated questions. *American Biology Teacher*, 69(9), 532-540.

- Baram-Tsabari, A., Sethi, R. J., Bry, L., & Yarden, A. (2006). Using questions sent to an ask-a-scientist site to identify children's interests in science. *Science Education, 90*(6), 1050-1072.
- Barba, R. H. (1993). A study of culturally syntonic variables in the bilingual/bicultural science classroom. *Journal of Research in Science Teaching, 30*(9), 1053–1071.
- Baron, J. (1991). Beliefs about thinking. In J. Voss, D. Perkins & J. Segal (Eds.), *Informal reasoning and education* (pp. 169–186). Hillsdale, NJ: Erlbaum.
- Baron, J. (1995). Myside bias in thinking about abortion. *Thinking and Reasoning, 1*(3), 221–235.
- Baron, J. (2000). *Thinking and deciding* (3rd ed.). Cambridge, MA: Cambridge University Press.
- Bartholomew, H., Osborne, J., & Ratcliffe, M. (2004). Teaching students "ideas-about-science": Five dimensions of effective practice. *Science Education, 88*(5), 655-682.
- Basu, S. J., & Barton, A. C. (2007). Developing a sustained interest in science among urban minority youth. *Journal of Research in Science Teaching, 44*(3), 466-489.
- Belcheir, M. J. (1999). The contribution of college to student growth: A Boise State University and National Public Colleges perspective. Boise, ID: Boise State University.
- Bell, R. L., Blair, L. M., Crawford, B. A., & Lederman, N. G. (2003). Just do it? Impact of a science apprenticeship program on high school students'

- understandings of the nature of science and scientific inquiry. *Journal of Research in Science Teaching*, 40(5), 487–509.
- Bell, R. L., & Lederman, N.G. (2003). Understandings of the nature of science and decision-making on science and technology based issues. *Science Education*, 87(3), 352-377.
- Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. (2000). Developing and acting upon one's conception of the nature of science: A follow-up study. *Journal of Research in Science Teaching*, 37(6), 563-581.
- Bell, R. L., & Matkins, J. J. (2003, March 23-26). Learning about the nature of science in an elementary science methods course: Content vs. context. Paper presented at the Annual meeting of the National Association for Research in Science Teaching (NARST), Philadelphia, PA.
- Benson, S., Schalk, K., A. McGinnis, J. R., Marbach-Ad, G. (2007a) Using student interest to foster reconstructive leaning in a non-majors microbiology course. Poster presentation at American Society for Microbiology (ASM), May 19 Buffalo, NY.
- Benson, S., Schalk, K., A. McGinnis, J. R., Marbach-Ad, G. (2007b). Using student interest to foster reconstructive leaning in a non-majors microbiology course. Poster presentation at the International Society for the Scholarship of Teaching and Learning (ISSoTL) Conference, July 2 – 5 Sydney, Australia.
- Berg, L. B. (2007). *Qualitative research methods for the social sciences* (6th ed.): Allyn & Bacon.

- Bianchini, J. A., Hilton-Brown, B. A., & Breton, T. D. (2002). Professional development for university scientists around issues of equity and diversity: Investigating dissent within community. *Journal of Research in Science Teaching*, 39(8), 738-771.
- Bischoff, P. J. (2006). The role of knowledge structures in the ability of preservice elementary teachers to diagnose a child's understanding of molecular kinetics. *Science Education*, 90(5), 936-951.
- Blackboard Inc. (2006). Enterprise learning management system (ELMS). Retrieved February 11, 2008, from <https://bb.rhsmith.umd.edu>.
- Brophy, J. (1987). On motivating students. In D. Berliner, & B. Rosenshine, B. (Ed.), *Talks to teachers* (pp. 201–245). New York: Random House.
- Buehl, M. M., & Alexander, P. A. (2001). Beliefs about academic knowledge. *Educational Psychology Review*, 13(4), 385-418.
- Buehl, M. M., & Alexander, P. A. (2005). Motivation and performance differences in students domain-specific epistemological belief profiles. *American Educational Research Journal*, 42(4), 697-726.
- Cajas, F. (1999). Public understanding of science: Using technology to enhance school science in everyday life. *International Journal of Science Education*, 21, 765–773.
- Calabrese Barton, A. (2001). Science education in urban settings: Seeking new ways of praxis through critical ethnography. *Journal of Research in Science Teaching*, 38 (8), 899-917.

- Carey, S., & Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist*, 28(3), 235– 251.
- Carnegie Foundation, (2002). The KEEP toolkit. Knowledge Media Lab for the Advancement of Teaching. Retrieved February 11, 2008, from <http://www.keep.umd.edu/>.
- Chin, C. (2006). Classroom interaction in science: Teacher questioning and feedback to students' responses. *International Journal of Science Education*, 28(11), 1315-1346.
- Choi, C. (2008). Super Microbes Create Better Ethanol. Retrieved March 6, 2008, from <http://www.livescience.com/environment/080102-better-biofuel-envirotech.html>.
- Chu, H. E., Treagust, D. F., & Chandrasegaran, A. L. (2008). Naive students' conceptual development and beliefs: The need for multiple analyses to determine what contributes to student success in a university introductory physics course. *Research in Science Education*, 38(1), 111-125.
- Cincinnati Children's Hospital Medical Center. (2006). Gene therapy appears to cure Myeloid blood diseases in groundbreaking international study. Retrieved February 11, 2008, <http://www.cincinnatichildrens.org/about/news/release/2006/3-gene-therapy.htm>.
- Clayton, J. (1991). Confusion in the joints: If the immune system becomes confused, it can turn against the body's own tissues, causing destructive diseases such as rheumatoid arthritis. Are bacteria to blame? Retrieved February 11, 2008,

from <http://www.newscientist.com/article/mg13017675.700-confusion-in-the-joints-if-the-immune-system-becomesconfused-it-can-turn-against-the-bodys-own-tissues-causing-destructivediseases-such-as-rheumatoid-arthritis-are-bacteria-to-blame.html>.

Col. Day, B. (2007). Information technology and information management .

Retrieved September, 2008 from

<http://www.dod.state.ga.us/hqang/boarstale/pages/nov2007boards.html>.

Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A., & Totterdell, I. J. (2007).

Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model . *Nature*, 408, 184 - 187. Retrieved October 1, 2008 from

<http://www.nature.com/nature/journal/v408/n6809/pdf/408184a0.pdf>.

Davie, R. (1996). *Listening to children in education*. London: David Fulton Publishers.

DeBoer, G. E. (1991). *A history of ideas in science education: Implications for practice*. New York, NY: Teachers College Press.

DeCorte, E., Op't-Eynde, P., & Verschaffel, L. (2002). Personal epistemology as a psychology and educational construct: An introduction. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology : The psychology of beliefs about knowledge and knowing* (pp. 297-320). Mahwah, New Jersey: Lawrence Erlbaum Associates.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, 10 (2-3), 105-225; *Responses to commentary*, 261-280. (*Cognition and Instruction*, Monograph No. 1.).

- Donohue, L. K. (2005). Censoring science won't make us any safer. *The Washington Post*. Retrieved October 14, 2008, from http://www.washingtonpost.com/wp-dyn/content/article/2005/06/25/AR2005062500077_pf.html.
- Durant, R. H., Ashworth, C. S., Newman, C. L., McGill, L., Rabun, C., & Baranowski, T. (1992). AIDS/HIV knowledge level and perceived chance of having HIV among rural adolescents. *Journal of Adolescent Health*, 13(6), 499-505.
- Eide, K. Y., & Heikkinen, M. W. (1998). The inclusion of multicultural material in middle school science teachers' resource manuals. *Science Education*, 82(2), 181–195.
- Ekborg, M., Ottander, C., & Ideland, M. (n.d.). Science for life: Development of a conceptual framework for modeling socio-scientific cases. Retrieved October 5, 2008, from http://209.85.165.104/search?q=cache:FXs5JJwtRIAJ:symposium9.khi.is/synopsis/nfsun9_submission_125.doc+socio-scientific+issues+in+chemistry&hl=en&ct=clnk&cd=9&gl=us&client=firefox-a.
- Evans, J. St. B. T. (2002). Logic and human reasoning: An assessment of the deduction paradigm. *Psychological Bulletin*, 128, 978–996.
- Evans, J. St. B. T. (2003). In two minds: Dual-process accounts of reasoning. *Trends in Cognitive Sciences*, 7, 454–459
- Fang-Ying, Y. (2004). Exploring high-school students' use of theory and evidence in an everyday context: the role of scientific thinking in environmental science

- decision-making. *International Journal of Science Education*, 26(11), 1345-1364.
- Finkelstein, N. D., & Pollock, S. J. (2005). Replicating and understanding successful innovations: Implementing tutorials in introductory physics. *Physical Review Special Topics - Physics Education Research*, 1(1), 010101.
- Finkelstein, N. D., Turpen, C., Pollock, S., Dubson, M., Iona, S., Keller, C., et al. (2005). Evaluating a model of research-based practices for teacher preparation in a physics department: Colorado PhysTEC Paper presented at the Physics Education Research Conference, Salt Lake City, U.T.
- Fisch, C. (2007). Did you Know III. On Did you Know? [Video]. Retrieved October 5, 2008, from http://www.youtube.com/watch?v=P7J_ereCiTo.
- Fleming, R. (1986a). Adolescent reasoning in socio-scientific issues, part I: Social cognition. *Journal of Research in Science Teaching*, 23(8), 677-687.
- Fleming, R. (1986b). Adolescent reasoning in socio-scientific issues part II: Nonsocial cognition. *Journal of Research in Science Teaching*, 23(8), 689-698.
- Flynn, H., & Ford, A. (n.d.). A System Dynamics Study of Carbon Cycling and Electricity Generation from Energy Crops. Retrieved October 1, 2008, from <http://systemdynamics.org/conferences/2005/proceed/papers/FLYNN277.pdf>.
- Ford, M. (2008). "Grasp of practice" as a reasoning resource for inquiry and nature of science understanding. *Science & Education*, 17, 147-177.

- Fox News Associated Press. (2006). Microbes Could Help Develop Alternative Energy Sources. Retrieved October 2, 2008, from <http://www.foxnews.com/story/0,2933,184819,00.html>.
- Gall, M. D., Gall, J.P., & Borg, W.R. (2002). *Educational research: An introduction*, Pearson Education, Inc.
- Grace, M. M., & Ratcliffe, M. (2002). The science and values that young people draw upon to make decisions about biological conservation issues. *International Journal of Science Education*, 24(11), 1157-1169.
- Greene, W. C., & Peterlin, B. M. (2006). Molecular insights into HIV biology. Retrieved October 1, 2008, from <http://hivinsite.ucsf.edu/InSite?page=kb-00&doc=kb-02-01-01>.
- Grindstaff, K., & Richmond, G. (2008). Learners' perceptions of the role of peers in a research experience: Implications for the apprenticeship process, scientific inquiry, and collaborative work. *Journal of Research in Science Teaching*, 45(2), 251-271.
- Guba, E. G., & Lincoln, Y. S. (1989). *Fourth generation evaluation*. Newbury Park, CA: Sage Publications, Inc.
- Hammer, D., & Elby, A. (2002). On the form of a personal epistemology. In P. R. Pintrich & B. K. Hofer (Eds.), *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing* (pp. 169-190). Mahwah, N.J.: Lawrence Erlbaum.

- Hand, B., Lawrence, C., & Yore, L. D. (1999). A writing in science framework designed to enhance science literacy. *International Journal of Science Education*, 21(10), 1021-1035.
- Hanrahan, M. U. (2006). Highlighting hybridity: A critical discourse analysis of teacher talk in science classrooms. *Science Education*, 90(1), 8-43.
- Hanuscin, D. L., Akerson, V. L., & Phillipson-Mower, T. (2006). Integrating nature of science instruction into a physical science content course for preservice elementary teachers: NOS views of teaching assistants. *Science Education*, 90(5), 912-935.
- Hart, C. (2002). Framing curriculum discursively: Theoretical perspectives on the experience of VCE physics. *International Journal of Science Education*, 24(10), 1055-1077.
- Hobson, A. (1995). Physics: Concepts and connections. In D. W. Cheek & K. A. Cheek (Eds.), *Proceedings of the National Technological Literacy Conference* (10th, Arlington, Virginia, March 2-5) (pp. 146-149).
- Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, 13(4), 353-383.
- Hofer, B. K. (2002). Personal epistemology as a psychology and educational construct: An introduction. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology : The psychology of beliefs about knowledge and knowing* (pp. 3-14). Mahwah, New Jersey: Lawrence Erlbaum Associates.

- Hofer, B. K. (2004a). Epistemological understanding as a metacognitive process: Thinking aloud during Online searching. *Educational Psychologist*, 39(1), 43-55.
- Hofer, B. K. (2004b). Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology*, 29(2), 129-163.
- Hogan, K. (2000). Exploring a process view of students' knowledge about the nature of science. *Science Education*, 84(1), 51-70.
- Hogan, K. (2002). Small groups' ecological reasoning while making an environmental management decision. *Journal of Research in Science Teaching*, 39(4), 341-368.
- Jime'nez-Aleixandre, M., Pereiro-Munoz, C., (2002). Knowledge producers or knowledge consumers? Argumentation and decision-making about environmental management. *International Journal of Science Education*, 24(11), 1171-1190.
- Kassem, I. (2006). Gasses, Grasses, and Bugs: the Fellowship of Global Warming Paper presented at the 106th General Meeting of the American Society for Microbiology. Retrieved October 1, 2008. from <http://www.asm.org/Media/index.asp?bid=42970>.
- Keefer, M. (2003). Moral reasoning and case-based approaches to ethical instruction in science. In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 241-259). Norwell, MA: Kluwer Academic Publishers.

- Keselman, A., Kaufman, D. R., & Patel, V. L. (2004). "You can exercise your way out of HIV" and other stories: The role of biological knowledge in adolescents' evaluation of myths. *Science Education*, 88(4), 548-573.
- Keselman, A., Kaufman, D. R., Kramer, S., & Patel, V. L. (2007). Fostering conceptual change and critical reasoning about HIV and AIDS. *Journal of Research in Science Teaching*, 44(6), 844-863.
- Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*, 39(7), 551-578.
- Khishfe, R., & Lederman, N. (2006). Teaching nature of science within a controversial topic: Integrated versus nonintegrated. *Journal of Research in Science Teaching*, 43(4), 395-418.
- King, P. M. & Kitchener, K. S., (2004). Reflective judgment: Theory and research on the development of epistemic assumptions through adulthood. *Educational Psychologist*, 39(1), 5-18.
- King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco, CA: Jossey-Bass.
- Kinraide, T. B., & Denison, R. F. (2003). Strong inference: The way of science. *American Biology Teacher*, 65(6), 419-424.
- Knowledge Media Lab at the Carnegie Foundation for the Advancement of Teaching. (2002). The KEEP toolkit. 2007, from <http://www.keep.umd.edu/>.

- Koballa, T. R., & Glynn, S. M. (2007). Attitudinal and motivational constructs in science learning. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education* (pp. 72 - 102). Mahwah, New Jersey: Lawrence Erlbaum Assoc Inc.
- Kolsto, S. D. (2001a). Scientific literacy for citizenship: tools for dealing with the science dimension of alternative socioscientific issues. *Science Education*, 85, 291–310.
- Kolsto, S. D. (2001b). 'To trust or not to trust,...'-pupils' ways of judging information encountered in a socio-scientific issue. *International Journal of Science Education*, 23(9), 877-901.
- Kolsto, S. D. (2006). Patterns in students' argumentation confronted with a risk-focused socio-scientific issue. *International Journal of Science Education*, 28(14), 1689-1716.
- Kolsto, S. D., Bungum, B., Arnesen, E., Isnes, A., Kristensen, T., Mathiassen, K., et al. (2006). Science students' critical examination of scientific information related to socioscientific issues. *Science Education*, 90(4), 632-655.
- Korpan, C. A., Bisanz, G. L., Bisanz, J., & Henderson, J. M. (1997). Assessing literacy in science: Evaluation of scientific news briefs. *Science Education*, 81(5), 515-532.
- Kortland, K. (1996). An STS case study about students' decision making on the waste issue. *Science Education*, 80(6), 673-689.

- Krumme, G. (2005). Major categories in the taxonomy of educational objectives (Bloom 1956). Retrieved October 1, 2008, from <http://faculty.washington.edu/krumme/guides/bloom.html>.
- Kuhn, D. (1989). Children and adults as intuitive scientists. *Psychological Review*, 96, 674-689.
- Kuhn, D. (1991). *The skills of argument*. Cambridge: Cambridge University Press.
- Ladson-Billings, G. (1995a). Toward a theory of culturally relevant pedagogy. *In American Educational Research Journal*, 32(3), 465-490.
- Ladson-Billings, G. (1995b). But that's just good teaching! The case for culturally relevant pedagogy. *In Theory Into Practice*, 34(3), 159-165.
- Leach, J., Millar, R., Ryder, J., & Sere, M. (2002). Students' images of science as they relate to laboratory work, *European Commission Labwork in Science Education Project Report*: University of York, UK.
- Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29, 331-359.
- Lederman, N. G. (2007). Nature of Science: Past, Present, and Future. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education* (pp. 831-880). Mahwah, New Jersey: Lawrence Erlbaum Assoc Inc.
- Lederman, N. G., Abd-El-Khalick, F., Bell, R.L., & Schwartz, R.S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497-521.

- Lee, O. (2002). Science inquiry for elementary students from diverse backgrounds. In W. G. Secada (Ed.), *Review of research in education* (Vol. 26, pp. 23–69). Washington, DC: American Educational Research Association.
- Lee, O. (2003). Equity for culturally and linguistically diverse students in science education: A research agenda. *Teachers College Record*, 105, 465–489.
- Lee, O. (2004). Teacher change in beliefs and practices in science and literacy instruction with English language learners. *Journal of Research in Science Teaching*, 41, 65–93.
- Lee, O., & Fradd, S. H. (1998). Science for all, including students from non-English language backgrounds. *Educational Researcher*, 27(3), 12–21.
- Lee, O., & Luykx, A. (2007). Culture, gender, society, and science learning. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education* (pp. 169-197). Mahwah, New Jersey: Lawrence Erlbaum Assoc Inc.
- Ley, R. E., Backhed, F., Turnbaugh, P., Lozupone, C. A., Knight, R. D., & Gordon, J. I. (2005). Obesity alters gut microbial ecology. *Proceedings of the National Academy of Sciences of the United States of America*, 102(31), 11070-11075.
- Linn, M. C., Clark, D., & Slotta, J. D. (2002). WISE design for knowledge integration. *Science Education*, 87, 517–538.
- LTG Croom, D., Defense Information Systems Agency. (2007, August 14, 2007). Keynote Address. Presented at the Air Force Information Technology Conference (AFITC), Montgomery, Alabama.

- Lyons, T. (2006). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education*, 28(6), 591 - 613.
- MacLeod, K. (2007). A practical example aiding understanding momentum in 1D: The water gun experiment. *Physics Education*, 42(5), 492-495.
- Maggioni, L., Riconscente, M. M., & Alexander, P. A. (2006). Perceptions of knowledge and beliefs among undergraduate students in Italy and in the United States. *Learning and Instruction*, 16(5), 467-491.
- Marbach-Ad, G., McGinnis, J. R., Dai, A. H., Pease, R., Schalk, K., A., and Benson, S. (2008). Promoting science for all by way of student interest in a transformative undergraduate microbiology laboratory for non-majors. *Journal of Microbiology and Biology Education*.
<http://www.microbelibrary.org>.
- Marks, R., Bertram, S., & Eilks, I. (2008). Learning chemistry and beyond with a lesson plan on potato crisps, which follows a socio-critical and problem-oriented approach to chemistry lessons - a case study. *Chemistry Education Research and Practice*, 9(3), 267-276.
- Maryland State Department of Education. (1997). Maryland voluntary state curriculum. Retrieved October 10, 2007, from
<http://mdk12.org/instruction/curriculum/index.html>.
- Matthews, C. E., & Smith, W. S. (1994). Native American related materials in elementary science instruction. *Journal of Research in Science Teaching*, 31, 363-380.

- May, D. B., & Etkina, E. (2002). College physics students' epistemological self-reflection and its relationship to conceptual learning. *American Journal of Physics*, 70(12), 1249-1258.
- Mayo Clinic Staff. (2008). HIV/AIDS: treatment. October 2, 2008, from <http://www.mayoclinic.com/health/hiv-aids/DS00005>.
- McComas, W. F. (1998). The principal elements of the nature of science: Dispelling the myths. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 53–70). Dordrecht, The Netherlands: Kluwer.
- McComas, W. F., Clough, M. P., & Almazroa, H. (2000). The role and character of the nature of science in science education. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 41–52). Dordrecht, The Netherlands: Kluwer.
- McDonald, J., & Dominguez, L. (2005). Moving from content knowledge to engagement. *Journal of College Science Teaching*, 35(3), 18.
- McGinnis, J. R. (2003). The morality of inclusive versus exclusive settings. In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 195-217). Norwell, MA: Kluwer Academic Publishers.
- McGinnis, J. R., & Simmons, P. (1999). Teachers' perspectives of teaching science-technology-society in local cultures: A sociocultural analysis. *Science Education*, 83(2), 179-211.

- McLure, G. T., Srikanta-Rao, A. M., & Lester, W. L. (1999, May 30 - June 3). Comparing student perceptions of general education and personal growth outcomes at HBCU and Non-HBCU institutions. Paper presented at the 39th Annual Forum of the Association for Institutional Research Seattle, WA
- McNeil, L. M. (2000). Creating new inequalities: Contradictions of reform. *Phi Delta Kappan*, 81, 729–734.
- Means, M. L., & Voss, J. F. (1996). Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels. *Cognition and Instruction*, 14, 139 – 178.
- Moje, E., Collazo, T., Carillo, R., & Marx, R. W. (2001). “Maestro, what is quality?”: Examining competing discourses in project-based science. *Journal of Research in Science Teaching*, 38, 469–495.
- Monterey Bay Aquarium Research Institute. (2004). Microbes and methane - DNA analysis shows how some deep-sea microbes limit global warming. Retrieved October 1, 2008, from <http://www.spaceref.com/news/viewpr.html?pid=14959>.
- Mufson, S. (2007, October 18). In Microbe, Vast Power for Biofuel. *The Washington Post*. Retrieved February 11, 2008, from <http://www.washingtonpost.com/wp-dyn/content/article/2007/10/17/AR2007101702216.html>.
- Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Educational Research*, 74(3), 317-377.

- Multicultural Canada in the 21st century: Harnessing opportunities and managing pressures. (2007). *Cultural diversity*. Retrieved September, 2008, from http://www.policyresearch.gc.ca/page.asp?pagenm=rp_mult_bkg.
- Munby, H., & Russell, T. (1983). A common curriculum for the natural sciences. In *The national society for the study of education, individual differences and the common curriculum: Eighty second yearbook of the national society for the study of education* (pp. 165-185). Chicago: University of Chicago Press.
- Murphy, P., Lunn, S., & Jones, H. (2006). The impact of authentic learning on students' engagement with physics. *Curriculum Journal*, 17(3), 229-246.
- National Cancer Institute. (2006). New Method of Gene Therapy Alters Immune Cells for Treatment of Advanced Melanoma. Retrieved October 1, 2008, from <http://www.cancer.gov/newscenter/pressreleases/MelanomaGeneTherapy>.
- National Commission on Excellence in Education. (1983). *A Nation at Risk*. Retrieved. from <http://www.ed.gov/pubs/NatAtRisk/index.html>..
- National Research Council & The Center for Science Mathematics and Engineering Education (2000, p. 115-128). *Inquiry and the national science education standards*. Washington, DC: National Academies Press.
- National Research Council (1996a). Chapter 6 Science content standards: 9-12. In *National science education standards*. Washington, D.C.: National Academy Press. Retrieved. from <http://www.nap.edu/readingroom/books/nses/6e.html>.
- National Research Council (1996b). *National science education standards*. Washington, D. C.: National Academy Press.

- National Science Board. (2006a). Elementary and secondary education. In *Science and engineering indicators*. Arlington, VA: National Science Foundation, Division of Science Resources Statistics. Chapter 1.
- National Science Board. (2006b). Higher education in science and engineering. In *Science and engineering indicators*. Arlington, VA: National Science Foundation, Division of Science Resources Statistics. Chapter 2.
- National Science Board. (2006c). Research and development: Funds and technology linkages. In *Science and engineering indicators*. Arlington, VA: National Science Foundation, Division of Science Resources Statistics. Chapter 4.
- National Science Board. (2006d). Science and engineering labor force. In *Science and engineering indicators*. Arlington, VA: National Science Foundation, Division of Science Resources Statistics. Chapter 3.
- National Science Board. (2006e). Science and technology: Public attitudes and understanding. In *Science and engineering indicators*. Arlington, VA: National Science Foundation, Division of Science Resources Statistics. Chapter 7.
- National Science Teachers Association. (1982). Science-technology-society: Science Education for the 1980's. Washington, DC: Author.
- Ninnes, P. (2000). Representations of indigenous knowledges in secondary school science textbooks in Australia and Canada. *International Journal of Science Education*, 22(6), 603–617.
- Oblinger, D. G. (2007). All of us bear responsibility for learning to be net savvy and supporting the members of our campus communities in the same lifelong

- process. *Educause Quartely*, 30. Retrieved September, 2008 from <http://connect.educause.edu/Library/EDUCAUSE+Quarterly/BecomingNetSavvy/44830?time=1220813575>.
- Oregon Public Broadcasting (January, 2000). Unseen Life on Earth: Annenberg/CPB online, from <http://www.microbeworld.org/look/telecourse.aspx>.
- Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: a review of the literature and its implications. *International Journal of Science Education*, 25(9), 1049-1079.
- Oulton, C., Dillon, J., & Grace, M. M. (2004). Reconceptualizing the teaching of controversial issues. *International Journal of Science Education*, 26(4), 411-423.
- Paddock, C. (2007). Gene Therapy Trial Halted While Woman's Death Investigated . *Medical News Today*. Retrieved October 1, 2008 from <http://www.medicalnewstoday.com/articles/79484.php>.
- Palmer, D. (2005). A motivational view of constructivist-informed teaching. *International Journal of Science Education*, 27(15), 1853-1881.
- Patronis, T., Potari, D., & Spiliotopoulou, V. (1999). Students' argumentation in decision-making on a socio-scientific issue: Implications for teaching. *International Journal of Science Education*, 21, 745–754.
- Paulsen, M. B., & Feldman, K. A. (2005). The conditional and interaction effects of epistemological beliefs on the self-regulated learning of college students: Motivational strategies. *Research in Higher Education*, 46(7), 731-768.

- Pedretti, E. & Hodson, D. (1995). From rhetoric to action: Implementing STS education through action research. *Journal of Research in Science Teaching*, 32, 463–485.
- Pedretti, E. (2003). Teaching science, technology, society and environment (STSE) education. In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 219-239). Norwell, MA: Kluwer Academic Publishers.
- Pella, M. O., O’Hearn, G. T., & Gale, C. W. (1966). Referents to scientific literacy. *Journal of Research in Science Teaching*, 4, 199-208.
- Perkins, D. N. (1985). Post-Primary Education Has Little Impact on Informal Reasoning. *Journal of Educational Psychology*, 77(5), 562-571.
- Perkins, D. N., Farady, N., & Bushey, B. (1991). Everyday reasoning and the roots of intelligence. In J. F. Voss, N. D. Perkins & J. W. Segal (Eds.), *Informal reasoning and education* (pp. 83 – 105). Hillsdale, NJ: Erlbaum.
- Piaget, J. (1970). Piaget’s theory In P. H. Mussen (Ed.), *Carmichael’s manual of child psychology* (Third ed., Vol. I). New York: John Wiley.
- Pinkus, R. L. B., Shuman, L. J., Norman, P. H., & Harvey, W. (1997). *Engineering ethics: Balancing cost, schedule, and risk—lessons learned from the space shuttle*. New York, N.Y.: Cambridge University Press
- Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond Cold Conceptual Change - the Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change. *Review of Educational Research*, 63(2), 167-199.

- Pintrich, P. R., Wolters, C. A., & Baxter, G. P. (2000). Assessing metacognition and self-regulated learning. In G. Schraw & J. C. Impara (Eds.), *Issues in the measurement of metacognition*. Lincoln, NE: Buros Institute of Mental Measurements.
- Pontecorvo, C., & Girardet, H. (1993). Arguing and reasoning in understanding historical topics. *Cognition and Instruction*, 11(3&4), 365-395.
- Project Nexus. (2005). The Maryland upper elementary/middle school science teacher professional continuum model 2007, Retrieved October 1, 2008, from <http://projectnexus.umd.edu/>.
- Rapier, R. (2008). The Politics of Renewable Energy: Unintended Consequences of Biofuel Policies. Retrieved March 6, 2008, from <http://www.e-ir.info/?p=327>.
- Ratcliffe, M. (1997). Pupil decision-making about socio-scientific issues within the science curriculum. *International Journal of Science Education*, 19(2), 167-182.
- Reeve, J., Hamm, D., & Nix, G. (2003). Testing models of the experience of self-determination in intrinsic motivation and the conundrum of choice. *Journal of Educational Psychology* 95, 375–392.
- Resnick, L. B., Salmon, M., Zeitz, C. M., Wathen, S. H., & Holowchak, M. (1993). Reasoning in conversation. *Cognition and Instruction*, 11(3&4), 347-364.
- Rest, J. R. (1979). *Development in judging moral issues*. Minneapolis, MN: University of Minnesota Press.

- Rivet, A. E., & Krajcik, J. S. (2004). Project-based science curricula: Achieving standards in urban systemic reform. *Journal of Research in Science Teaching*, 41(7), 669-692.
- Rivet, A. E., & Krajcik, J. S. (2008). Contextualizing instruction: Leveraging students' prior knowledge and experiences to foster understanding of middle school science. *Journal of Research in Science Teaching*, 45(1), 79-100.
- Roberts, D. A. (1995). Junior-High-School Science Transformed - Analyzing a Science Curriculum Policy Change. *International Journal of Science Education*, 17(4), 493-504.
- Roberts, D. A. (2007). Scientific literacy / Science literacy. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education* (pp. 729-780). Mahwah, New Jersey: Lawrence Erlbaum Assoc Inc.
- Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *The Journal of the Learning Sciences*, 21(1), 61-94.
- Rubba, P. A. (1977). *Nature of scientific knowledge scale: Test and users' manual*. Carbondale, IL Dr. Peter A. Rubba, Jr., Department of Curriculum, Instruction and Media, Southern Illinois University.
- Ryder, J., & Leach, J. (2000). Interpreting experimental data: the views of upper secondary school and university science students. *International Journal of Science Education*, 22(10), 1069-1084.
- Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. *Journal of Research in Science Teaching*, 36(2), 201-219.

- Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, 41(5), 513-536.
- Sadler, T. D. (2004a). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, 41(5), 513-536.
- Sadler, T. D. (2004b). Moral sensitivity and its contribution to the resolution of socioscientific issues. *Journal of Moral Education*, 33(3), 339-358.
- Sadler, T. D. (2005). Evolutionary theory as a guide to socioscientific decision-making. *Journal of Biological Education*, 39(2), 68-72.
- Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific Argumentation: The effects of content knowledge and morality. *International Journal of Science Education*, 28(12), 1463 - 1488.
- Sadler, T. D., & Fowler, S. R. (2006). A threshold model of content knowledge transfer for socioscientific argumentation. *Science Education*, 90(6), 986-1004.
- Sadler, T. D., & Zeidler, D. L. (2003). Scientific errors, atrocities and blunders: Using cases to promote moral reasoning. In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 261-285). Norwell, MA: Kluwer Academic Publishers.
- Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education*, 88(1), 4-27.

- Sadler, T. D., & Zeidler, D. L. (2005a). Patterns of informal reasoning in the context of socioscientific decision-making. *Journal of Research in Science Teaching*, 42(1), 112-138.
- Sadler, T. D., & Zeidler, D.L. (2005b). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education*, 89(1), 71-93.
- Sadler, T. D., Amirshokoohi, A., Kazempour, M., & Allspaw, K. M. (2006). Socioscience and ethics in science classrooms: Teacher perspectives and strategies. *Journal of Research in Science Teaching*, 43(4), 353-376.
- Sadler, T. D., Barab, S. A., Scott, B. (2007). "What do students gain by engaging in socioscientific inquiry?" *Research in Science Education* 37(4): 371-391.
- Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education*, 26(4), 387-409.
- Sandoval, W. A. (2003). "Conceptual and Epistemic Aspects of Students' Scientific Explanations." *Journal of the Learning Sciences* 12(1): 5 – 51
- Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, 89(4), 634-656.
- Savage, N. (2007). Building better biofuels: Startup LS9 is developing microbes that produce hydrocarbons. *Technology Review*. Retrieved April 9, 2008. from <http://www.technologyreview.com/Biztech/18827/>.
- Schauble, L. (1996). The development of scientific reasoning in knowledge-rich contexts. *Developmental Psychology*, 32(1), 102-119.

- Schommer, M. (1993). Comparisons of beliefs about the nature of knowledge and learning among postsecondary students. *Research in Higher Education*, 34(3), 355-370.
- Schommer-Aikins, M. (2002). Personal epistemology as a psychology and educational construct: An introduction. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology : The psychology of beliefs about knowledge and knowing* (pp. 103-118). Mahwah, New Jersey: Lawrence Erlbaum Associates.
- Schommer-Aikins, M., Duell, O. K., & Hutter, R. (2005). Epistemological beliefs, mathematical problem-solving beliefs, and academic performance of middle school students. *Elementary School Journal*, 105(3), 289-304.
- Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88(4), 610-645.
- Schwartz, R., & Lederman, N. (2008). What Scientists Say: Scientists' views of nature of science and relation to science context. *International Journal of Science Education*, 30(6), 727-771.
- Sconiers, Z. D., & Rosiek, J. L. (2000). Historical perspective as an important element of teachers' knowledge: Asonata-form case study of equity issues in a chemistry classroom: Voices inside schools. *Harvard Educational Review*, 70, 370-404.

- Seiler, G. (2001). Reversing the “standard” direction: Science emerging from the lives of African American students. *Journal of Research in Science Teaching*, 38, 1000–1014.
- Seiler, G. (2002). Understanding social reproduction: The recursive nature of structure and agency within a science class. Ph.D. dissertation, University of Pennsylvania.
- Seiler, G. (2006). Student interest-focused curricula. In K. Tobin (Ed.), *Teaching and learning science: A handbook*. Westport, CT: Greenwood.
- Sere, M.-G., Fernandez-Gonzalez, M., Gallegos, J. A., Gonzalez-Garcia, F., De Manuel, E., Perales, F. J., & Leach, J. (2001). Images of science linked to laboratory work: A survey of secondary school and university students. *Research in Science Education*, 31, 499-523.
- Sinatra, G. M., Southerland, S. A., McConaughy, F., & Demastes, J. W. (2003). Intentions and beliefs in students' understanding and acceptance of biological evolution. *Journal of Research in Science Teaching*, 40(5), 510-528.
- Slovan, S. A. (1996). The empirical case for two systems of reasoning. *Psychological Bulletin*, 119, 3–22.
- Smith, C. L., & Wenk, L. (2006). Relations among three aspects of first-year college students' epistemologies of science. *Journal of Research in Science Teaching*, 43(8), 747-785.
- Smith, N. F. (1974). The challenge of scientific literacy. *Science Teacher*, 41(6), 34-35.

- Solomon, J. (2000). Science education for scientific culture. *Israel Journal of Plant Sciences*, 48(3), 157-163.
- Southerland, S. A., Abrams, E., Cummins, C. L., & Anzelmo, J. (2001). Understanding students' explanations of biological phenomena: Conceptual frameworks or p-prims. *Science Education*, 85(4), 328-348.
- Stephanopoulos, G. (2007). Challenges in engineering microbes for biofuels production. *Science* 315(5813), 801-804.
- Stolberg, S. G. (1999). The Biotech Death of Jesse Gelsinger . *The New York Times Magazine*. Retrieved October 1, 2008 from <http://query.nytimes.com/gst/fullpage.html?res=9C03E4DE1F3CF93BA15752C1A96F958260>.
- Sullivan, D. (2006). Searches per day. Search Engine Watch. Retrieved September, 2008 from <http://searchenginewatch.com/showPage.html?page=2156461>.
- Tolhurst, D. (2007). The influence of learning environments on students' epistemological beliefs and learning outcomes. *Teaching in Higher Education*, 12(2), 219-233.
- Toplak, M. E., & Stanovich, K. E. (2003). Associations between myside bias on an informal reasoning task and amount of post-secondary education. *Applied Cognitive Psychology*, 17(7), 851-860.
- Toulmin, S. E. (1958). *The uses of argument*. Cambridge, England: Cambridge University Press.

- Trivedi, B. (2005, October 1). Slimming for Slackers. Retrieved February 11, 2008, from <http://www.newscientist.com/channel/being-human/mg18825191.900-slimming-for-slackers.html>.
- Tsai, C. C., & Kuo, P. C. (2008). Cram school students' conceptions of learning and learning science in Taiwan. *International Journal of Science Education*, 30(3), 353-375.
- Tytler, R., Duggan, S., & Gott, R. (2001). Dimensions of evidence, the public understanding of science and science education. *International Journal of Science Education*, 23, 815 – 832.
- U.S. Department of Education. (2001). *No Child Left Behind Act (Public Law 107-110)*. Retrieved. from <http://www.ed.gov/policy/elsec/leg/esea02/index.html>.
- University of California San Francisco. (2008). HIV InSite Gateway to HIV infection and knowledgebase. Retrieved October 1, 2008, from <http://hivinsite.ucsf.edu/InSite>.
- Veal, W. R. (2004). Beliefs and knowledge in chemistry teacher development. *International Journal of Science Education*, 26(3), 329-351.
- Vhurumuku, E., Holtman, L., Mikalsen, O., & Kolsto, S. D. (2006). An investigation of Zimbabwe High School chemistry students' laboratory work-based images of the nature of science. *Journal of Research in Science Teaching*, 43(2), 127-149.
- Volkman, M. (2000). Where's the science? In T. Koballa & D. Tippins (Eds.), *Cases in middle and secondary science education: The promise and dilemmas* (pp. 84–88). NJ: Merrill.

- Wade, S. E. (2001). Research on importance and interest: Implications for curriculum development and future research. *Educational Psychology Review*, 13, 243–261.
- Walker, K. A., & Zeidler, D. L. (2007). Promoting discourse about socioscientific issues through scaffolded inquiry. *International Journal of Science Education*, 29(11), 1387-1410.
- Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday language. *Journal of Research in Science Teaching*, 38, 529–552.
- Weiss, F. (1979). Nuclear power plant simulation game. *Science Teacher*, 46(5), 42-44.
- White, H. B., III, Brown, S. D., & Johnston, M. V. (2005). Contemporary moral problems in chemistry: Effect of peer presentations on students' awareness of science and society issues. *Journal of Chemical Education*, 82(10), 1570-1576.
- Wolt, J. D., Peterson, R. K. D., Bystrak, P., & Meade, T. (2003). A screening level approach for nontarget insect risk assessment: Transgenic Bt corn pollen and the monarch butterfly (Lepidoptera: Danaidae). *Environmental Entomology*, 32(2), 237–246.
- Wong, S. L., Hodson, D., Kwan, J., & Yung, B. H. W. (2008). Turning crisis into opportunity: Enhancing student-teachers' understanding of nature of science and scientific inquiry through a case study of the scientific research in severe

- acute respiratory syndrome. *International Journal of Science Education*, 30(11), 1417-1439.
- Wu, Y. T., & Tsai, C. C. (2007). High school students' informal reasoning on a socio-scientific issue: Qualitative and quantitative analyses. *International Journal of Science Education*, 29(9), 1163-1187.
- XEC Internet. (n.d.). Types of Biofuel. Retrieved October 2, 2008, from <http://biofuel.org.uk/types-of-biofuel.html>.
- Yang, F. Y. (2005). Student views concerning evidence and the expert in reasoning a socio-scientific issue and personal epistemology. *Educational Studies*, 31(1), 65-84.
- Zacharia, Z., & Barton, A. C. (2004). Urban middle-school students' attitudes toward a defined science. *Science Education*, 88(2), 197-222.
- Zeidler, D. L. (1997). The central role of fallacious thinking in science education. *Science Education*, 81(4), 483-496.
- Zeidler, D. L., (2003). *The role of moral reasoning on socioscientific issues and discourse in science education*: Kluwer Academic Publishers.
- Zeidler, D. L., & Keefer, M. (2003). The role of moral reasoning and the status of socioscientific issues in science education In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 7-40). Norwell, MA: Kluwer Academic Publishers.
- Zeidler, D. L., & Sadler, T. D. (2008). The role of moral reasoning in argumentation: Conscience, character and care. In S. Erduran & M. Pilar Jimenez-Aleixandre

- (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 201-216). New York, NY: Springer Press.
- Zeidler, D. L., & Schafer, L. E. (1984). Identifying mediating factors of moral reasoning in science-education. *Journal of Research in Science Teaching*, 21(1), 1-15.
- Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing reflective judgment through socioscientific issues. *Journal of Research Science Teaching*.
- Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, 89(3), 357-377.
- Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, 86(3), 343-367.
- Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, 39(1), 35-62.