Case Studies of Secondary School Teachers Designing Socioscientific Issues-Based Instruction and Their Students' Socioscientific Reasoning

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Dedication

This dissertation is dedicated to the flying ants in my bathroom…

Abstract

Addressing socioscientific issues (SSI) has been one of the main focuses in science education since the Science, Technology, and Society (STS) movement in the 1970s (Levinson, 2006); however, teaching controversial socioscientific issues has always been challenging for teachers (Dillon, 1994; Osborne, Duschl, & Fairbrother, 2002). Although teachers exhibit positive attitudes for using controversial socioscientific issues in their science classrooms, only a small percentage of them actually incorporate SSI content into their science curricula on a regular basis (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006; Lee & Witz, 2009). The literature in science education has highlighted the significant relationships among teacher beliefs, teaching practices, and student learning (Bryan & Atwater, 2002; King, Shumow, & Lietz, 2001; Lederman, 1992). Despite the fact that the case studies present a relatively detailed picture of teachers' values and motivations for teaching SSI (e.g. Lee, 2006; Lee & Witz, 2009; Reis & Galvao, 2004), these studies still miss the practices of these teachers and potential outcomes for their students. Therefore, there is a great need for in-depth case studies that would focus on teachers' practices of designing and teaching SSI-based learning environments, their deeper beliefs and motivations for teaching SSI, and their students' response to these practices (Lee, 2006).

This dissertation is structured as three separate, but related, studies about secondary school teachers' experiences of designing and teaching SSI-based classes and their students' understanding of science and SSI reasoning. The case studies in this dissertation seek answers for (1) teachers' practices of designing and teaching SSI-based instruction, as well as its relation to their deeper personal beliefs and motivations to teach

SSI, and (2) how their students respond to their approaches of teaching SSI in terms of their science understanding and SSI reasoning.

The first paper presents case studies of three secondary science teachers within three high schools located along the Minnesota River Basin. The findings of this study documented the experiences of the participant teachers, as well as the contextual influences on those experiences. The second paper presents a case study of a science teacher and a social studies teacher which describes how these two teachers collaboratively designed and taught an environmental ethics class. The results of this study documented teachers' ways of sharing responsibilities, bringing their content and pedagogical expertise, and promoting the agency of their students in the environmental ethics class. The final paper in this dissertation presents case studies of secondary school students who were the participants in the SSI-based science classes described in the first two studies. The results of this study provided evidence for participant students' understanding of science and their socioscientific reasoning, as well as how they were influenced by the instructional decisions their teachers made.

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Chapter 1: General Introduction

Despite the strong support for incorporating socioscientific issues (SSI) into science curriculum in reform documents and research studies, the literature reports that science teachers still follow a traditional view in teaching science (Davis, 2003; Jenkins, 2002). Addressing socioscientific issues has been one of the main focuses in science education since the Science, Technology, and Society (STS) movement in the 1970s (Levinson, 2006); however, teaching controversial socioscientific issues has always been challenging for teachers (Dillon, 1994; Osborne, Duschl, & Fairbrother, 2002). Although teachers exhibit positive attitudes for using controversial socioscientific issues in their science classrooms, only a small percentage of them actually incorporate SSI content into their science curricula on a regular basis (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006; Lee & Witz, 2009). The motivations for the few teachers who do implement SSI are mostly personal and related to their understanding of larger values, social awareness and worldview (Witz, Goodwin, Hart, & Thomas, 2001), rather than coming from the major reform efforts (Lee & Witz, 2009). The literature in science education has highlighted the significant relationships among teacher beliefs, teaching practices, and student learning (Bryan & Atwater, 2002; King, Shumow, & Lietz, 2001; Lederman, 1992). In order to explore this relationship in detail in the context of SSI, the case studies in this dissertation seek answers for (1) teachers' practices of designing and teaching SSI-based instruction, as well as its relation to their deeper personal beliefs and motivations to teach SSI, and (2) how their students respond to their approaches of teaching SSI in terms of their science understanding and SSI reasoning.

The literature indicates that research in SSI-based interventions is relatively new

(Sadler, 2004; Zeidler, Sadler, Applebaum, & Callahan, 2009), and there is a need for understanding more about the effects of SSI-based learning environments (Sadler, 2004). Despite the growing body of literature in SSI, only a few researchers have gathered empirical data on the effects of SSI-based interventions (Schalk, 2009). The qualitative case studies in SSI focus on teachers' perceptions and opinions on teaching SSI, rather than individual teachers' involvement in teaching SSI and their deeper beliefs and motivations for teaching SSI (Lee & Witz, 2009). Despite the fact that the case studies present a relatively detailed picture of teachers' values and motivations for teaching SSI (e.g. Lee, 2006; Lee& Witz, 2009; Reis & Galvao, 2004), these studies still miss the practices of these teachers and potential outcomes for their students. Therefore, there is a great need for in-depth case studies that would focus on teachers' practices of designing and teaching SSI-based learning environments, their deeper beliefs and motivations for teaching SSI, and their students' response to these practices (Lee, 2006).

Organization of Dissertation

This dissertation is structured as three separate, but related, studies about secondary school teachers' experiences of designing and teaching SSI-based classes and their students' understanding of science and SSI reasoning. It is presented in nontraditional dissertation format including three publishable journal articles (see Table 1.1 for the summary of the three articles in this dissertation), an introduction and a concluding chapter. The focus of each chapter is described below.

Chapter 1: General introduction. The first chapter of this dissertation introduces the problem statement, then outlines the organization of the dissertation chapters, discusses the overall rationale and literature review, and describes the context of the studies and lastly summarizes the general methodology employed in all three studies.

Chapter 2: The case studies of secondary school science teachers designing technology rich SSI-based instruction. The first paper presents case studies of three secondary science teachers within three high schools located along the Minnesota River Basin. The primary goal for this study was to understand and describe the experiences of these teachers while designing and implementing technologically enriched SSI-based learning experiences. The secondary goal was to investigate how contextual factors (e.g. teacher beliefs and motivations, student bodies, conditions established in communities and schools) impacted those experiences. Using a multiple case study approach to explore the differences in the level of interest, semi-structured interviews were conducted with these three teachers. In addition, observation data with complementary reflective journals were collected from each classroom. The findings of this study documented the experiences of the participant teachers, as well as the contextual influences on those experiences.

Chapter 3: A case study of a science and a social studies teachers' experiences of co-teaching SSI-based environmental ethics class. The second paper presents a case study of a science teacher and a social studies teacher co-teaching an SSI-based high school environmental ethics class. The primary purpose of this study was to describe how these two teachers collaboratively designed and taught an SSI-based environmental science class. The secondary purpose was to explore the strategies these teachers used in order to promote student agency in their environmental ethics class via student-driven projects. A single case with embedded units design was chosen in order to explore the different decisions made by participant teachers. Individual and group interviews were conducted with the teachers, in addition to collecting classroom observations data. The results of this study documented teachers' ways of sharing responsibilities, bringing their content and pedagogical expertise, and promoting the agency of their students in the environmental ethics class.

Chapter 4: Secondary school students' understanding of science and their socioscientific reasoning. The final paper in this dissertation presents case studies of secondary school students who were the participants in the SSI-based science classes described in the first two studies. The purpose of this study was to explore these students' understanding of science and their socioscientific reasoning that was developed through SSI-based instructions. A multiple case study having embedded units of analysis was implemented for this research because of the contextual differences for each case. Semi-structured interviews were conducted with the participant students. In addition, the classroom observation data was used in order to describe the experiences of these students in their classrooms. The results of this study revealed participant students' understanding of science and their socioscientific reasoning, as well as how they were influenced by the instructional decisions their teachers made.

Chapter 5: Synthesis and recommendations. The final chapter of this dissertation summarizes the findings of the three research studies and presents ideas for future research. In addition, implications associated with researchers, teachers, and communities are discussed in this chapter. Lastly, the limitations that emerged in this study are addressed.

Table 1.1.

Summary of the three articles in this dissertation

Case Studies of Secondary School Teachers Designing Socioscientific Issues-Based Instruction and Their Students' Socioscientific Reasoning		
Paper 1: Case studies of secondary school science teachers designing technology rich SSI-based instruction	*Paper 2: A case study of a science and a social studies teachers' experiences of co-teaching SSI-based environmental ethics class*	*Paper 3: Secondary school students' understanding of science and their socioscientific reasoning in the context of a river basin*
How do secondary school teachers experience designing and implementing technologically enriched SSI-based instruction? *How do contextual factors play a role on secondary school teachers' experiences of designing and implementing technologically enriched SSI-based instruction?*	*How do a science and a social studies teacher experience co-teaching an SSI-based environmental ethics class?* *How do a science and a social studies teacher promote student agency in an SSI-based environmental ethics class?*	*How does secondary school students' understanding of science around SSI develop through SSI-based science instruction?* *How does secondary school students' socioscientific reasoning develop through SSI-based science instruction?*
Three secondary school science teachers	*A science and a social studies teacher co-teaching an SSI focused environmental ethics class*	*Twelve secondary school students from four schools within the watershed*
Semi-structured interviews: Teachers way of judging information about SSI (individual teacher interviews) *Semi-structured interviews: TPACK in the context of SSI (individual teacher interviews)* *Observational Field Notes* *Reflective Journals*	*Semi-structured interviews: Teachers way of judging information about SSI (individual teacher interviews)* *Semi-structured interviews: TPACK in the context of SSI (group teacher interview)* *Observational Field Notes* *Reflective Journals*	*A semi-structured interview protocol: Students' understanding of science and their socioscientific reasoning in the context of a large river basin* *Observational Field Notes* *Reflective Journals*
Case Study (a multiple case) *Thematic analysis* *Open coding (Strauss & Corbin, 1990),* *Identification of patterns and categories (LeCompte & Preissle, 1993),* *Building themes and models for cross-case analysis (Miles & Huberman, 1994).*	*Case Study (a single case having embedded units)* *Thematic analysis* *Open coding (Strauss & Corbin, 1990),* *Identification of patterns and categories (LeCompte & Preissle, 1993),* *Building themes (Miles & Huberman, 1994).*	*Case Study (a multiple case having embedded units)* *Thematic analysis* *Open coding (Strauss & Corbin, 1990),* *Identification of patterns and categories (LeCompte & Preissle, 1993),* *Building themes and models for cross-case analysis (Miles & Huberman, 1994).*

Rationale

The role and importance of science in social controversies has increased over the past decades (Stewart, 2009). Citizens in a society need to be involved in resolving controversies created by the changing relationships between science, technology, and society (Patronis, Potari, & Spiliotopoulou, 1999). Goals of science education in the 1950s changed to focus not only developing future scientists needed by society, but also educating citizens on scientific progressions largely supported through public funding (DeBoer, 2000). This became the primary goal of scientific literacy (DeBoer, 2000), a term that was first stated in *Science Literacy: Its Meaning for American Schools* (Hurd, 1958).

Reform movements in science education have continually highlighted the goal of achieving scientific literacy for all students (Bybee, 1997). In the 1970s, the National Science Teachers Association (NSTA) identified the notion of scientific literacy as the most important goal of science education, and over time it has become more closely aligned with "science in its social context" (DeBoer, 2000, p. 588). Several reform documents such as Science for All Americans (AAAS, 1989), the Benchmarks for Science Literacy (AAAS, 1989; 1993), and the National Science Education Standards (National Research Council, 1996) indicated the urgent need for scientific literacy in various areas in the society. The Benchmarks for Science Literacy was recently updated in 2009, thus providing one of the most recent directives for achieving scientific literacy. All these documents determined the goal of science education to be enriching the scientific literacy of students who are then able to intelligently engage in public discourse and sociopolitical decision-making processes on topics that involve science and technology. The most recent reform document, Next Generation Science Standards (2012), also addresses the importance of science in both personal and social contexts despite the fact that it did not use the word ‘scientific literacy’ explicitly.

Several initiatives in the field of science education have been implemented to address the goal of educating scientifically literate citizens. Ziedler and his colleagues introduced socioscientific issues as a pedagogical strategy to “achieve functional view of scientific literacy” (Zeidler, Sadler, Simmons, & Howes, 2005, p. 361). Sadler, Chambers, and Zeidler (2004) claimed that to be considered scientifically literate citizens, students should be able to negotiate societal issues related to applications of science and technology, described as socioscientific issues. The main motivation of this socioscientific framework is to pursue a functional view of scientific literacy- creating informed decision-makers with personal, cognitive, and moral development (Zeidler, Sadler, Simmons, & Howes, 2005). Although the socioscientific issues in science classes mainly built upon the Science, Technology, and Society movement, taking into consideration to ethical and moral values, it goes beyond the boundaries of this movement (Zeidler, Sadler, Simmons, & Howes, 2005). In describing the differences of SSI from the STS movement, Sadler (2009) argued that

> the SSI movement represents an evolution of the progressive agenda for science education (over STS) in that a framework that explicitly considers the psychological and sociological development of learners is central to SSI-based education. One of the strengths of work completed under the banner of SSI has been the explicit focus on learner negotiation of the ethical aspects of controversial science issues and the attention paid to character development.

Negotiating socioscientific issues, involves understanding the scientific content related to a social issue, processing information regarding the issue, considering moral and ethical values, and developing a position on the issue (Sadler, Chambers, & Zeidler, 2004). Socioscientific issues have become an important pedagogical and curricular approach in science education due to their key role in the advancement of scientific literacy (Bingle & Gaskell, 1994; Driver, Leach, Millar, & Scott, 1996; Zeidler & Keefer, 2003). Levinson (2008) reported that socioscientific issues drive much of the content in science courses around the world. He added that "prominent reasons given for the inclusion of such [socio-scientific] issues tend to link them to scientific literacy, to focus on the need for scientific knowledge, to help in decision-making and to sustain democracy" (p. 856). Socioscientific issues have been considered an important curricular approach for democratic citizenship through science education because of their potential for bridging school science and students' lived experiences (Kolsto, 2001; Zeidler, Sadler, Simmons, & Howes, 2005). The literature has highlighted SSI approaches for an essential reform to science curricula, focusing on controversial and socially relevant issues (Davies, 2004; Hodson, 2003; Kolsto, 2001; Lee & Witz, 2009; Levinson, 2006; Ratcliffe & Grace, 2003; Sadler, Barab, & Scott, 2007; Zeidler, 2003).

Several science educators have strongly argued using socioscientific issues in teaching science, but these arguments bring concerns that using socially relevant curricula can threaten the integrity of traditional science curriculum and students' understanding of basic science concepts (DeBoer, 1991). In contrast, SSI advocates argued that many concepts in science classrooms are translated, simplified, and abstracted from their contextual origins causing students to have difficulties understanding these classroom concepts (Sadler, 2009). Even though science itself has direct ties with society, socioscientific issues specifically hold a unique standing as they are informed by not only science but also social, cultural, political, and ethical concerns (Sadler & Ziedler, 2003). Therefore, socioscientific issues in science education provide a great opportunity to connect abstract science concepts with a context that is relevant to students' lives (Berkowitz & Simmons, 2003; Sadler, 2009). Because learning experiences in socioscientific contexts involve scientific processes in situations similar to those of students experience as citizens and future decision-makers in society, they have a great potential to enhance students' science learning experiences (Sadler, 2011), which need to be enriched for the enhancement of student learning (Dewey, 1938).

The integration of socioscientific issues in science classrooms provides a unique opportunity for teaching students the democratic nature of science. Science in formal school environments has usually been described as authoritative, monolithic, fixed, and finished (Fensham, 1997; Yager, 1992). Ravetz (2002) criticized this portrayal as follows:

> The inherited institution of science education is one of the last surviving authoritarian social-intellectual systems in Europe. Its teaching style is dogmatic, and it is designed around the social function of training and selecting future scientific research workers. By example and exclusion, students absorb the lesson that every real scientific problem has only one simple, correct answer. This mindset can be seriously disabling for all who eventually deal with science-related policy problems. (p. 109)

Teaching science in socioscientific contexts can help students recognize its tentative and organic nature, as well as being “a way of knowing that has freed us from the shackles of received wisdom” (Osborne, MacPherson, Patterson, & Szu, 2012, p. 4).

Literature Review

Socioscientific issues. The role of the citizen in a society is to be involved in resolving controversies in societal issues caused by the interactions between science, technology, and society (Patronis, Potari, & Spiliotopoulou, 1999). Therefore, “education must be transformed from the passive, technical, and apolitical orientation that is reflective of most students’ school-based experiences to an active, critical, and politicized life-long endeavor that transcends the boundaries of classrooms and schools” (Kyle, 1996, p. 1). Because more than 90% of societal issues are grounded in science and technology (Yager, 1987), students should be able to negotiate the societal issues related to the applications of science and technology for a well-rounded citizenship (Sadler, Chambers, & Zeidler, 2004).

Sadler (2011) highlighted that “it is not enough for science educators to teach science content if what we really want to do is help students become better able to negotiate the challenges of science as it is represented in the real issues of society” (p. 4). In response to these calls, controversial socio-scientific issues and decision-making procedures related to these issues have been included in the science curriculum in industrialized countries. Socioscientific issues are situations having conceptual and/or procedural links to science and a social significance as identified by society (Fleming, 1986; Kolstø, 2001; Patronis, Potari, & Spiliotopoulou, 1999; Sadler, 2004; Sadler, 2009; Sadler & Zeidler, 2003; Zeidler, Walker, Ackett, & Simmons, 2002). These problems are subject to different social factors such as politics, economics, and ethics (Sadler, 2011), various social domains, and areas of open inquiry (Klosterman, Sadler, & Brown, 2012). The solutions of these issues are multiple and uncertain, and are necessarily influenced by scientific concepts and theories, as well as social factors such as political, economic, humanistic and ethical (Klosterman, Sadler, & Brown, 2012). Several researchers (e.g. Klosterman & Sadler, 2010; Sadler, 2009; Zohar & Nemet, 2002) describe socioscientific issues as ill-structured problems, which "do not have single correct answers, cannot be meaningfully addressed through memorized or well-rehearsed responses and are not subject to relatively simple algorithms" (Sadler, 2009, p. 11).

Levinson (2008) reported that socioscientific issues drive much of the content in science courses all around the world and "prominent reasons given for the inclusion of such [socioscientific] issues [in the science curriculum in industrialized countries] tend to link them to scientific literacy, to focus on the need for scientific knowledge, to help in decision-making and to sustain democracy" (p. 856). Interest in socioscientific issues in both teaching and research in science education has grown dramatically over the last decade (Sadler, 2011, p. 355). Socio-scientific issues have been highlighted in the field of science education to make science content more relevant to students' lives (Pedretti, 1999).

Science educators (e.g. Kolsto, 2001; Mertens & Hendrix, 1990) frequently highlighted that students should be sufficiently informed to understand the social consequences of scientific and technological developments. The central goal of science education should be "to equip students with the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental, and moral-ethical concerns" (Hodson, 2003, p. 653). Socioscientific issues serve as a pedagogical strategy which stimulates "individual intellectual development in morality and ethics as well as awareness of the interdependence between science and society" (Zeidler et al., 2005, p.360). "SSI instruction has shown great promise, not just in getting teachers and their students interested in science content, but also in showing them the importance of science to society and helping them become better critical thinkers and citizens" (Cook, 2012, p. 23). Research in SSI has documented student gains in science content knowledge (Applebaum, Barker, & Pinzino, 2006; Barab et al., 2007; Klosterman & Sadler, 2009; Kolstø et al., 2006; Sadler & Zeidler, 2004; Sadler, Barab, & Scott, 2007; Zohar & Nemet, 2002), argumentation skills (Jimenez-Aleixandre & Erduran, 2007; Kolstø et al., 2006; Sadler & Donnely, 2006; Zeidler & Sadler, 2011), understanding of the nature of science (Liu, Lin, & Tsai, 2011; Khishfe & Lederman, 2006; Walker & Zeidler, 2007; Wu & Tsai, 2011; Zeidler, Walker, Ackett, & Simmons, 2002), interest and motivation (Albe, 2008; Bingle & Gaskell, 1994; Dori, Tal, & Tsaushu, 2003; Harris & Ratcliffe, 2005; Zeidler & Keefer, 2003), and socioscientific reasoning (Laius & Rannikmae, 2011; Testa, 2013).

Skills such as critical thinking and problem solving are essential when considering SSI learning. Research related to technology integration in science education (e.g. Chanlin, 2008; Guzey & Roehrig, 2009; Novak & Krajcik, 2006; Pedroni, 2004) has shown that effective use of technology in science classrooms promotes development and use of these sorts of skills. Therefore, technology in science classrooms shows a great promise for effective SSI-based instruction.

Technology integration. Technology is "the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment" (Encyclopedia Britannica Online, 2004). Researchers (e.g. Prensky, 2008; Trilling & Fadel, 2008; Wagner, 2008) describe technology in educational contexts as a learning tool that enhances students' authentic learning experiences and their critical thinking, problem solving, creativity, collaboration, and communication skills. "The International Society for Technology in Education (ISTE, 2008) emphasized the need for teachers to gain the fundamental knowledge, skills, and attitudes for incorporating contemporary tools and resources within their classrooms to maximize student learning" (Sadaf, Newby, & Ertmer, 2012, p. 172). In the last few decades, the educational systems around the world have been built on the idea that a new culture of learning is happening all around us where technology is constantly creating and responding to change (Thomas & Brown, 2011).

Recently, computers in classrooms and media labs have made technology more accessible to teachers and students (Smerdon et al., 2000). However, the integration of technology in instruction is limited. Teachers with vast technology resources in their schools use these technologies mostly for administrative and organizational purposes (Kurt, 2010; Palak & Walls, 2009). Technology integration is mainly limited to computer programming courses, and teachers rarely integrate technology into the instruction of core curriculum subjects (Kurt, 2010). A recent survey (Project Tomorrow, 2008) reported that 51% of teachers who claimed that they used technology to facilitate student learning described their use of technology as asking students to complete their assignments using computers and assigning practice work at the computer.

The quantity of technology use in the classroom has almost no impact on student achievement, but high-quality technology integration is beneficial to students academically (Lei, 2010). To provide high-quality technology integration, students need to be active users of technology instead of passively receiving instruction through technology devices. In other words, the emphasis has to be learning *with* technology rather than learning *from* technology (Niles, 2006). Shapley et al.'s (2010) study showed that teachers using classroom technologies, such as interactive white boards, were less successful as compared to teachers who actually encourage their students to use these technologies actively.

Doering, Hughes, and Huffman (2003) reported that only 3% of teacher graduates felt well prepared for integrating technology into their instruction, while 11.3% of teachers nationwide felt that they had advanced technology integration skills. A more recent study showed that despite their proficiency in using technologies, teachers are not prepared enough to use these technologies for educational purposes (Lei, 2010). Ogwu and Ogwu (2010) argued that the reason teachers do not integrate technology in their classrooms is that they lack the skills needed to use the equipment. Several researchers (e.g. Almekhlafi & Almeqdadi, 2010; Dede, 2008; Ertmer, 2005; Ertmer & Ottenbreit-Leftwich, 2010; Maigo & Mei-Yan, 2010; Varma, Husic, & Linn, 2008) addressed the need for professional development opportunities for teachers to integrate technology into their classrooms successfully, which usually result in increased student achievement (Varma, Husic, & Linn, 2008). In addition, teachers who receive professional development related to technology integration increase their levels of self-efficacy in using technology in classrooms (Inan & Lowther, 2010; Niederhauser & Perkmen, 2008).

Research Context: Water Sustainability and Climate (WSC)

The objective of promoting sustainability in education is consistent with the socioscientific issue (SSI) approach as they both highlight the necessary interlink between science and society (Laws et al., 2004). Many SSIs are classified as sustainability issues, which is perhaps one of the most important themes nested within the SSI construct (Klosterman, Sadler, & Brown, 2011). The literature in science education indicated that in order to teach sustainability in science classrooms, SSI approaches need to be formally included into science curriculum and classroom instruction (Tytler, 2011). In this section, an overview of the sustainability-focused professional development program used as the setting for the three research studies.

The Minnesota River Basin (MRB) is a watershed where natural and human-induced changes have converged within a central landscape to exhibit a large and diverse set of water, sediment, and biotic responses to change. It has long been a site of focus for researchers seeking ways to stem the erosion that degrades water quality while being responsive to agricultural needs. The river basin has been one of the most polluted rivers in the nation, with sediment and nutrients being the primary pollutants of concern. The flat agricultural lands and steep riverbanks that rapidly erode are the main reasons for the pollution in the river. The sources of change in the MRB are listed as follows: (1) natural geological change, (2) climate change (e.g. increased precipitation), and (3) land use change (conversion from prairie, wetland and forest to row crop agriculture) (Resilience Under Accelerated Change [REACH], 2015).

A large Water Sustainability and Climate (WSC) grant from the National Science Foundation (NSF) is funding a multi-institutional science team to study how climate, water, and human land use interact in the watershed. The primary goal of this grant is to develop tools to study similar situations nationwide with potentially global applications.

A secondary goal is to model community-based K-12 educational initiatives designed to heighten awareness of environmental social sustainability issues related to the MRB. The project calls for the development of a SSI-based watershed curriculum implemented in technologically enriched learning environments and the establishment of a framework for water sustainability studies. While immediately focused in the MRB, he developed methodologies, framework, and curriculum are generalizable and could apply to any basin where effective remediation actions require a predictive understanding of the cascade of changes and local amplifications between climatic, human, hydrologic, geomorphologic, and biologic processes.

The Water Sustainability and Climate (WSC) project provides teachers professional development experiences in order to successfully integrate a socioscientific issues approach into their science classes. The educational component of this project, The River Run, is an on-going professional development program striving to provide secondary science teachers a context for teaching local socioscientific issues related to a large river basin watershed in technology rich learning environments. Five secondary science teachers and one social studies teacher from schools within the basin participated in yearly week-long intensive professional development workshops to investigate different socioscientific issues related to the MRB in addition to receiving academic support throughout the year. The workshop focused on improving teachers' understanding of the science and social components of these issues through field experiences and interaction with content experts. The goals of this project are (1) to model community-based K-12 educational initiatives designed to heighten awareness of environmental social sustainability issues, and (2) to provide teachers professional development experiences in order to successfully integrate a socioscientific issues approach into their science classes.

During the first year of River Run, the week-long professional development workshop was dedicated to developing content and context for learning and teaching about socioscientific issues in the Minnesota River Basin. During the workshop, subject matter experts engaged the teachers in learning experiences and discussions about scientific perspectives on water sustainability issues in the Minnesota River. In addition, the professional development team modeled different types of classroom activities in teaching SSI and worked with the teachers during the week in thinking through curriculum questions and exploring how the teachers might address different watershed issues in their courses.

To address the goal of implementing SSI within technology rich learning environments, the professional development program drew on the framework suggested by the International Society for Technology in Education (ISTE) for technology related professional development programs (see Figure 1.1). To respond to the demands for effective technology related professional development models, ISTE proposed a professional development model that integrates context, collaboration, and technology. This framework includes three critical elements. The first element is effective coaching. Coaching is an important aspect of professional development programs that has shown great potential to improve the knowledge, skills, and practice of teachers, thus enhancing students' academic achievement (Beglau et al. 2011). Research has shown that if teachers have access to coaching and mentoring opportunities, they are more likely to integrate technology into their instruction (Strudler & Hearrington, 2009). The second element is collaboration through online learning communities. Beglau et al. (2011) highlighted the potential of intensive, ongoing, learning-focused professional development and connecting peers with purpose via social learning. The last critical element of this framework is technology rich learning experiences. Using coaching methods, learning communities, and technology as power partners in order to tap into existing resources, experts and support structures can together provide better professional development experiences for teachers, which ultimately increase students' academic achievement (Beglau et al, 2011).

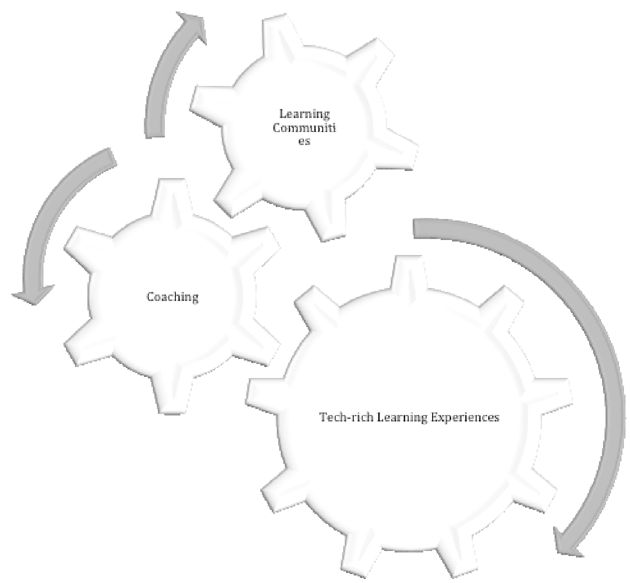

Figure 1.1. Technology rich professional development framework (ISTE)

Minnesota River Basin (MRB) as a Controversial SSI. The Crick Report described a controversial issue as "an issue about which there is no one fixed or universally held point of view. Such issues are those which commonly divide society and for which significant groups offer conflicting explanations and solutions" (Crick, 1998, p. 56). Socioscientific controversies are extended argumentative engagements in socially significant issues and communication practices in both scientific and nonscientific domains (Stewart, 2009). Based on his extensive review of the literature, Levinson (2006) listed three characteristics included in any definition of controversial issues. These characteristics are: "(1) people start from different premises, hold different key beliefs, understandings, values, or offer conflicting explanations or solutions that are rationally derived from the premises; (2) it involves a substantial number of people or different groups; and (3) the issue is not capable of being settled by appeal to evidence" (p. 1204). Despite the agreement on the fact that sediment and nutrients are the primary pollutants of concerns in the Minnesota River Basin, people and groups involved in the issue hold a variety of different key beliefs, values, and perspectives about the sources of change in the river basin and possible solutions to the problem. Therefore, as suggested by Levinson (2006), the scientific arguments and evidences have not been capable of settling the controversy, or changing the minds of those different people and groups.

Research Design and Methodology

Qualitative research. Qualitative research traditions often offer a richer understanding in educational contexts (Jacob, 1987). The research studies in this dissertation employ a qualitative approach with a pragmatist worldview. Creswell (1998) described pragmatism as an approach that not only focuses on what works and outcomes to address research problems, but it also gives the researcher freedom of choice in methods and a number of approaches for collecting and analyzing data. The intent of conducting qualitative research is to "explore human behaviors within the contexts of their natural occurrence" (Hatch, 2002, p. 7) and to focus on "process, meaning, and understanding" (Merriam, 1998, p. 8). According to Bogdan and Biklen (2003), qualitative research has five characteristics: (1) naturalistic- assuming that human behavior is significantly influenced by the context in which it occurs; (2) descriptive- description in the form in which data are collected; (3) concern with the process instead of only outcomes; (4) inductive- building understanding as the research progresses; and (5) meaning- how people make sense of their experiences. Researchers conducting qualitative studies commit extensive time in the field and data analysis in order to provide a detailed view of the natural setting (Creswell, 1998).

Case studies. Case is generally described as “a phenomenon of some sort occurring in a bounded context” (Miles & Huberman, 1994, p. 25). Case study research, like other forms of qualitative research, is a form of interpretive research (Merriam, 1998; Stake, 1995). It has the ability to bring deep understanding of a case, and to provide intrinsic knowledge and details regarding a problem or issues of interest to a researcher (Stake, 1995). Yin (2003) described case study as an empirical inquiry that investigates a contemporary phenomenon which occurs within its real life authentic context, especially when the boundaries between phenomenon and context are not clearly evident. It focuses on contemporary events but does not require control of behavioral events (Yin, 2003). Case study is considered a strong methodology to explore a single entity or phenomenon by using diverse data collection sources and procedures (Stark & Torrance, 2005; Creswell, 1994).

The research studies in this dissertation are designed to gain insights about the experiences of secondary school teachers and their students within the context of a local controversial socioscientific issue. Using the descriptive type of case study (Yin, 2003), these studies aim to describe phenomena and the real-life context in which they occur.

According to Merriam (1998), descriptive case studies in education are useful in "presenting basic information about areas of education where little research has been conducted. Innovative programs and practices are often the focus of descriptive case studies in education" (p. 38).

Case study research design is selected for the studies in this dissertation for a number of reasons. According to Yin (2003), a case study design is more appropriate when: (1) the study aims at answering 'why' and 'how' questions; (2) the researcher has no control over the behavior of those involved in the study; (3) contextual conditions need to be covered due to their relevance to the phenomenon under study; and/or (4) the boundaries are not clear between the phenomenon and context. In each of the studies in this dissertation, the researcher aimed to answer 'how' questions. Second, the researcher did not have any control over the behavior of participants. Third, the contextual conditions were an integral part of the study because of their significance for the phenomenon studied. Lastly, the boundaries were not clear between the phenomenon and context due to the participants' lived experiences in the socioscientific context.

There are four types of designs for case studies, which are single case (holistic) designs, single-case (embedded) designs, multiple-case (holistic) designs, and multiple-case (embedded) designs (see Figure 1.2). Yin (2003) argued that the primary distinction in designing case studies is between single- and multiple-case studies. The first and third studies in this dissertation were multiple case studies, while the second study was a single case study. The five rationales for a single case study are those where the case represents a critical case in testing a well-formulated theory, an extreme or a unique case, the representative or typical case, the revelatory case, or the longitudinal case (Yin, 2003).

Because the phenomena investigated in the second study was extreme and unique (a science and a social studies teacher co-teaching an elective class that was free of any academic standards), a single case study approach was employed in this study. On the other hand, the rationale for multiple-case designs derives directly from the understanding of literal and theoretical replications.

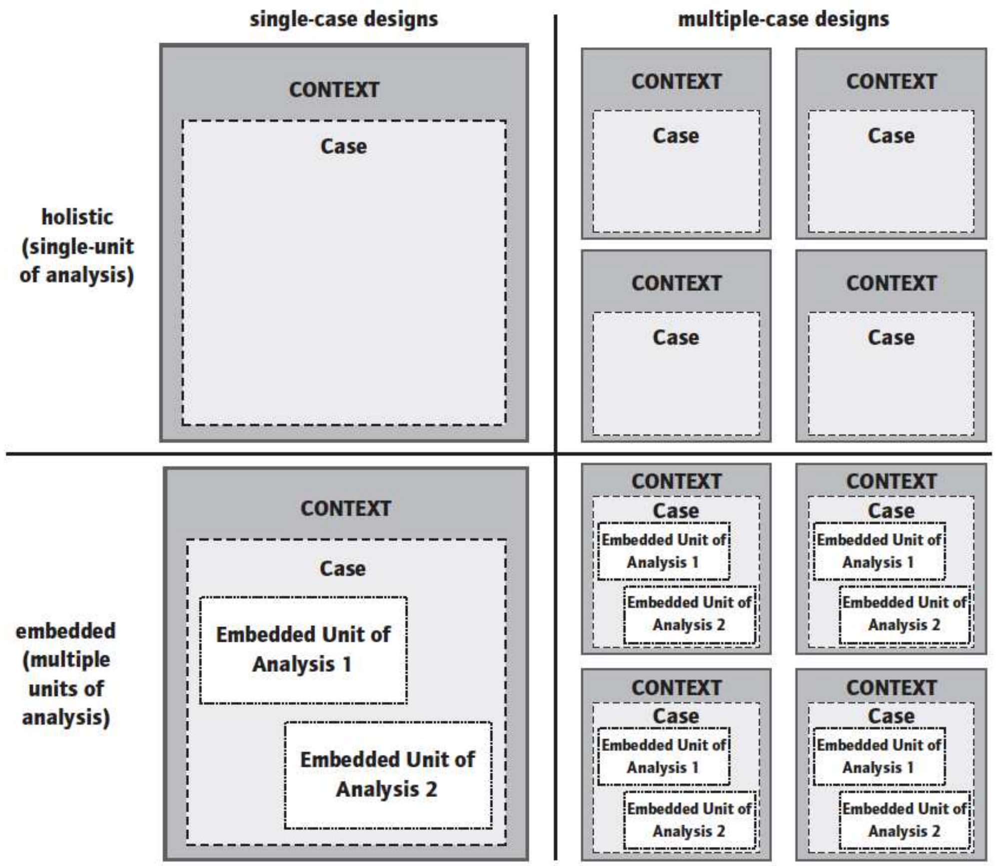

Figure 1.2. Basic types of designs for case studies (Yin, 2003)

Validity and Reliability

Validity. Eisner and Peshkin (1990) described validity as "the congruence of the researcher's claims to the reality his or her claims seek to represent" (p. 97). There were three kinds of validity considered in this study.

Construct validity. The structural validity of this study was granted by employing more than one data collection method. Also, the results were discussed with the other members of the research team who were also present at the research site during the study.

Internal validity. Creswell (2007) recommends using at least two of the possible validation strategies. In this study, four different validation strategies were employed. The first validation strategy was the prolonged engagement of the researcher in the field in order to learn from the culture and build trust with the participants. The second one was triangulation, which is considered one of the strongest validation methods. A variety of data sources were used in this study to answer each research question. The codes that emerge within one data source were considered with other data sources to support or disprove the validity of the naturalistic code, essentially triangulating the code against multiple data sources. The third validation strategy used in this study was to provide readers rich and thick descriptions in order to increase the level of transparency. The readers will be able to draw their own conclusions based on the descriptions provided by the researcher, and then they will be able to compare their conclusions with those of the researcher. The last validation strategy was discussion of the data collection and analysis processes with the experts in the field.

External validity. The approach that was employed in this study to improve external validity was proximal similarity (Trochim, 2000). The ways the context of this study and others differ was described in detail by providing data about the degree of similarity between various groups of people, places, and times.

Reliability. According to Joppe (2000), reliability is “the extent to which results are consistent over time and an accurate representation of the total population under study … and if the results of a study can be reproduced under a similar methodology” (p. 1).

Internal reliability. The internal reliability in this study was provided with these actions: (1) The data coming from qualitative sources was presented with the direct quotes of the participants; (2) the data coming from the researcher’s perspective such as observations was triangulated with the other data.

External reliability. To provide external reliability in this study, two criteria was considered: (1) The participants of the study were described in detail to help other researchers decide their sample; and (2) research design, instructional intervention, data collection and analysis, and results were described very clearly.

Chapter 2: Case Studies of Secondary School Science Teachers Designing Technology Rich SSI-Based Instruction

Introduction

Leading educational reformers argue that educational reforms depend on teachers' beliefs and practices and thus, the success of these reforms are significantly connected to the efforts of teachers (Fullan, 1982; Crandall, 1983). Cuban (2004) states that "teachers are gatekeepers to school and classroom improvements. Their perceptions, beliefs, knowledge, attention, motivation, and skills come into place when policies from state, federal, and district levels arrive at the schoolhouse steps" (p. 106). Teachers are central to any educational outcome and their epistemological and pedagogical beliefs guide their practices in the classrooms (Zeidler, 2014). Furthermore, a teacher's self-understanding, larger values, social awareness, and worldview are "important factors affecting his/her teaching practice and personal and professional growth and development, [thus, they demonstrate] numerous details of how that teacher would be related to new educational approaches" (Witz, Goodwin, Hart, & Thomas, 2001, p. 198). Even though teachers do not directly decide what is included in the standards, they are the ones who decide which standards are actually taught (Spillane & Callahan, 2000).

Socioscientific issues are personally relevant, controversial, and ill-structured scientific problems with social ramifications that require scientific, evidence-based and moral reasoning (Zeidler, 2014). Current reforms such as Science for All Americans (AAAS, 1989; 2009), the Benchmarks for Science Literacy (AAAS, 1989; 1993), and the National Science Education Standards (National Research Council, 1996) have called for teachers to address controversial socioscientific issues for enriching the scientific literacy of students to develop their abilities to intelligently engage in public discourse and social and political decision-making processes on matters involving science and technology. However, teaching controversial issues has always been challenging for teachers (Dillon, 1994; Osborne, Duschl, & Fairbrother, 2002) although addressing these issues in the context of science has been one of the main focuses in science education since the beginning of the Science, Technology, and Society (STS) movement in the 1970s (Levinson, 2006).

In science education, research related to technology integration (e.g. ChanLin, 2008; Guzey & Roehrig, 2009; Novak & Krajcik, 2006; Pedroni, 2004) has shown that effective use of technology in science classrooms promotes students' critical thinking and problem solving skills, which is critical when considering SSI instruction. Considering the challenges of teaching controversial SSI and the potential of technology in teaching SSI, this study investigated secondary school science teachers' experiences of designing and implementing technology rich SSI-based instruction, as well as the impacts of contextual factors (e.g. their beliefs) on those experiences. Therefore, the following research questions were addressed in this study:

- How do secondary school teachers experience designing and implementing technologically enriched SSI-based instruction?
- How do the contextual factors play a role in secondary school teachers' experiences of designing and implementing technologically enriched SSI-based instruction?

Literature Review

Socioscientific issues. An important role of a citizen in society is to be involved in resolving controversies in societal issues caused by the interactions between science, technology, and society (Patronis, Potari, & Spiliotopoulou, 1999). As Sadler (2011) highlighted, “it is not enough for science educators to teach science content if what we really want to do is help students become better able to negotiate the challenges of science as it is represented in the real issues of society” (p. 4). The central goal of science education should be “to equip students with the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental, and moral-ethical concerns” (Hodson, 2003, p. 653). In response to these demands, controversial socioscientific issues and decision-making procedures about such issues have started to be included in the science curriculum in industrialized countries. Levinson (2008) reported that socioscientific issues drive much of the content in science courses all around the world, and “prominent reasons given for the inclusion of such [socioscientific] issues [in the science curriculum in industrialized countries] tend to link them to scientific literacy, to focus on the need for scientific knowledge, to help in decision-making and to sustain democracy” (p. 856). Interest in socioscientific issues in research in science education has grown dramatically over the last decade (Sadler, 2011) as these issues have been highlighted in the field of science education to make science content more relevant to students’ lives (Pedretti, 1999).

Sadler (2004) describes socio-scientific issues as controversial social problems with conceptual and/or procedural links to science. These problems are subject to various social domains such as politics, economics, and ethics, as well as areas of open inquiry

(Klosterman, Sadler, & Brown, 2012). The solutions of these issues are multiple and uncertain, and are necessarily influenced by science concepts and theories as well as social factors such as political, economic, humanistic and ethical aspects (Klosterman, Sadler, & Brown, 2012). Socioscientific issues serve as a pedagogical strategy that stimulates "individual intellectual development in morality and ethics as well as awareness of the interdependence between science and society" (Zeidler et al., 2005, p.360). Cook's (2012) extensive review of the empirical literature showed that "SSI instruction has shown great promise, not just in getting teachers and their students interested in science content, but also in showing them the importance of science to society and helping them become better critical thinkers and citizens" (p. 23).

The literature in science education has documented the significant relationships between teacher beliefs and teaching practices (Bryan & Atwater, 2002; Haney, Czerniak, & Lumpe, 1996; King, Shumow, & Lietz, 2001; Lederman, 1992; Tobin & LaMaster, 1995). Teachers' motivations for teaching SSI were mostly personal, including their values, ideals, philosophies, or personal concerns instead of the major reform efforts (Lee & Witz, 2009). The literature in science education indicates that although teachers exhibit positive attitudes for using controversial socioscientific issues in their science classrooms, only a small percentage of them actually incorporate SSI content into their science curricula on a regular basis (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006; Lee & Witz, 2009). Sadler et al. (2006) examined teacher perspectives on the use of SSI and on the inclusion of ethics in SSI instruction. They found five profiles that captured views and practices in SSI:

Profile A comprising teachers who embraced the notion of infusing science curricula with SSI and cited examples of using controversial topics in their classes. Profile B supported SSI curricula in theory but reported significant constraints which prohibited them from actualizing these goals. Profile C described teachers who were non-committal with respect to focusing instruction on SSI and ethics. Profile D was based on the position that science and science education should be value-free. Profile E transcended the question of ethics in science education; these teachers felt very strongly that all education should contribute to their students' ethical development. (p. 353)

Due to the significant relationship highlighted between teachers' beliefs and their practices, this study investigates secondary school teachers' experiences of teaching SSI, as well as the way their beliefs influence teaching practices.

Technology integration and technological, pedagogical, and content knowledge. In the last few decades, educational systems all around the world have been redesigned around the idea that a new culture of learning is happening all around us where technology is constantly creating and responding to change (Thomas & Brown, 2011). The technology integration in US classrooms has been increasing significantly due to the policy demands that encourage technology instruction in K-12 settings (Hughes, 2004). Recently, the United States Department of Education (2010) has recognized technology as a vehicle for schools to foster more authentic and engaging learning environments with their potential impact on student achievement. The plan to improve education encourages teachers to integrate technology into their instruction in order to create learning environments that meet the diverse needs of all students (United States Department of Education, 2010). In the National Education Technology Standards for

Teachers (NETS-T, 2008), teachers in the 21st century are described as "facilitators of collaborative student learning through a wide variety of media-rich, interactive, and authentic learning experiences" (International Society for Technology in Education [ISTE], 2008).

The National Science Education Standards [NSES] encouraged science teachers to apply various technologies to support student inquiry (National research Council [NRC], 1996). Utilizing technology tools in science classrooms helps students understand the way scientists work (Novak & Krajcik, 2006, p. 76). When technology tools are used appropriately and effectively in science classrooms, students not only learn the science content better (Bell & Bull, 2008; Bull & Bell, 2008), but they also actively construct their knowledge and improve their critical thinking and problem solving skills (Trowbridge, Bybee, & Powell, 2008). In order to effectively integrate technology in their instruction, teachers need to decide the appropriate technologies for specific topics (McCrory, 2008), and choose sound pedagogies that undergird these technologies (Bull & Bell, 2008).

In recent years, many researchers in the field of educational technology have been focused on the role of teacher knowledge on technology integration (Hughes, 2005; Koehler & Mishra, 2005, 2008; Mishra & Koehler, 2006). As a result, the TPACK framework has emerged as a knowledge base for teachers incorporating technology in their instruction (Guzey & Roehrig, 2009). Koehler and Mishra (2009) stated that the development of TPACK by teachers is critical for effective teaching with technology. They described their TPACK model as follows:

At the heart of good teaching with technology are three core components: content,

> pedagogy, and technology, plus the relationships among and between them. The interactions between and among the three components, playing out differently across diverse contexts, account for the wide variations seen in the extent and quality of educational technology integration. These three knowledge bases (content, pedagogy, and technology) form the core of the technology, pedagogy, and content knowledge (TPACK) framework (p. 62).

Theoretical Framework

Controversial issues are seen as "an issue about which there is no one fixed or universally held point of view. Such issues are those which commonly divide society and for which significant groups offer conflicting explanations and solutions" (Crick, 1998, p. 56). Levinson (2008) listed three typical characteristics of controversial issues as follows:

> (1) people start from different premises, hold different key beliefs, understandings, values, or offer conflicting explanations or solutions that are rationally derived from the premises (Crick, 1998; Oulton, Dillon, & Grace, 2004; Wales & Clarke, 2005); (2) it involves a substantial number of people or different groups (Bailey, 1975; Crick, 1998; Inner London Education Authority, 1986); and (3) the issue is not capable of being settled by appeal to evidence (Stenhouse, 1970; Stradling, 1984; Wellington, 1986) (p. 1204).

Socioscientific issues are described as controversial social problems with conceptual and/or procedural links to science (Sadler, 2004). Highlighting the elements of principal characteristics, Zeidler (2014) described the socioscientific framework as personally relevant, controversial, and ill-structured scientific problems with social ramifications that require scientific, evidence-based and moral reasoning. He also highlighted the integration of ethical components, as well as the virtue and character development as long-term pedagogical goals. The framework (see Figure 2.1) based on Levinson's (2008) characteristics of controversial issues and Zeidler's (2014) characteristics of socioscientific issues drove this study.

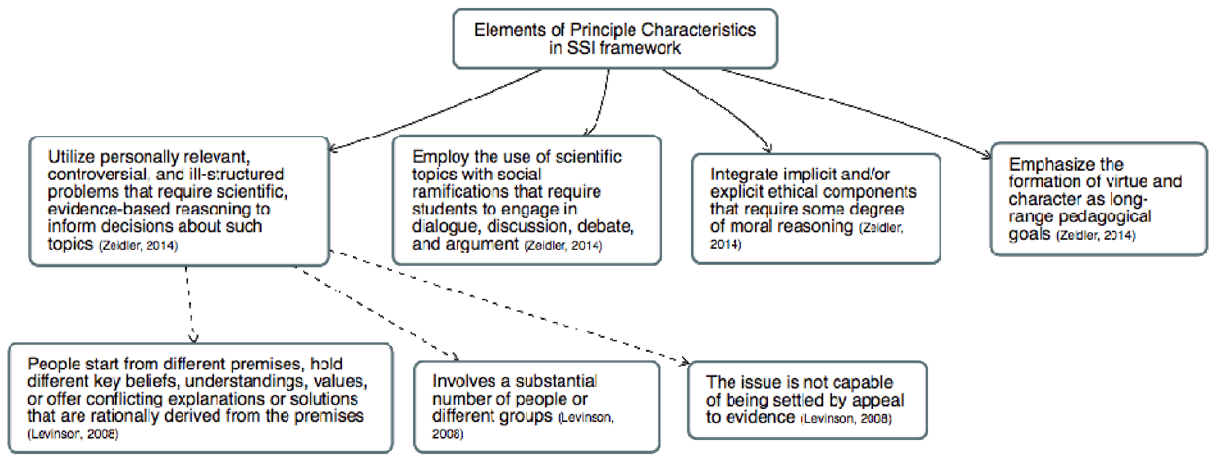

Figure 2.1. SSI Theoretical Framework

Research Context

The Minnesota River Basin (MRB) is a watershed where natural and human-induced changes have converged within a central landscape to exhibit a large and diverse set of water, sediment, and biotic responses to change. The Minnesota River Basin has long been a site of focus for researchers seeking ways to stem the erosion that degrades water quality while being responsive to agricultural needs. The effective remediation actions require a predictive understanding of the cascade of changes and local amplifications between climatic, human, hydrologic, geomorphologic, and biological processes. A large Water Sustainability and Climate (WSC) grant from the National Science Foundation (NSF) is funding a multi-institutional science team study of how climate, water, and human land use interact in the watershed. The primary goal of the WSC grant is to develop tools to study similar situations nationwide with potentially global applications. A secondary goal is to model community-based K-12 educational initiatives designed to heighten awareness of environmental social sustainability issues. The project calls for the development of a socioscientific issue based watershed curriculum to implement in technologically enriched learning environments and establish a framework for water sustainability studies. The developed methodologies, framework, and curriculum are, however, generic and apply to any basin where effective remediation actions require a predictive understanding of the cascade of changes and local amplifications between climatic, human, hydrologic, geomorphologic, and biologic processes.

The educational component of the larger WSC project, The River Run, is an on-going professional development program striving to provide secondary science teachers a context for teaching local socioscientific issues related to a large river basin watershed in technology rich learning environments. Four secondary science teachers and one social studies teacher from schools within the basin participated in yearly week-long intensive professional development workshops to investigate different socio-scientific issues related to the MRB, in addition to receiving academic support throughout the year. The week-long professional development workshop in the first year was dedicated to developing content and the context for learning and teaching about socioscientific issues in the Minnesota River Basin. During the workshop, subject matter experts in water, soil, and climate (WSC) engaged the teachers in learning experiences and discussions about scientific perspectives on water sustainability issues in the Minnesota River. In addition, the professional development team modeled different types of classroom activities in teaching SSI and worked with the teachers during the week in thinking through curriculum questions and exploring how the teachers might address different watershed issues in their courses.

The Study

The purpose of this study is to understand and describe the experiences of three secondary school science teachers while designing and implementing technology rich learning experiences in the context of a local controversial socioscientific issue. Technology-rich learning environments are generally defined as environments where technology-based activities are integrated with curriculum (Tiene & Luft, 2001), which allows learners to use technology as an integral part of their learning process due to the pedagogical stance of teachers (McLeod, 2011). Specifically, the following research questions were addressed:

- How do secondary school teachers experience designing and implementing technologically enriched SSI-based instruction?
- How do the contextual factors play a role in secondary school teachers' experiences of designing and implementing technologically enriched SSI-based instruction?

Research Design

This descriptive case study was designed to gain insights into how secondary school teachers experience designing technology-rich learning environments within the context of a local controversial socioscientific issue. A descriptive case study (Yin, 2003) allows the researchers to describe a phenomenon and the real-life context in which it occurred. Yin (2003) defines a case study as investigating a phenomenon (e.g. teachers' ways of designing and implementing SSI based instruction) which occurs within authentic contexts (e.g. in the secondary schools within a large watershed in the Midwest) especially when the boundaries between the phenomenon and context are unclear. Because the contextual factors for the socioscientific issues addressed in each case were so distinct, each classroom within the context of the community it is located in was represented as its own case and then compared and contrasted to the others in order to understand the experiences of teachers in each setting. Thus, a multiple case study was chosen instead of a single case study as the levels of interest were the experiences of teachers as designers and implementers of the technologically enriched SSI based learning processes.

In order to describe the contexts where the phenomena occurs, Porras-Hernandes and Salinas-Amescua's (2013) three-level context model was employed. The first level, the macro context, relates to social, political, technological, and economic conditions that include the rapid technological developments worldwide, as well as national and global policies. The meso context level includes social, cultural, political, organizational, and economic conditions established in the local community and the educational institution. The last level, the micro context, involves the expectations, beliefs, preferences, and goals of teachers and students as they interact. Since the macro context was not different for each participant, the study emphasized the meso and micro levels that impacted the phenomena for each case significantly.

Participants

Participant teachers of this study were chosen based on their involvement in a National Science Foundation (NSF) funded WSC project. Three secondary school science teachers within Minnesota River Basin were the participants of the study. The teachers (male=2, female=1) represented a range of years of experience from 2-7 years (see Table 2.1). Their teaching assignments were mostly high school grade levels including biology, ecology, environmental science, environmental biology, and earth science, with some teachers assigned to multiple subject areas and grade levels.

Table 2.1.

Information about participant teachers

	Thom	***Amy***	***Jonny***
Age	27-30	24-26	20-23
Teaching Experience	7 years	3 years	2 years
Teaching in Current School	7 years	1 year	2 years
Subjects Currently Teaching	Biology (10th Grade), Environmental Science (11-12th Grade), Earth Science (7-8th Grade), Life Science (7-8th Grade), Anatomy (11-12th Grade)	Algebra-based Physics, Biology, Ecology	Biology (10th Grade), Earth Science (8th Grade)
Subjects Previously Taught	Biology (7 years), Environmental Science (7 years), Life Science (4 years), Earth Science (4 years), Anatomy (3 years)	Physics (3 years), Biology (1 year), Ecology (3 years), Astronomy/Meteorology (1 year)	Biology (2 years), Earth Science (2 years), Earth and Space Science (1 year), Environmental Science (1 year)
Classes/Specific MRB Content	11/12th Grade Environmental Science (MN River Water Quality), 10th Grade Biology (Ecological interactions)	Biology (Ecosystems, nutrient cycles, biological interactions, environmental issues), Wildlife Ecology (Ecosystems, nutrient cycles, water issues, runoff, water cycle)	10th Grade Biology (Ecology)

Degrees Held	Biology (BS), Education	Biology (BA), Secondary Education (BA)	Biology (BA)
Teaching License	5-8th Grade Middle School, 9-12th Grade Life Science	Biology Teaching, Middle School Science, Coaching Certificate	9-12th Grade Life Science

Data Collection

The data collected for this case study took on three different forms: interviews, observational field notes, and reflective journals. Interviewing is described as "the best technique to use when conducting intensive case studies of a few selected individuals" (Merriam, 1998, p. 72), and useful to reveal the insights of participants' beliefs and understanding (Davis, 2003; Irez, 2007). In addition to interviewing, participant observation was chosen in order to "hear, see, and begin to experience reality as the participants do" (Marshall & Rossman, 1995, p. 79) in natural research settings. Therefore, the researcher's presence in the site was less obtrusive as the researcher began to understand the participants' views of their own world (Malinowski, 1961). Lastly, reflective journals were used to complement the observation data in order to find a reflective balance (Clandinin & Connelly, 2000).

There were two different semi-structured interview protocols. The first interview protocol explored participant teachers' epistemological and pedagogical beliefs about socioscientific issues, specifically those related to the MRB (see Appendix B). Even though the interviews were centered around the sediment and chemical load issue in Minnesota River and its tributaries, semi-structured nature of the interviews led the participant teachers to bring other river-related issues that they considered significant. The second interview protocol targeted participant teachers' technological, pedagogical, content knowledge (TPACK) in teaching socioscientific issues and how their classroom practices revolved around this knowledge (see Appendix C). In addition, the observation data from each participant teacher's classroom with the complementary reflection journals was included to support and validate the primary data sources. Each classroom was visited 3-6 times during the academic year. The researcher contacted the participant teachers to determine the times to observe their classes in order to make sense of their SSI-based instruction. The researcher recorded his observations during the class, as well as before and after the class. In addition, the researcher wrote reflection journals after each observation to complement the observation data in order to find a reflective balance (Clandinin & Connelly, 2000).

Data Analysis

Qualitative data analyses were done through the use of NVivo 10.0 software. Thematic analyses of data were done via this qualitative analysis software. Spradley (1979) discussed several techniques to identify themes which include examining dimensions of contrast for several domains to find similar dimensions, doing a componential analysis using cover terms of all the domains uncovered, and making a schematic diagram of relationships among domains. The data analysis procedure in this study occurred in three stages: (1) open coding, (2) identification of patterns and categories, and (3) building themes. In the open coding process, a selective reading approach was used by reading the data several times in order to explore the codes that were particularly essential or revealing about the phenomenon being described (van Manen, 1990). After gathering all the open codes, main ideas emerged as patterns. These patterns represented each participant's beliefs and classroom practices of SSI integration. Lastly, the researcher examined the patterns in each individual case to find common themes that were used in cross case analysis.

The Cases

In this section, the cases of the three teachers are presented. Each case includes the social, cultural, and economic conditions established in the local community and the educational institution (meso context level), the expectations, beliefs, preferences, and goals of the participant teachers (micro context level), and the instructional experiences of those teachers during the academic semester.

Case I: Thom.

The community. Thom lives in a rural community located in the southern part of a Midwestern state. It is well watered and drained by a major river and its two tributaries. The population of the community has been decreasing since the 1960s. This pattern is projected to continue over the next few decades. Thom described farming as the longstanding economical driver of the community, as well as the transformation of agriculture over the last 25 years. His statements highlighted the takeover of corporate farms:

> *The main thing that drives our economy out here is agriculture. The thing that has changed maybe in the last 25 years is the size of the farms. 25 years ago, there were a lot of small farms. Now, you have less small farms, less people doing the farming, but the people that are doing it now are mostly doing in larger scales. #Semi-structured teacher interview II*

The Minnesota River and two tributaries pass through Thom's town. Recently, there have been two main issues people in the town have experienced related to the river. The first one was a dam removal conducted by the Department of Natural Resources (DNR) almost a year before this study was conducted. And, the second one was various flooding events that occur almost every spring.

The school and classroom. Thom's school district has experienced a 30-40% decrease in enrollment in the last decade. The school serves students in grades 6 through 12. Thom's environmental science class is comprised of 26 students (14 female and 12 male) including eight students with special needs supported by a paraprofessional. Due to his extended knowledge of the environment, forestry, and agriculture, the paraprofessional frequently helped Thom during instruction. Thom's classroom was a traditional science room with an additional space for teachers to use as an office. The classroom was arranged for students to work in groups with a smart board connected to a desktop computer that Thom frequently used. There was an iPad cart at the back of the classroom, which students could use in and out of class.

Thom's teaching background. Thom is a very active member of his community, and he has been an important actor in decision-making processes for his school and community. He is very involved in programs outside of science class and committed to positive growth in both the school environment and his community. As he plans his instruction, Thom tries to use different teaching strategies in order to address the needs of students with different learning styles. Overall, he is quite confident trying new instructional strategies, as well as newly introduced technologies. Thom specifically noted that he is not the kind of a teacher who lectures all the time. He described his teaching style as follows:

> *So, as I plan my units, I try not to do same thing over and over again…I am not a sit down and take notes, here is the worksheet. I hate that. I hate grading worksheets, too. And, I really I had teachers I don't know if I had learned anything from the worksheets. I've learned here is your answer. I did not really learn the thing. #Semi-structured teacher interview II*

Thom's beliefs.

Beliefs about the issues around the river basin. Being an active member of his community and focusing on community-based issues in his classes, Thom was well aware of and involved in the social and environmental changes around his community. He recognized the complexity of environmental issues and the necessity of taking a multi-perspective approach in order to understand and solve them. Thom added that the involvement of different interest groups required people with a variety of different positions putting their heads together to solve problems:

> *I think the big thing is because it's so complex. I don't think – the one thing that I've come out of here with is that this system is very dynamic. It isn't just one thing or another… It's going to take a lot of people putting their heads together to solve. #Semi-structured teacher interview I*

Growing up on a farm and talking with the farmers in his community, he was usually supportive of farmers even though he did not ignore the role of farmers in adding more sediment and chemicals into the river system. He empathized with farmers by recognizing their feelings about the bad reputation they have in their communities,

> *You know because farmers don't want to have a bad name for what's going on, they wanna be good stewards on the land. Growing up on a farm and talking with a few farmers in the area, they're proud…They feel that they do a fairly good job already and they don't like the finger pointing at them. #Semi-structured teacher interview I*

He believed that farmers had recently worked hard to minimize the runoff from their fields. In order to support his perspective about farmers, he provided examples of their efforts in his community such as participation in the Future Farmers of America (FFA) program in order to improve their agricultural practices.

To support the famers' side of the sediment and chemical load issue in the river, Thom used two different types of arguments: the conflict between the scientists studying the Minnesota River Basin and his own observations that the water coming from the drainage tiles gets to the river faster than it used to, which could indicate a positive change in farming practices:

> *Although there has been a lot of – you look at the drainage of land on top of the less – seeing less and less shallow water and marshes. The water gets to the river a lot faster. Even though there might be runoff from the farmer's field directly, they do have some role in the water getting there faster. #Semi-structured teacher interview I*

Even though he often supported farmers, Thom also claimed that people living in cities have the right to say no to spending tax dollars on an issue where farming activities in rural towns are to blame.

In addition to farmers, Thom also shared his point of view about the other actors taking part in the issues around the river basin. For example, he believed that despite their critical position on the issue, policy makers were not fully able to understand those issues because they almost never visit farm country and make observations firsthand. Furthermore, he recognized the fact that the businesses owned by policy makers could potentially impact their decision-making. However, he believed that the government would eventually make the right decision. Lastly, Thom believed that the environmental agencies are the most neutral and unbiased actors in the scenario because they have no stake unlike the other actors such as farmers and local residents in the community:

> *I believe in the environmental agencies. I think they go with the most unbiased information. Their job is to look at the issue and nothing more than that. They don't really have a stake they have their own things they would like to see that fits their agenda the best. #Semi-structured teacher interview I*

Beliefs about science. Overall, Thom was quite skeptical about the research going on around the Minnesota River Basin. He claimed that the sources of funding and groups' agendas could potentially drive the scientific research at different points of the studies, such as testing or data collection and interpretations. He also pointed out the separate entities and groups with set agendas that are conducting their own data collection and testing processes:

> *I think when you look at the watershed itself and all the problems we are dealing with it, there is so many opinions and there is even research to back up these different opinions. (Pauses) There is no good answer, you know. Or, there could be you know it is certain groups pushing their agenda, and their data is driven by what their agenda is instead of being truly scientifically objective. #Semi-structured teacher interview I*

In contrast to researchers supported by private corporations, he expected researchers from universities to be less biased, as he believed that the funding of their studies mostly came from taxes:

> *Where the funding is coming from. It isn't all taxpayer dollars that fund some of those things. You also have your separate entities that are doing their own testing that have their own biases as well. You look at researchers from the university level, I would think most of their work would be unbiased. #Semi-structured teacher interview I*

However, funding was not the only factor he considered as an effect on scientific research. He believed that peer pressure in the research world could cause some researchers to be hesitant about presenting data different from their peers.

In describing what he wanted to see in scientific studies, he addressed two main points. First, he specifically wanted to see the trend in long-term data. He added that the trend in data could have potential to reveal whether the main causes of the sediment load in the Minnesota River were agricultural activities or bluff erosion. Second, he highlighted that scientists should have a clear idea for the future directions of their research and what solutions they would propose.

Beliefs about technology. Thom's beliefs about technology mainly centered around the use of technology in his classroom. As he described technology in the context of teaching, Thom used the term 'science technologies' which he distinguished from computer-based technologies. He stated that the main function of science technologies is collecting data and showing students what is happening around them,

> *The science technology isn't so much a computer-based thing. It is giving them something that is gonna collect data. It is gonna show them what's actually happening around them. #Semi-structured teacher interview II*

Thom also addressed several affordances of technology in his interviews. One of the affordances he addressed frequently was that students gain access to a wide source of information via technology. Indeed, his main use of technology was to provide students with opportunities for finding information on the web. In addition, he also described sharing information as one of the affordances of technology. The last affordance of technology he mentioned was that technology had the potential to bring alive abstract scientific concepts,

> *When you put that tool in front of them, all of a sudden, the point you are trying to make about something whether nitrate or phosphate or sediment, you know in the river, all of a sudden it tells a story. #Semi-structured teacher interview II*

Despite his motivation to integrate technology in his classes, he believed that there needed to be a balance in technology integration because the young generation, including his students, had limited experience with the 'real world' due to their frequent use of technology. This was especially true in environmental science classes where students need to go out and experience the world around them.

Beliefs about SSI based instruction. Teaching socioscientific issues in his environmental science class, Thom's ultimate goal was to help his students develop informed opinions and thus become educated voters. He believed that his efforts would eventually cause positive changes in his community. In addition to his long-term goals, Thom aimed to encourage his students to take active roles in their community. He suggested two ways to involve his students in community-based environmental problems: conducting community-based service learning projects and educating their community about environmental issues. As he highlighted the community involvement projects for his environmental science class, Thom added that it was important to first build conceptual understanding before students started their projects,

> *It has really been a process because it is, you can't just tell the kids, you know like, there is service-learning project. You can't just tell them. All right, let's clean up, do something to clean up the river. We have spent time talking about soil and dirt. And the soil profiles. #Semi-structured teacher interview II*

Thom was well aware that, in addition to the science, there were a variety of different social aspects he needed to cover in order to present the full picture to his students. Thus, he made an effort to include social aspects of river basin issues, such as economics and ethics. He stated that science teachers need to cover not only science content, but they also need to address aspects of social studies in environmental science,

> *I don't wanna just be too sciency, science-like because there is economics, there is ethics, there is a lot of things that's going on drives policy…What I really want to get into and we spend some time talking about it, the policy-making things. You know what drives that is it ethics, is it science. Really, we are juggling between being a science teacher and social studies teacher. #Semi-structured teacher interview I*

While including social aspects of environmental issues, Thom stated the importance of being neutral and not giving his opinions about these different perspectives and positions. He believed that it was the way to help students have their own opinions, *As you are doing that, is it just geology that's driving the sediment problem or is it really the farmer that gets the bad name? I try not to give my opinion. It is really hard sometimes, but I want them to have their own. I don't want to push my opinion on them. #Semi-structured teacher interview II*

Thom also addressed some potential challenges in teaching socioscientific issues. One of his biggest concerns was the geographical distance of their school from the locations where the impacts of those issues are significantly experienced. Even though both their town and Lake Pepin were parts of a big watershed system, it would still be hard to sell the significance of those issues to his students due to the geographical distance,

We're quite a ways away from Lake Pepin and that would be an issue that'd be tough to sell to our kids right way. We are part of that entire system, even as far back as we are, and that would be one thing that would be a challenge. #Semi-structured teacher interview I

Thom also believed that students were not fully able to be skeptical about the information presented about environmental issues. He stated that it was a challenge for him to teach his students to be skeptical of information without considering the level of authority factor,

I don't think they catch it [bias]. They just trust that what scientists are saying is true. I think that even though you try to teach them to be skeptical, it's not an easy thing. They speak from a level of authority and that might get lost sometimes. #Semi-structured teacher interview I

Instruction. Thom divided his curriculum into two parts: i) building a conceptual scientific understanding about community-based environmental issues and ii) student-driven service learning projects and public service announcement projects that documented students' experiences while working on their service learning projects. Thom's curriculum dealt with a wide range of different environmental issues in the following nine units: (1) Introduction to environmental science and the scientific method; (2) Organization of ecosystems; (3) Aquatic ecosystems; (4) Storm water management; (5) Atmosphere and climate; (6) Land use and agricultural practices; (7) Human population patterns; (8) The environment and human health; and (9) Economics, policymaking and the future. Following the River Run professional development, Thom decided to integrate content related to issues around the river basin into his existing environmental science curriculum instead of adding a new unit about the Minnesota River Basin. Describing the overall structure of the academic year, he stated that the integration of community-focused river basin content throughout the academic year was very critical for students' civic development while working on their projects,

> *I think that using the first semester and a half to give our students a bunch of information about the MN river watershed helped prepare our kids for the service-learning projects.*

As one strategy to build conceptual understanding, Thom introduced authentic case studies in order to help his students develop their own opinions, which was the overarching objective he identified for his Environmental Science class. In addition to in-class activities, Thom actively used his teacher web page for sharing resources in written or multimedia form. He uploaded the online textbooks he created, as well as articles and videos, so that students could have access to this content via the classroom iPads.

The second semester was mostly dedicated to students working on their service learning projects and public service announcements. Before students started working on their projects, Thom provided an overview sheet that indicated the objectives and key deadlines. He also discussed Low Impact Design (LID) with the students at that time, which was all about green development. Then, students in groups of three to four identified possible topics of interest from the first semester. Aligned with the service learning projects, Thom asked his students to document their experiences, as well as an expert's view about their chosen issues. The service learning and complementary public service announcement projects chosen by students were explorations of six topics experienced in their community: a rain garden, wood duck houses, a bio-retention area, compost barrels, rain barrels, and river sediment. In order to help them stay on track, he asked them to complete reflections at different points throughout the semester. When students completed their projects, they presented their videos in the class, and put those videos on Thom's YouTube channel for the public. Overall, Thom's teaching approaches were aimed at not only awakening his students' consciousness about environmental problems, but also to encourage them to take active roles in their communities to address these issues. He believed in the significant role his school could play in his community.

Case II: Amy.

The community. Located in southern Minnesota, Amy's town is located along a large bend of the Minnesota River. The town recently experienced a significant growth in the marketplace attributed by the gains in private sector jobs, specifically goods-producing and service-providing jobs. Statistics compiled by the Department of Commerce indicate that the economy of the town grew faster than any other metropolitan area in the state. As Amy described the general population, she stated that her community was mainly composed of white collar and well-educated people. She added that, due to the recent economical changes, it was no longer possible to call her town an agriculture-based community. However, that the farming-based communities surrounding the town supplied the town with a student body with agriculture background. Even though her students had different experiences in farming lands, she believed that all were able to observe the factors affecting the river due to the agricultural lands surrounding their town,

> *When we talk about factors affecting the river, I mean we are surrounded by a lot of farmland, even though our kids aren't participating in that, they see that, so I think, compared to a place that's not by the river at all, they've got a feel for it. #Semi-structured teacher interview II*

The school and classroom. Enrollment in Amy's school district slightly increased in the last decade (10%). The school serves students in grades 9 through 12. Compared to the other school she taught at another part of her town, Amy stated that the student body in this school had more diversity both culturally and financially. Amy's biology classroom included a pretty wide space which allowed students to move chairs around while working in small groups. Amy had a small library of biology books and magazines for student use. At the other side of the hallway, a laboratory room was available for Amy to reserve. She frequently asked her students to move to the laboratory during the middle of the class period. In addition, students were able to use computers in the media center whenever they needed. The environmental science classroom observed involved 24 students (13 girls and 11 boys). When Amy taught the class, she had neither assistance nor a paraprofessional.

Teaching background. The way Amy organizes her science classroom gives strong clues about her teaching practices. She writes down the plan for each class on the whiteboard before the day starts. Using the smart board and her personal laptop, she usually starts her instruction with a PowerPoint presentation related to the topic of the day. After the teacher-centered instruction, Amy usually asks students to work in groups on an activity she prepares related to the instruction. Aligned with the activity, she frequently brings handouts that help students follow directions. In addition to her personal classroom, Amy has access to different facilities in the school building, such as a science laboratory and a media room where she often takes her students.

As a relatively new teacher, Amy was quite motivated to change the traditional science classes which she described as isolated in the school building. Therefore, she frequently planned field trips for her students and invited guest speakers to her classes. She was also quite motivated to use new technologies and instructional strategies in her classes. She designed a personal webpage to share information with her students that included links, sharing assignments, etc. She also created an email group for each of her classes to share news, resources, and updates related to course content, as well as communicating with her students outside of the class.

Amy's beliefs.

Beliefs about the issues around the river basin. In describing the complexity, Amy addressed different variables playing a role in controversial environmental issues. She stated that it was necessary to identify all these different variables in order to fully understand those issues. In addition, the involvement of different actors and the perspectives they held made the controversies harder to resolve.

When Amy addressed the sediment load in Lake Pepin, as well as other locations downstream, she believed that the problems experienced by downstream communities experienced would not affect her personally, thus she did not really care about those problems,

You know, Lake Pepin or other parts downstream, I appreciate that, but I don't *live there so I don't really care if that fills up. It won't affect me … That I feel like – I know what happens in Lake Pepin and if that gets filled up, it would affect us living upstream to some degree, but not as much. #Semi-structured teacher interview I*

Even though she recognized the other factors contributing to the sediment load in the river basin, Amy strongly believed that agriculture was the leading cause. As people have no control over natural factors, she believed that agricultural impacts needed to be focused on,

I think in this case, agriculture is the leading factor there and then there's also this continuing question 'could it be something else?' We can't control the rain so if that's what's really causing it, I feel like that's more out of our control, but we can control what farmers are doing in their fields and along river banks. #Semi-structured teacher interview I

In preventing the sediment and nitrogen load in the river, Amy believed that it was not enough to tell farmers what to do, but some entity, preferably the government, had to regulate the agricultural practices negatively impacting the health of the river. However, she added that the general public, especially environmentalists, needed to be more open-minded to be aware of contributors other than agricultural practices.

Beliefs about science. Amy's understanding of science was mainly centered on quantitative perspectives. She often highlighted that numeric data and statistical analysis was very important for the trustworthiness of scientific studies. She added that scientists needed to quantify their arguments in order to make decisions. It was important for her to hear about the statistical findings when different researchers presented their studies. Only the researchers who were able to show a correlation in their data were unbiased,

"What's the data telling us?" That's what science is all about…I think scientists have to have some significant – you have to quantify it somehow. To make a decision, you have to be able to say 'yeah, there is a positive correlation between these two variables' #Semi-structured teacher interview I

Despite her strong emphasis on the role of data in science, Amy also noted that scientists included personal opinions and perspectives in their studies. She specifically pointed out those opinions and perspectives as source of bias in science. Therefore, she concluded that scientific studies had to be the only factor affecting people's mind as long as scientists remained faithful to data and facts.

Beliefs about technology. Describing her access to instructional technologies, Amy was not quite sure what could be considered a technology or not. She described technology as not only tools with digital structures, but also any human invented tool including whiteboard and books. Therefore, she noted that different technologies were accessible to her students in her classroom,

> *(A) I guess it depends on what you consider technology. (laughs) (I) How do you mean? (A) I don't know. Is a book technology? You know what I mean. Technology or a lack of technology. It's, I think if every single kid in my room had access to something in this room, but it would look different, but what technology. #Semi-structured teacher interview II*

In terms of the use of technology in science classes, Amy stated that instructional technologies not only help teachers teach the content more effectively, but they also help students access richer and more meaningful information. Thus, she believed that technology itself had the potential to take the instruction to a deeper level,

> *First of all. Just having technology I think definitely took it to another level. I think that when you start talking about numbers and getting measurements with probes, you can go so much deeper, um, I think, I don't know, just the ability to get information and how I teach stuff. #Semi-structured teacher interview II*

Beliefs about SSI based instruction. Similar to her views of science, Amy's beliefs about teaching socioscientific issues centered on learning processes focused on quantitative aspects. She strongly suggested that any information presented in the class needed to be supported with a quantitative data,

> *I think my bias then takes over as far as what I'm presenting to them. It's kind of sad, but it's the truth too. I guess my criteria would be, especially being in a science class, that whatever anyone is saying has some quantitative support for it…As a science teacher, it's about the data. #Semi-structured teacher interview II*

Amy also believed in keeping her students away from less factual opinion-based resources. She believed in encouraging her students to find resources supported with quantitative data. The resources involving more quantitative support and less opinion would be a better way to introduce socioscientific issues to her students,

> *Well, whenever my students are doing a research project, I try to steer them away from certain types of resources that are less factual and more opinion … When I'm looking at resources to bring to them or I'm encouraging them to find other resources, yeah. I'm trying to steer them toward anything supported with numbers.* #Semi-structured teacher interview II

Amy highlighted her intention to bring different perspectives related to the issue in her classes. Describing the resources that could potentially be used in teaching socioscientific issues, she pointed out the use of different types of articles from local media and academic journals which, in her opinion, were reliable resources to use in her science classes. Lastly, she recognized her bias in selecting the resources that she used in her science classes. As she sought for the truly unbiased information resources, Amy's criteria were quantitative support in arguments, as well as less opinionated points of views.

Instruction. Amy taught the Wild Life Ecology class in the fall and the Biology class in the spring semester. Instead of integrating SSI based content in her existing curriculum, she decided to develop a separate unit and spend a couple weeks on water analysis and related activities. Being a strong advocate of quantitative focus in her science classes, Amy stated that she covered the SSI based content factually based on the data. Even though she recognized the different aspects of the issue such as ethics, Amy did not attempt to cover those aspects.

> *We didn't get into so much about the ethics or, the opinions as I maybe was expecting to. If I were I would, of course, try to get both side, but…of an angle, of an idea. But I don't know, I kind of kept it pretty factual and just this is what we think is happening based on the data and I didn't… I don't know. I mean they share their opinion on what they think should happen, not much more than that. #Semi-structured teacher interview II*

Amy started her unit with a field trip where students tested the water quality in two different locations, a creek in a well-maintained park and one of the tributaries of the Minnesota River. Eight student groups collected four different types of data (pH levels, turbidity, nitrate, and phosphate), so that they had two sets of data from each type of analysis unit. Following the field trip, students brought back their data to the media center in the school and used computer programs to create data tables and graphs. Based on their findings in the water analysis process, Amy encouraged the student groups to take an idea and argue how the chosen idea was evident in the data they collected,

> *I guess after we did those tests and they got their data we talked about it and, I can't remember how I did I it exactly, we had them do a follow up project where they, they could choose a bunch of different angles, oh yeah, it's coming back to me now. Um, so they could either compare two of the sites, two of the rivers, or they could take an idea and they could run with it like how are pesticides really affecting Mankato and how is that evident in our data? So they got to choose one aspect and take it a little bit further. #Semi-structured teacher interview II*

Even though students were free to choose any format to use for their final projects, when students presented their argument to the whole class, most groups chose the PowerPoint format in order to present their projects. Based on her experience teaching socioscientific issues around the river basin the first time, Amy stated that she would be interested in covering the content in depth in the future,

> *I'm sure (thinking). Trying to think what that would be. I think it would be just, I think I could have taken it to another level of depth, now that I've done it once I think I would do that in the future. #Semi-structured teacher interview II*

Despite the limited time she took to cover the socioscientific content, Amy believed that based on the conversations with students, her students were more aware of the issues around the river basin than they had been before,

> *I think they're a lot more aware of it than, or issues surround it, than they were before just judging by the conversation that we had earlier on in the unit. #Semi-structured teacher interview II*

Case III: Jonny.

The community. Jonny's school is in a small rural community located in southern Minnesota. It is located in a double river valley and predominantly surrounded by farmland and prairies, as well as river valleys with small bluffs. Even though historically the town was an agricultural center, Jonny noted that corporate farms have taken over the small family farms in the last few decades. As a result, people in his town started commuting to other towns that created job opportunities for people living in his community. In addition to this, Jonny highlighted that people in smaller towns have been moving away because of the loss of employment opportunities,

> *A lot of high schools are actually losing a lot of enrollment because of that, because a lot of people are moving away. It's getting smaller in a lot of these different areas. Especially in smaller towns it's tough. #Semi-structured Teacher Interview I*

Describing how river-related issues have directly impacted his community, Jonny shared the high nitrate levels in city water. Consequently, most people in his community drink bottled water instead of city water, which has increased the people's awareness about the river issues.

The school and classroom. Jonny's school district has a predominantly White student population (89%), followed by Hispanic (7%). The school serves students in grades 9 through 12. Jonny and another science teacher interchangeably used two different classrooms connected to each other, although these classrooms were not different from each other physically. Both classrooms contained a smart board and a loudspeaker system. In general, all student chairs were turned to the front side of the room where the smart board was located. Despite the limited space to move the chairs around easily, Jonny frequently asked his students to work in groups. Jonny taught four sections of the same Biology course. There were 25-30 students in each of these sections.

Teaching background. Being a new teacher in his school, the biggest challenge Jonny faced was that his teaching assignments were determined at the last minute, partly due to the ambiguity in the other environmental science teacher's retirement plans. Thus, he struggled to make long-term plans about his future teaching assignments, as well as the content he wanted to cover,

> *The biggest thing I'm worried about next year. As a science department, we all decide what we teach and I don't know if I would be teaching the upper level classes and lose the environmental biology and the bio 1 It all just depends on what classes are offered next year. Then we'll figure out who is teaching them. I don't know for sure, it changes every other week. #Semi-structured Teacher Interview II*

In teaching environmental science topics, Jonny often took advantage of the prior experiences of his more experienced colleague who was close to retirement. In addition, Jonny aimed at continuing his tradition of taking kids down to the river after his colleague's retirement.

In describing his teaching, Jonny repeatedly noted that his main goal was to increase students' engagement in his classes. He believed that if students do not have fun, it is almost impossible to pay attention in class. Jonny often stated that students in this generation have a hard time staying focused, so he aimed at having shorter activities in one class period,

> *The biggest thing I've been trying pushing in Bio is just so that the kids have fun. They learn and they have fun. If they come into the class 'oh God, I'm in bio…' then I don't have any of their attention the whole rest of the time. I make sure that nothing I do takes too long. Each maybe 20 minutes. We'll do different activities throughout the class period rather than me just talking for the whole hour. #Semi-structured Teacher Interview II*

Influenced by his colleague who was a strong storyteller, Jonny believed in the power of stories in keeping students engaged. Thus, he frequently started his classes with short interesting stories, either personal or related to science. Jonny also used different technologies, such as online response systems, in order to engage students. Jonny's students often described him as fun and friendly. He led his students to use different kinds of technologies because he was aware that his students were into new technologies. Being a relatively young teacher, he was able to understand what his students were interested in.

Jonny's beliefs.

Beliefs about the issues around the river basin. As he highlighted the complexity of the issues around the river basin, Jonny noted that it was not a black or white issue. Hence, the ideas based on different perspectives could all be relatively correct from the perspectives and values different people or groups held,

> *I think the biggest thing is that there are so many different variables out there. There are a lot of different things and it's difficult to put it on one thing. This isn't a black and white issue. This is a lot of different things. They all could be, in their own way, correct. #Semi-structured Teacher Interview I*

Furthermore, he believed that the economical consequences of proposed actions made those issues more complex. In addition to agricultural impacts on the river, Jonny also addressed the increased precipitation and its impacts on riverbank erosion. Because increased precipitation was something hard to manage, he believed that people needed to focus on the contributors that could be controlled,

> *I would look at what are the problems, what are the things we can control to stop it from coming? If it's something we can't control, necessarily – it could be the increased precipitation –we can't really control that, so, we're going to have more rainfall, but how do we manage that? How do we find a way to manage it? #Semi-structured Teacher Interview I*

Jonny also addressed the negative connotations people held about farmers because of their role on the sediment load in the river. Empathizing with the famers in his community, he stated that farmers had the right to not to listen other groups, such as environmentalists and media, because of the ignorance of those groups about the economical consequences for them. Jonny added that he personally preferred listening to scientists over other groups because they held no bias in presenting information,

> *To me, the ones that I, because I'm kind of a nerd, I would say researchers and maybe government/state organizations. I would say that I would have to, I would listen to them and hear what they're saying because researchers have no bias in most cases. #Semi-structured Teacher Interview I*

Beliefs about science. Jonny believed in the significance of data in the overall trustworthiness of a scientific study. He stated that he would expect researchers to focus only on data and that the data itself was enough to show the problem,

> *If it's just a researcher trying to figure out the data, yeah, that'd be great…I like*

just seeing the raw data. It tells what the problem is. #Semi-structured Teacher Interview I

In order to decide the stronger side in a scientific argument, Jonny noted that evidence and the interpretation of data played a critical role. Describing the disagreement in the scientific research around the river basin, Jonny believed that the scientists reached different conclusions because of the difference in data and the methods of inquiry,

> *I would say they used different data. I would have to look at where they got their data and at what specific spots…I think they took two different types of inquiries – two different ways to come to their own opinion. #Semi-structured Teacher Interview I*

Lastly, Jonny believed that the reputation of the scientists did not affect the quality of their report, but funding from private corporations needed to be considered. He provided examples of researchers with a good reputation disgracing themselves in the scientific community due to producing low quality reports to meet the demands of biased funders.

Beliefs about technology. Jonny described technology as digital tools although he recognized that technology was broader than this. He was generally critical about people's use of technology, especially students'. He believed that technology caused distractions for his students, so he had to work harder to get their attention during the class,

> *It's changed since even I was in high school where kids have flashing lights, they have their cell phones; they need to find a way to disconnect so that they can think. I think everyone has ADHD basically. #Semi-structured Teacher Interview II*

In addition, Jonny believed that technology, specifically social media, caused younger generations to not be able to understand ideas longer than a certain number of characters. Another criticism he made about technology was the fact that students were not able to be skeptical about the information on the web,

> *If it's on the Internet, it's Gospel. It's true. They don't understand that when someone puts it on the Internet, it can be anyone. They can be someone that has never even covered this concept, but when you put it in print, you have to be able to back up your information, where you go it. That's another thing they have a difficult time understand. Print, getting stuff from print, it's more likely to be true. #Semi-structured Teacher Interview II*

Even though he described himself as a teacher who used different technologies to engage students, Jonny also stated that technology did not cause significant changes in his instruction with regards to content. He added that today's teachers needed to be confident in using technologies in order to meet the expectations of students who are already familiar with using technology.

Beliefs about SSI based instruction. Jonny's main objective for his SSI instruction was aimed at creating scientifically literate students able to think critically in dealing with SSI. While describing what he meant with critical thinking, Jonny addressed asking critical questions before deciding whether to accept or reject an idea, as well as making up their own minds based on the different sources of information,

> *I would want them to be able to read something, understand it, and choose for themselves if they want to believe it…Make up their own mind, instead of reading, understand 'okay, that's true' but there's all this other research over here that says it isn't true. That's a kind of critical thinking I want my students have. #Semi-structured Teacher Interview I*

In terms of the resources that could be used in SSI focused science classes, Jonny strongly suggested the use of scientific studies and reports over other kinds of resources that he considered potentially biased. He added that scientific studies and reports had the potential to create rich discussions and lead to critical thinking. Lastly, relevant to his beliefs about science, Jonny suggested providing students with opportunities to interact with unbiased researchers and the data those researchers could provide,

> *Presentation of a researcher, hopefully in the middle, is unbiased and able to interpret a few of the things and give the kids the data so they can see there are different sides of the issue*

Instruction. Jonny frequently mentioned that the extensive standards in biology prevented him from including more river basin content. Therefore, in his yearlong biology class, Jonny planned a weeklong unit that involved water quality analysis and debate around the issue of sediment load in the river. During water analysis, students working in groups of 4-6 were assigned different kinds of data sets from each aspect such as pH levels, turbidity, nitrate, and phosphate. He also led individual students to collect more simple data such as temperature. In addition to all these water analysis units, Jonny included micro invertebrate species in his data collection agenda. After the field trip, students brought back their data to the classroom for analysis, and then presented their findings to the whole class. Jonny stated that the water analysis on the field helped his students to become aware of the sediment and chemical related issues in the river, as well as the connection between different water analysis units such as sediment, nitrate, phosphate, temperature, and turbidity levels in the river,

> *We brought them out to the river and they did the testing. So, they did the hands-on stuff. They know that there is an issue with the sediment, they know there are issues with nitrates, they know there are issues with phosphates; all these different things. They are seeing how things are related. Turbidity to temperature. Flow rate to turbidity. All of these different things. #Semi-structured Teacher Interview II*

In general, Jonny experienced two important issues in the activities related to water analysis. The first problem was the limited time for visiting different spots on the river. Because he decided to take students from four consequent Biology sections separately, the 45-minute slot was not enough for water analysis on three different locations in addition to the time for transportation. The second problem was the unexpected weather conditions. Because Jonny took his students to the field around the end of fall, their process was interrupted due to the early snow. Even though they revisited the activity next semester, not all students were able to work in the groups they were in previously.

The in-class activity that followed the water analysis was having a debate around the sediment load issue in the river. Jonny assigned each group made up of 4-8 students one of the interest groups in the issue such as farmers and environmentalists. Spending the first day on doing research, collecting information, and preparing presentations for their arguments, students did the actual debate on the following day. Students in debate groups were very motivated and engaged during this particular activity, according to Jonny,

> *We did the debate that we did this summer. The debate where one group is scientists, one group is agriculture, business, and environmentalists. That one got them really fired up. They were really excited about that. I got to see a little fire from some kids I haven't seen it from in a while. #Semi-structured Teacher Interview II*

Even though he covered these two activities as part of the isolated river basin unit, Jonny also addressed the history of the Minnesota River in his class via readings and stories he shared during the academic year.

Cross-case Analysis

Using the themes that emerged from each case, the similarities and differences across the three portraits were explored to build themes for the cross-case model (see Figure 2.2 for abbreviated version of model and Appendix 1 for the full model). The following seven themes were developed through the cross-case analysis (see Table 2.2) and are discussed in detail in this section based on the characteristics of controversial issues (Levinson, 2008) and the elements of principle characteristics of SSI (Zeidler, 2014).

Table 2.2.

Cross-case themes

Teacher Beliefs	Beliefs about the SSI around the river basin	The complexity of the issue and taking multiple perspectives
	Beliefs about science	The role of data and evidence in science
	Beliefs about technology	Technology has affordances
	Beliefs about the SSI-based instruction	The inclusion of social domains
		Students having informed opinions about the issue
Instruction		The structure of the SSI-based unit
		Use of technology in teaching SSI

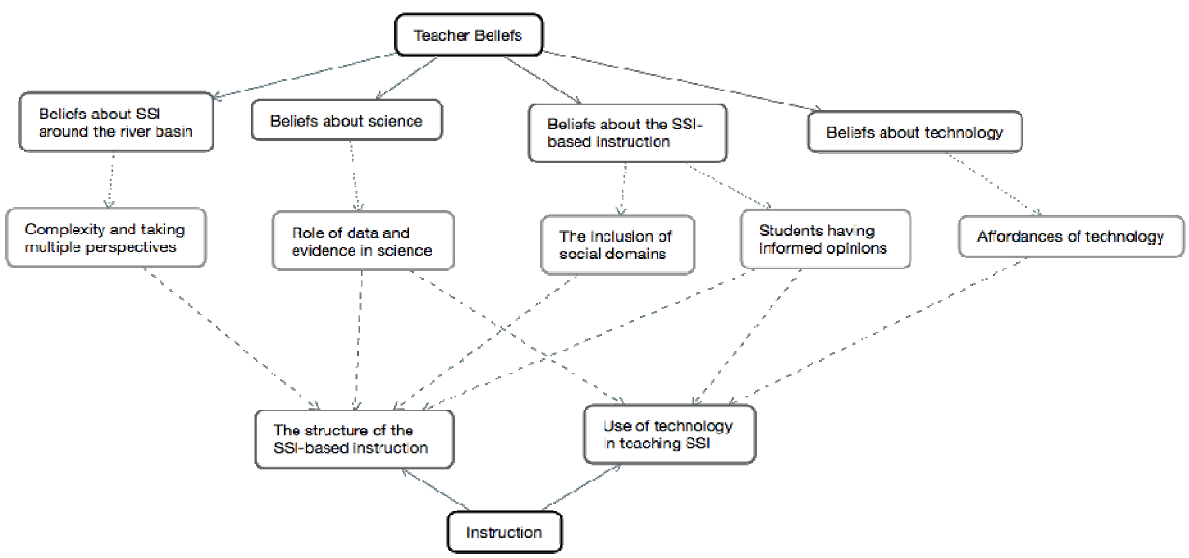

Figure 2.2. Cross case model

Teacher beliefs.

Beliefs about the socioscientific issues around the river basin.

The complexity of the issue and taking multiple perspectives. Socioscientific issues are usually described as complex, ill-structured problems (Zeidler, 2014), and recognizing this complexity is considered one of the preconditions for dealing with those issues (Sadler, Barab, & Scott, 2007). Participant teachers' beliefs about the issues around the Minnesota River Basin mainly centered around its complexity. All teachers recognized the complexity of the issues at different levels. For instance, Thom stated that "there was no magic bullet," because "the system was so dynamic" that one action to prevent the issue could potentially trigger another issue. Amy similarly believed that there were "many variables playing a role" in the issues around the river basin. Jonny also brought a unique perspective about the complexity of the issue by stating that, since "it was not a black or white issue", it was not possible to find one true position or argument.

The involvement of a number of people or groups with different premises, values, and beliefs (Levinson, 2008) requires people to examine those controversial issues from multiple perspectives (Sadler, Barab, & Scott, 2007). As Thom highlighted the complexity of river basin issues, he strongly suggested "taking multiple perspectives and approaches" in order to fully be able to understand the issues. On the other hand, even though Amy and Jonny also believed that the issue was so complex, they both believed that people needed to focus on the agricultural impacts because it was "hard to control the other factors" such as increased precipitation. In contrast to Thom's opinions about taking a multi-perspective approach to deal with the issue, Amy believed that "different perspectives caused loss of focus" which resulted in making the issue more complex to resolve. Thus, she believed that the actions needing to be taken should be agriculture focused. Lastly, Jonny believed that people dealing with controversial issues similar to the ones around the river basin needed to be open to different perspectives and arguments because all arguments could be right from the perspectives, interests, and values of different people or groups.

Beliefs about science.

The role of data and evidence in science. The role of data and evidence is one of the most complicated aspects in SSI. Even though dealing with SSI requires scientific, evidence-based reasoning (Zeidler, 2014), unlike most scientific problems, controversial issues are not really capable of being settled by appeal to evidence (Levinson, 2008). In general, there were two perspectives on the role data and evidence played in science represented in the teachers' responses. Amy and Jonny strongly highlighted the significance of data in the trustworthiness of scientific studies, whereas Thom was more skeptical. To illustrate, Amy believed that "data was what science was all about." Using the term 'quantitative' frequently in her interviews, she stated that the actors needed to provide "numerical data in order to back up their argument." Similar to Amy, Jonny also valued scientific data most in scientific controversies. He argued that scientists needed to focus on only data because "the data was enough to portray the problem." Both Amy and Jonny believed that although science itself could be biased, the scientific data was isolated from the bias. Thus, scientists' arguments about the socioscientific issues should mainly focus on their data. However, Thom was not convinced about the exclusion of scientific data from the idea of bias in science. Specifically addressing the funding factors in scientific studies around the river basin, Thom stated that “sources of funding potentially drove scientific research” including the processes of data collection and analysis.

In terms of the trustworthiness of science and scientists, all three participants believed that scientists were the least biased group in the controversy around the river basin issues. Both Amy and Jonny stated that scientists were the least biased group in the river basin scenario, as long as they supported their arguments with data. That is why “science should be the only factor affecting people’s mind,” according to Amy. On the other hand, Thom was more skeptical about the credibility of scientists and their studies. He listed some of the factors affecting the credibility of scientific studies, such as sources of funding or peer pressure. Therefore, people dealing with SSI “needed more than scientific data and evidence to get the full picture”, according to Thom.

Beliefs about technology.

Technology has affordances. In the interviews, participant teachers frequently addressed the affordances of technologies, which were strong indicators of how they integrated particular technologies in their SSI instructions. The affordances that Thom and Jonny listed centered on students’ use of technology, whereas Amy focused on her use of technology for instructional purposes. Thom stated that students could “get access to vast sources of information” via technology, as well as sharing information with others. In addition, according to him, “technology could tell a story” when students started seeing abstract science concepts through technology devices. He specifically gave the example of Vernier probes, through which students made sense of data in water analysis activities. Jonny addressed the positive impacts of technology on his students’ motivation and engagement. Allowing his students to use their personal technology tools, Jonny believed that their "use of technology engages his students in class because they were into technologies." When Amy addressed the affordances of technology, she described its potential to "take instruction to a deeper level" by specifically addressing "her ability to get information and teach stuff." In terms of getting access to sources of information via technology, all three teachers shared their concerns about the trustworthiness of web-sources. While they criticized their students for not being critical about those information resources, participant teachers still believed that technology had potential to help students to reach different kinds of resources with a variety of different perspectives.

Beliefs about the SSI-based instruction.

The inclusion of social domains in SSI instruction. In his SSI framework, Zeidler (2014) describes SSI as scientific problems with social ramifications. Socioscientific issues are subject to various social domains, such as economics, ethics, and values that play a critical role in dealing with those issues (Sadler, 2011). In terms of structuring SSI-focused units, the main challenge of the participant teachers was whether to include social aspects of the issues or to stay focused on the science behind those issues. Because their classes were all science-focused, it was a challenge for them to address the social domains of those controversial issues. Thom was the one who thought that it was "necessary to address the social aspects" of the river basin issue. As he described his efforts to cover both scientific and social aspects of the issue in his classes, Thom stated that he often "juggled between being a science and social studies teacher." On the other hand, both Amy and Jonny believed that it was their role to stay focused on the science as science teachers. Saying, “science is all about data,” Amy believed that her role as a science teacher was to take a quantitative perspective in covering socioscientific issues. She also believed that any information presented in science classes needed quantitative support, specifically scientific data. Similar to Amy, Jonny also believed that there was no need to cover social aspects in SSI-based instruction because “the data itself was enough to portray the problem.” Both argued that designing SSI-based units around scientific data and isolating it from social aspects was the way to present unbiased information to their students.

Students having informed opinions about the issue. Being able to make informed decisions is one of the principal characteristics of SSI (Zeidler, 2014). The participant teachers all noted objectives of their SSI instruction for their students to develop opinions about the issues around the river basin. However, the ways in which they structured their SSI units in order to achieve that goal were varied. As previously mentioned, Amy and Jonny believed that the scientific data itself was enough for students to make decisions about the issue. In particular, Amy believed that as long as “students interpreted their own data”, they would be able to have their own perspectives and opinions. Jonny also said that “students needed to be able to ask critical questions to make decisions and have opinions.” That is why he was strongly motivated to have a debate activity where students took the role of different interest groups and argued about their positions. Similarly, Thom believed that students needed to be skeptical and critical to have opinions. In order to do that, Thom suggested “being neutral and not giving his opinions” about the issue when he presented. In addition, he said it was effective to “play devil’s advocate” to challenge students. Lastly, Thom believed that using actual case studies and providing real world examples could help students have informed opinions.

Instruction.

The structure of the SSI unit. Even though there were some common activities in their units, such as water analysis in the field, participant teachers designed their SSI units quite differently. Amy's SSI unit mainly focused on the water analysis activities that involved data collection and analysis, as well as presenting an argument that was evident in student-collected data. To illustrate, students who found high nitrate level in their analysis of data investigated the possible sources of elevated nitrate levels, then presented their findings to the whole class. Parallel to her stated beliefs, Amy "kept her instruction factual" based on the data they collected in the field. Similarly, the water analysis activity was a big part of Jonny's SSI unit. However, he also included a debate activity in order to be able to cover different interest groups and their perspectives about the sediment and chemical load issue in the river. Different from the other two participants, Thom's unit was mainly centered on student-driven community involvement projects. As they explored the community-based socioscientific issues, Thom explicitly addressed the social domains of those issues such as economics, culture, and ethics. Since he believed that "it was necessary to build conceptual understanding before starting the projects", Thom connected every piece of his unit to those community based projects. His main goal was to help his students "actively engage in community-based issues".

Use of technology in teaching SSI. During their SSI instruction, participant teachers integrated a variety of different technologies. The common technology tool that all participant teachers integrated in their SSI-focused units was the use of Vernier probes during water analysis. The teachers designed their water analysis activities around those tools based on the specific variables used to explore the sediment and chemical load in the river and its tributaries. Both Thom and Amy used online technologies, such as personal webpages and email groups, in order to share information and resources with their students. Unlike the other two teachers, Thom encouraged his students to document their experiences in community-based service learning projects in a multimedia format. As she designed her unit around data collection and analysis, Amy's use of technology was mainly students creating data tables and graphs on computers. Jonny's use of technology was quite different than the other two. As he believed in the role of technology in student engagement, Jonny used technologies like online response systems in order to motivate students to participate in the discussions. In addition, he allowed his students use their personal devices in the classroom, unlike any other participant teachers.

Discussion

Using the themes that have emerged through the cross-case analysis, this study generated meaningful discussions in order to answer each research question.

RQ1: How do secondary school teachers experience designing and implementing technologically enriched SSI-based instruction. As participant teachers designed their SSI focused units, their main objective for students was to develop informed opinions about the issues around the river basin. However, the ways they structured their units based on this goal were quite different. To illustrate, Amy decided to center their instruction on scientific data collection and analysis and to exclude the social aspects of the environmental issues around the river basin intentionally, whereas Thom tried to find a balance in covering both scientific and social domains. Even though Jonny's beliefs indicated the exclusion of social facets of the river basin issues in SSI-based science classrooms, he decided to integrate a debate activity around the sediment load issue in a local lake that was modeled in the professional development workshop. Exploring teacher perspectives on teaching SSI and dealing with ethics and moral aspects in science classrooms, Sadler, Amirshokoohi, Kazempour, and Allspaw (2006) delineated five profiles of teachers that characterized different perspectives of teachers on the inclusion of social aspects in science instructions. The findings of this study suggested that Thom fit into Profile A, a teacher who embraces the notion of infusing science curricula with SSI and the inclusion of social aspects such as ethics and values. Alternately, Amy fit into Profile D, a teacher who believes in the position that science and science education should be free of social facets such as ethics, morals, and values. Lastly, Jonny fit into in Profile C, a teacher who understands the link between social aspects and science in the context of SSI, but finds it more appropriate to other subjects like social studies. Although they do not intentionally plan to include social aspects in their instruction, teachers in Profile C still possibly address those aspects when they arise in the classroom, as was the case with Jonny and his use of a debate.

The literature (e.g. Pedretti, Bencze, Hewitt, Romkey, & Jivraj, 2007) shows that teachers in their early years are hesitant to teach controversial issues and question their place in science curriculum. As she defended her instructional decisions, Amy stated that she intentionally excluded the social aspects and only focused on scientific data and findings in order to provide students the least biased information, which was her way of presenting the issue in a less controversial way. On the other hand, Thom, who was the most experienced teacher among the three participants, tried to cover multiple facets of the issue, including both scientific and social ones, as he stated that 'there was no magic bullet'. Using different kinds of strategies such as playing devil's advocate in the class, Thom was quite confident about using controversy to help his students take their own position on the environmental issues. Jonny, another participant teacher in his early years, was hesitant to teach controversial issues comprehensively. However, after experiencing a successful application of a debate activity in the professional development workshop, he decided to integrate this particular activity in his SSI-focused unit. Therefore, this study suggested that providing professional development experiences and modeling learning activities around controversial topics has the potential to encourage teachers in their early years to include controversies in their SSI-based instruction.

As suggested by Zeidler (2014), pedagogical goals around socioscientific issues instruction aim at engaging students in dialogue, discussion, debate, and argument. Thom's confidence in presenting controversy in his environmental science class encouraged his students to discuss the controversial local environmental issues from different perspectives, and debate those issues based on the positions they held. In addition, Thom's community based projects helped students create dialogues with the members of their community while exploring those issues. Even though Jonny's students engaged in a debate in order to explore multiple perspectives about the sediment load issue in Lake Pepin, the dialogue and debate around that particular issue occurred in smaller social circles for a limited time in Jonny's class. Even though teaching controversial topics in science classrooms has been considered a challenge for teachers (Dillon, 1994; Osborne, Duschl, & Fairbrother, 2002), the findings of this study suggested that those controversial topics promote dialogue and discussion not only among students, but also between students and real actors outside of school borders.

The literature suggests that personally meaningful and relevant discussions around socioscientific issues provide students opportunities to learn the complex decision making processes (Burek & Zeidler, 2015). Because the controversial issues that the participant teachers focused on in their SSI-focused units were close to students' homes, the discussions around those controversial SSI were more personally relevant. While this provided opportunities for teachers to promote meaningful dialogue and discussions about the socioscientific issues around the river basin, teachers were sometimes hesitant to encourage their students to be part of the conversations in the classrooms, especially when there were conflicts with their backgrounds or beliefs. Therefore, it required teachers to find a balance by evaluating the advantages and disadvantages of addressing the controversy, as well as finding the right tone based on their student body.

In terms of their use of technology in SSI-based instruction, Jonny and Amy's use of technology was mainly technology-related teacher tasks, whereas Thom's instruction involved several technology-supported student activities. In general, all three teachers integrated Vernier probes for their water analysis activities. They believed that these tools supported their collection of quantitative data, which was important to all of the teachers because of its significance in understanding the science behind sediment and chemical load in the river. Teachers' observations indicated that this particular technology helped students make sense of scientific data. In addition to water analysis tools, Thom's students used technology for complex and sophisticated activities such as designing multimedia presentations to inform others about their projects because of the objective of students taking active roles in community based environmental issues. On the other hand, both Amy and Jonny integrated technologies for instructional purposes and information sharing with students. Even though they used technologies in their instruction, neither Amy nor Jonny had their students actively use technology for complex tasks. The integration of socioscientific issues in science curriculum aims at giving students the opportunities to participate in community-based environmental issues (Zeidler, 2014), and Thom's use of technology, which particularly focused on student-centered design tasks for the creation of multimedia products, helped his students actively participate in the dialogue around the local environmental issues in their community.

RQ2: How do contextual factors play a role on secondary school teachers' experiences of designing and implementing technologically enriched SSI-based instruction. The findings of this study suggest that there is a strong connection between the contextual levels demonstrated by Porras-Hernandes and Salinas-Amescua (2013) and participant teachers' design and implementation of SSI instructions. Teachers' epistemological and pedagogical beliefs and the culture of the school and community they lived in strongly impacted they way they structured their instruction. The literature indicates that the personal beliefs teachers hold have great impact on their classroom instruction (Berkman et al., 2008; Rutledge & Mitchell, 2002), and variations in the participant teachers' understanding of the nature of science can lead to different instructional practices in their classrooms (Lederman, 1999). This study showed that teachers' epistemological and pedagogical beliefs about science, technology, and socioscientific issues drove their SSI-focused instructional practices. To illustrate, Amy's beliefs about science that "science is all about data*"* resulted in instruction that centered around data collection, analysis, and interpretation activities. Another example would be the fact that the affordances of technology each teacher addressed in the interviews determined their use of technology in their classes. For instance, as Thom believed in the role of technology in giving students a voice, he encouraged his students to document their experiences of helping their community in order to share those experiences with others in their school and community.

In addition to participant teachers' beliefs, the social and cultural structure of their school and community played an important role in designing their instruction around socioscientific issues. The literature indicated that teachers are usually hesitant to integrate community-based controversial issues because those issues can potentially cause conflicts between teachers, students, and community members (McGinnis & Simmons, 1999). However, participants of this study took advantage of the personal relevance of the sediment and chemical load issue in spite of the possible conflicts. To illustrate, the preexisting bond between Thom's school and community encouraged his students to find connections and take actions in preventing community-based environmental issues. Both students and community members were more comfortable in engaging dialogue in the controversial topics such as the impacts of agricultural practices on their local river. Another example would be how Jonny intentionally structured the student groups in the debate activity, as the student body in his class involved a good number of students with farming backgrounds. Taking advantage of those students, he included the voice of farmers in this activity quite effectively.

The literature indicates that social and cultural factors (Basalla, 1996), as well as teachers' beliefs and attitudes toward technology, influence their selection and usage of technology. This study showed that teachers' epistemological and pedagogical beliefs, the content they taught, the student body, and the social and cultural structure of their school and community were stronger indicators of their use of technologies than simply the availability of technology. To illustrate, teachers' beliefs about the affordances of technology, as well as their criticisms about technology use by teachers, played a role in participant teachers' designs of technology rich learning experiences. In addition, the objectives they decided for their SSI-based class significantly impacted the use of technology in their classroom. To illustrate, the main use of technology in Amy's classroom was data collection, whereas Thom's students used technologies as a medium to have their own voice in their community. That is why, even though participant teachers had access to similar technologies, if not the exact same ones, their technology integration strategies were different in each classroom.

Chapter 3: A Case Study of a Science and a Social Studies Teachers' Experiences of Co-Teaching SSI-Based Environmental Ethics Class

Socioscientific issues are situations that have conceptual and/or procedural links to science and a social significance as identified by society (Fleming, 1986; Kolstø, 2001; Patronis, Potari, & Spiliotopoulou, 1999; Sadler, 2004; Sadler, 2009; Sadler & Zeidler, 2003; Zeidler, Walker, Ackett, & Simmons, 2002). Researchers (Klosterman & Sadler, 2010; Kuhn, 1991; Sadler, 2009; Zohar & Nemet, 2002) describe socioscientific issues as ill-structured problems, which "do not have single correct answers, cannot be meaningfully addressed through memorized or well-rehearsed responses and are not subject to relatively simple algorithms" (Sadler, 2009, p. 11). These issues are subject to different social factors such as politics, economics, and ethics (Sadler, 2011), various social domains, and areas of open inquiry (Klosterman, Sadler, & Brown, 2012). Their solutions are multiple and uncertain, and are necessarily influenced by science concepts and theories as well as social factors such as political, economic, humanistic and ethical (Klosterman, Sadler, & Brown, 2012). The literature in science education indicates that science educators do not always feel comfortable in teaching socioscientific issues that are infused with several social domains (Levinson & Turner, 2001; Zeidler, 2014). In spite of the challenges that science teachers experience in teaching of social and ethical aspects of science in secondary schools, only few studies (e.g. Levinson & Turner, 2001; Harris & Ratcliffe, 2005) explored the collaboration between science teachers and social studies teachers in teaching socioscientific issues. In order to address this problem in teaching SSI, this study investigated how a science teacher and a social studies teacher collaboratively designed and implemented an SSI-based environmental ethics class. The following research question was addressed:

- How do a science and a social studies teacher experience co-teaching an SSI-based environmental ethics class?
- How do a science and a social studies teacher promote student agency in an SSI-based environmental ethics class?

Literature Review

Co-teaching. The profession of teaching has long been recognized as an isolated work (Barth, 1990). However, research on teaching has been intrigued with the possibilities created by collaboration among educators in the same physical space (Lynne & Marilyn, 1995). Several instructional strategies have been proposed for collaboration, such as collaborative consultation (Idol, Paolucci-Whitcomb, & Nevin, 1994), mainstream assistance teams (Fuchs, Fuchs, & Bahr, 1990), teacher assistance teams (Chalfant, Pysh, & Moultrie, 1979), and cooperative teaching (Bauwens, Hourcade, & Friend, 1989). The research indicates that collaboration among teachers on their planning and teaching help them meet the needs of diverse students, as well as fulfill their professional responsibilities in the classrooms (Thousand, Villa, & Nevin, 2006). When teachers with varied expertise and frames of references come together and collaborate on a daily basis, their students benefit more socially, behaviorally, and academically (Morgan, 2012).

Co-teaching is not a new concept in education. It became popular during the era of open schools (Cohen, 1973). In co-teaching, "two or more professionals deliver substantive instruction to a diverse or blended group of students in a single physical space" (Cook & Friend, 1995, p. 2). Friend and Cook (2007) explained co-teaching as having four components: two certified teachers, instruction delivered by both teachers, a heterogeneous groups of students, and a single classroom where all students are taught together. It aims to bring the strengths of teachers with different expertise together, therefore allowing them to better meet student needs (Bauwens, Hourcade, & Friend, 1989; Walsh, 1992). Murawski (2003) states that co-teaching occurs when both teachers plan for and provide substantive instruction together, as well as assess and evaluate student progress together.

Students in co-taught classes can "receive more instruction and are involved more systematically in their learning than would be possible in a classroom with only one teacher, [therefore] the combination of two teachers reduces the student-teacher ratio and provides opportunities for greater student participation and engaged time" (Cook & Friend, 1995, p. 6). The research indicates that the positive outcomes of co-teaching models included improved academic and social skills, attitudes, and self-concepts for low achieving students (Walther-Thomas, 1997; Schulte, Osborne, & McKinney, 1990), and increased student performance on high-stakes assessments (Thousand, Villa, & Nevin, 2006). Students with diverse learning characteristics in K-12 could be taught effectively in settings where teachers collaborate (Villa, Thousand, Nevin, & Malgeri, 1996). In addition to student outcomes, co-planning and co-teaching also results in a variety of positive outcomes for the teachers (Thousand, Villa, & Nevin, 2006).

Research on co-teaching in K-12 consistently found three requisite conditions for successful co-teaching: (a) common planning time, (b) institutional or administrative support, and (c) professional development and training (Walther-Thomas, Bryant, & Land, 1996). Thousand, Villa, and Nevin (2006) listed four predominant co-teaching approaches as follows:

> (a) supportive teaching, in which one teacher takes the lead and others rotate among students to provide support, b) parallel teaching, in which co-teachers work with different groups of students in different areas of the classroom, c) complementary teaching, in which co-teachers do something to enhance the instruction provided by another co-teacher, and d) team teaching, in which co-teachers jointly plan, teach, assess, and assume responsibility for all of the students in the classroom. (p. 242)

In this study, participant teachers jointly designed and taught an environmental ethics class, therefore their co-teaching practice was categorized as team teaching.

Agency. Humans have the capacity not only to be moved by their desires and inclinations, but they also have the capacity to step back and reflect on them (Bratman, 2007). One aspect of this capacity is to arrive at higher-order attitudes concerning a desire or inclination to act in a certain way (p. 22). Freirean pedagogy aims at liberating students through the development within students of attitudes and capacities to view themselves as capable of taking action on their world in order to change it (Freire, 1970; Freire & Macedo 1987). From a Freirean perspective, people should be seen as subjects capable of transforming their own lived realities as they see them, as opposed to objects acted upon by others (Freire, 1970). Basu (2008) noted that

> the principle of neutrality can apply to science classrooms in that students would have choice in what and how they learn rather than the teacher entirely choosing

> curricula, topics, and strategies for pedagogy. Choice is important for student learning—youth improve their abilities to tackle new problems in science when they shape their own inquiries (Basu, 2008, as cited in Basu & Barton, 2010, p. 75).

At the very basic level, agency can be defined as purposeful actions taken by a student in their own interest (Pruyn, 1999; Podolefsky, Rehn, & Perkins, 2013) or the power of the individual to choose what happens next (Lindgren & McDaniel, 2012). According to Martin (2004), agency is "the capability of individual human beings to make choices and act on these choices in a way that makes a difference in their lives" (p. 135). Inden (1990) provided a more detailed description of agency as

> The realized capacity of people to act upon their world and not only to know about or give personal or intersubjective significance to it. That capacity is the power of people to act purposively and reflectively, in more or less complex interrelationships with one another, to reiterate and remake the world in which they live. (p. 23)

Similar to Martin (2004)'s description, Holland (1998) described agency as the acts of individuals or groups upon, modify, and give significance to the world in purposeful ways, with the aim of creating, impacting and/or transforming themselves and/or the conditions of their lives. Pruyn (1999) stated that agency can be seen as "purposeful action taken by an individual, or group of individuals, to facilitate the creation of counter-hegemonic practices" (p. 20) such as actions directed against any given society's cultural and political normative practices. It helps individuals examine their identities because it naturally involves reflection and awareness (Basu, Barton, &

Tan, 2011). On the other hand, Basu, Calabrese Barton, Clairmont, and Locke (2008) proposed another term, critical science agency, which was described as how students "identify themselves within science in ways that advance their participation in community" (p. 345). The development of critical science agency includes not only students developing deep understanding of science concepts and scientific inquiry, but also the ability and desire to take actions at the individual and community levels (McNeill & Vaughn, 2010; Basu et al. 2009; Calabrese Barton, 2008).

Research Context

The Minnesota River Basin (MRB) is a watershed where natural and human-induced changes have converged within a central landscape to exhibit a large and diverse set of water, sediment, and biotic responses to change. The Minnesota River Basin has long been a site of focus for researchers seeking ways to stem the erosion that degrades water quality while being responsive to agricultural needs. Effective remediation actions require a predictive understanding of the cascade of changes and local amplifications between climatic, human, hydrologic, geomorphologic, and biological processes. A large Water Sustainability and Climate (WSC) grant from the National Science Foundation (NSF) is funding a multi-institutional science team study of how climate, water, and human land use interact in the watershed. The primary goal of the WSC grant is to develop tools to study similar situations nationwide with potentially global applications. A secondary goal is to model community-based K-12 educational initiatives designed to heighten awareness of environmental social sustainability issues. The project calls for the development of a socioscientific issue-based watershed curriculum to implement in technologically enriched learning environments and establish a framework for water sustainability studies. The developed methodologies, framework, and curriculum are, however, generic and apply to any basin where effective remediation actions require a predictive understanding of the cascade of changes and local amplifications between climatic, human, hydrologic, geomorphologic, and biologic processes.

The educational component of the larger WSC project, The River Run, is an on-going professional development program striving to provide secondary science teachers a context for teaching local socioscientific issues related to a large river basin watershed in technology rich learning environments. Four secondary science teachers and one social studies teacher from schools within the basin participated in yearly week-long intensive professional development workshops to investigate different socio-scientific issues related to the MRB, in addition to receiving academic support throughout the year.

The week-long professional development workshop was dedicated to developing content and the context for learning and teaching about socioscientific issues in the Minnesota River Basin. During the workshop, subject matter experts in water, soil, and climate (WSC) engaged the teachers in learning experiences and discussions about scientific perspectives on water sustainability issues in the Minnesota River. In addition, the professional development team modeled different types of classroom activities in teaching SSI and worked with the teachers during the week in thinking through curriculum questions and exploring how the teachers might address different watershed issues in their courses.

The Study

The purpose of this study is to understand and describe the experiences of a science teacher and a social studies teacher, who co-designed and co-taught an SSI-based environmental ethics class. This study utilizes Cook and Friend's (1995) definition of co-teaching as "two or more professionals delivering substantive instruction to a diverse or blended group of students in a single physical space" (p. 2). The two teachers in this study aimed to promote student agency around environmental and socioscientific issues. For this study, agency is defined as purposeful actions taken by a student in their own interest (Pruyn, 1999; Podolefsky, Rehn, & Perkins, 2013) or the power of the individual to choose what happens next (Lindgren & McDaniel, 2012). Accordingly, this study involves in-depth interviews with participant teachers, classroom observations and reflective journals. Specifically, the following research question was addressed in this study:

- How do a science and a social studies teacher experience co-teaching an SSI-based environmental ethics class?
- How do a science and a social studies teacher promote student agency in an SSI-based environmental ethics class?

Participants

The participants of this study included a science teacher and a social studies teacher who co-taught a high school environmental ethics class. Participant teachers of this study were chosen based on their involvement in a National Science Foundation (NSF) funded WSC project. The teachers (male=2) differed in their years of teaching experience 8-20 years. Their teaching assignments were mostly in Biology, Ecology, Environmental Ethics, World History, Microeconomics, and Humanities (see Table 3.1).

Table 3.1.

Information about participant teachers

	Alex	*Dirk*
Age	31-35	41-45
Teaching Experience	10 years	20 years
Teaching in Current School	8 years	20 years
Subjects Currently Teaching	Biology, Ecology, Environmental Ethics	World History, Humanities, CIS Microeconomics, Environmental Ethics
Subjects Previously Taught	Biology (10 years), Ecology (5 years)	World History (20 years), Microeconomics (15 year), Humanities (15 years), Environmental Ethics (6 year)
Classes/Specific MRB Content	Ecology, Environmental Ethics	Environmental Ethics
Degrees Held	Life Science (BA), Education (MA)	Economics (BA), Educational Leadership (MEd)
Teaching License	7-12th Grade Life Science	7-12th Grade Social Studies

Research Design

This study was designed to gain insights into how a science and a social studies teacher co-design and co-teach an environmental ethics class that focuses on socioscientific issues around a large watershed. Using a descriptive type of case study (Yin, 2003), it aimed to describe a phenomenon and the real-life context in which it occurred. Yin (2003) defines a case study as investigating a phenomenon (teachers' ways of co-designing and co-teaching an SSI-based environmental ethics class) which occurs within authentic contexts (a community within a large watershed in the Midwest), especially when the boundaries between the phenomenon and context are unclear. Since the contextual factors for the socioscientific issues addressed in this case were so significant, the classroom within the context of the community it is located in was represented as a whole case in order to understand the experiences of teachers in the setting.

Among three types of case studies (Yin, 2003), the case study design implemented for this study is considered a single case having embedded units, which allows the researcher looking at the same issue, but are interested in the different decisions made by participants. In this kind of case study design, “the ability to look at sub-units that are situated within a larger case is powerful when you consider that data can be analyzed within the subunits separately (within case analysis), between the different subunits (between case analysis), or across all of the subunits (cross-case analysis)” (Baxter & Jack, 2008, p. 550). For this single case with embedded units, the embedded units included the science and social studies teachers in a school located in a large watershed. The justification for this configuration is that even though the experiences of each participant (science teacher and social studies teacher) centered around an SSI-based environmental ethics class, the smaller contexts they were in (e.g. their roles in the class, background, and expertise) let them be categorized as subunits within the big case.

In order to describe the context where the phenomena occurs, Porras-Hernandes and Salinas-Amescua’s (2013) three-level context model was employed. The first level, the macro context, included social, political, technological, and economic conditions worldwide, as well as national and global policies. The meso context level included social, cultural, political, organizational, and economic conditions established in the local community and the educational institution. The last level, the micro context, involved the expectations, beliefs, preferences, and goals of teachers and students as they interacted. Since the meso and micro context levels were the ones that differentiated this study from others, these two levels are addressed in the findings.

Data Collection

The data collected for this case study took on three different forms: interviews, observational field notes, and reflective journals. Interviewing is described as “the best technique to use when conducting intensive case studies of a few selected individuals” (Merriam, 1998, p. 72), and useful to reveal the insights of participants’ beliefs and understanding (Davis, 2003; Irez, 2007). In addition, participant observation was chosen in order to “hear, see, and begin to experience reality as the participants do” (Marshall & Rossman, 1995, p. 79) in natural research settings. Therefore, the researcher’s presence in the site was less obtrusive as the researcher began to understand the participants’ views of their own world (Malinowski, 1961). Lastly, reflective journals were used to complement the observation data in order to find a reflective balance (Clandinin & Connelly, 2000).

Two different semi-structured interview protocols for participant teachers were designed and implemented. The first interview protocol aimed at illustrating participant teachers’ epistemological and pedagogical beliefs about socioscientific issues, specifically the ones around the MRB (see Appendix B). The second interview protocol targeted how participant teachers’ co-teaching practices incorporated technology in teaching SSI. The first interview protocol was implemented with each teacher individually as they held unique perspectives about the socioscientific issues, whereas the second interview protocol was a group interview conducted with both teachers to explore their co-designing and co-teaching experiences (see Appendix C). In addition to interview data, the observation data from the participant teachers’ classroom with the complementary reflection journals was included to support and validate the primary data sources. This particular study site was visited eight times during the academic year.

Based on the conversations prior to the class, the researcher and teachers decided together the best times for the observations in order to get a full sense of what was happening in the classroom. After each observation, the researcher wrote reflective journals in order to complement observation data and to find a reflective balance.

Data Analysis

The thematic analyses of this qualitative study were done through the use of NVivo 10.0 software. Spradley (1979) discussed several techniques to identify themes which include examining dimensions of contrast for several domains to find similar dimensions, doing a componential analysis using cover terms of all the domains uncovered, and making a schematic diagram of relationships among domains. The data analysis procedure in this study occurred in three stages: (1) open coding, (2) identification of patterns and categories, and (3) building themes. In the open coding process, a selective reading approach was used by reading the data several times in order to explore the codes that were particularly essential or revealing about the phenomenon being described (van Manen, 1990). After gathering all the open codes, main ideas emerged as patterns. These patterns represented the meso context level (social, cultural, political, organizational, and economic conditions established in the local community and educational institution), the micro context (expectations, beliefs, preferences, and goals of teachers), and eventually participant teachers' co-teaching practices of SSI integration. Lastly, the themes were built based on those patterns that initially emerged.

The Case

In this section, the contexts of community and school are first described. Then, each participant teacher's beliefs about the issues around the MRB, as well as teaching

SSI around those issues are addressed. Lastly, their co-teaching experiences are portrayed.

The community. The high school is located in a large suburb in the Midwest, US. Having a rapid growth in population in the last ten years, the city has experienced sprawling commercial and industrial development, as well as a very changed residential demographic from just a generation ago. 2010 Census statistics indicate 74.3% of the city's residents classify themselves as Caucasian, while 10.2 % describe themselves as Asian and 7.8 % describe themselves as Hispanic or Latino. Other common ethnicities include Black or African American (4.2 %), a mix of two or more races (2.2 %) and American Indian or Alaska Native (1 %). People growing up here have witnessed a shift from a primarily agricultural community, to a second-ring suburb of retail shopping, single-family home subdivisions, and an increasing variety of local industry. The residential population in the same period has ballooned 88%, and increased the percentage of non-white residents from 7% to nearly 25%.

In describing the river-related issues in their communities, participant teachers discussed a variety of different problems and their use of those problems in their classroom. The issues participant teachers mentioned involved seasonal floods, frac sand mining, renewable energy efforts in malt brewing, and algae blooms in a local lake. The teachers frequently complained about lack of awareness and even ignorance of residents in their community about the issues around the river. In addition to the residents, teachers also stated that their students did not have real experiences using the river despite the fact that they spend time around it, *Even just that chance to go down the river and see things from a different perspective. These things are in their backyard but never been on it, most of them. They have looked at it, walk by it, maybe jumped into it, but they are not really just had a chance to experience it. #Semi-structured teacher interview II (Dirk)*

Because they live in a community, neither a rural town nor a metropolis, the teachers believed that it was a challenge for the residents to have a solid perspective. They added that individual interests and backgrounds of the community members played a significant factor in dealing with those community-based issues,

What group do you represent? Do you own a farmland? Then you're the guy who says it's not the agriculture. If it's someone else, someone actually live close by the river, they're going to say they need to stop it – river is a huge attraction for us and so we need the farmers to stop, so we're going to agree with the people from the NPCA. #Semi-structured teacher interview II (Alex)

The school and classroom. The student population in the district mainly consisted of Caucasians (63%), followed by Asians (13%), Hispanic/Latinos (13%), Black/African Americans (9%), and American Indians (2%) respectively. The school serves students in grades 8 through 12. The district had an enrollment of more than 1500 students with a 34% minority rate in the academic year of 2013-2014.

This study took place in an environmental ethics class which is co-taught by a science teacher and a social studies teacher. The class was comprised of 25 male and 6 female students. The class content mainly focused on various community-based environmental problems. The physical space of the class was the Environmental Learning Center (ELC), a free-standing classroom that sits on the edge of the high school's campus, surrounded by plenty of open space. Thus, the nature of this class was different than that of most classes which take place in formal school environments. The students taking this elective class had been mostly the ones "who wanted to go out in the environment and take responsibilities in community-based issues", Alex stated.

The ELC building is surrounded by the area where the different projects of former students are located. For instance, the botanic garden next to the building was one group of the former students' project. The technologies available for each student in the class involved iPads and ChromeBooks, in addition to a desktop computer for teacher use. There was also a connected room where students maintained small in-door projects. The building is mostly used by Alex and another science teacher for the science classes, and Dirk uses the ELC only for the Environmental Ethics class. Comparing his classroom in the main school building with the ELC, Dirk stated that teaching in the ELC building challenged them to teach with technology because technology in the ELC is more available and reliable than it is the main school building,

> *He [Alex] is probably all set in here. He is probably getting more used to it. This becomes a land of opportunities when I come here from my desert of technology in that building. Here, tech is immediately available to kids, so you can go spontaneously. Here I think I gotta start using these things more and challenge myself as a teacher to integrate it more into the process. We are not used to that just yet.* #Semi-structured teacher interview II (Dirk)

Portrait I. Alex is a science teacher with 10 years of experience. His teaching assignments have mostly been Biology, Ecology, and Environmental Sciences. In addition to the ELC where he teaches most of his classes, Alex sometimes uses another classroom in the school building. In general, Alex was confident in using the classroom in the ELC and the different technologies available there, because it was the place where he usually taught his environmental classes. As he described his teaching style, Alex frequently highlighted the idea of place-based education and project-based learning. "We need to push that idea of kids learning by doing, and helping their community" Alex often said. Even though he strongly supported the idea of student-centered instruction, Alex also admitted that he sometimes gives lectures, especially in his Biology classes.

Alex's beliefs.

Beliefs about the SSI around the river basin. Alex had focused on community-based environmental issues in his previous environmental science classes and was well aware of the issues around the river basin. Through the student projects in which groups of students focused on a variety of different community-based environmental problems, he had become more aware of those issues, as well as being actively involved in the solution of those problems. He addressed the complexity of the issues around the river basin and different perspectives and positions involved in the issue. Alex described how people's interests affect their perspectives about the issue as follows:

> *Depending on what your interest is or what you see value in, you're going to make it so you don't feel that what your interests are, are causing the problem…If it's someone else, someone actually living on Lake Pepin or a representative from that area, they're going to say they need to stop it – this lake is a huge tourist attraction for us and so we need the farmers to stop, so we're going to agree with the people from the NPCA. #Semi-structured teacher interview I*

While expressing his point of view about the issue, Alex often used the analogy of a 'silver bullet' to describe the multifaceted nature of the issue. He stated that although there was no silver bullet in the issue, many people still considered agriculture as the only focus. Alex criticized the perspective of the people who focused on agriculture as the only contributor to the issue,

> *Trying to do the right thing and trying to find the silver bullet and that's exactly what can be used for this whole issue. The silver bullet – it's agriculture. It's got to be those practices. But wait a minute here? Is that truly going to stop that sediment build up in? Probably not. #Semi-structured teacher interview I*

In order to demonstrate his empathy for farmers, Alex often made arguments about the ambiguity of the controversy. For instance, he specifically pointed out Native Americans' long-term observations about the conditions of the river. He stated that the Native American community in their town believed that the sediment was always in the river, which caused them to call the river 'cloudy river'.

Regardless of their interests, Alex believed that every actor in the issue held some sort of bias based on their vested interests. Therefore, the public needed to hear the voice of each actor in order to be able to take a multi-perspective approach. He also criticized environmental agencies for dominating the controversy by blaming only farmers for being responsible for the sediment and chemical load in the river.

Beliefs about scientific studies around the river issues. Being a science teacher, Alex often addressed scientific data collection and analysis used while studying the river. According to him, comparison of the data collected in different times and locations was the way to explore the problem. In terms of studying the river, he often suggested that scientists needed to collaborate with the local residents as they had been observing the changes in the river for a long time. He believed that researchers studying the river basin needed to have conversations with the local residents in order to understand the science behind what those residents had been observing for their whole lives,

> *They have residents who see, have been there their whole lives, see the runoff, see the stream banks eroding, the researchers know the science behind it. I don't think those two can work independently of one another. I think they need to work together…You would hope the researchers and scientists would talk to the people as well and understand what they know. #Semi-structured teacher interview I*

In general, Alex was quite skeptical about scientists and their studies. He often addressed the different factors affecting the trustworthiness of science, such as funding and personal background. He highlighted that scientists could possibly skew their data in order to show what their funders wanted them to show,

> *Well, I think a lot of it has to do with how they're being funded. Looking at 'well we want you to look at this piece of information and see how it's not the agriculture's fault' or 'we want you to take a look at this piece of information and blame it all on the agriculture.' I think you can skew data and numbers, there's definitely ways to do that. I think funding can have an important role. In skewing the data in certain ways. #Semi-structured teacher interview I*

As he recognized the potential bias in science, Alex also highlighted that the public usually listened to the scientists who had better arguments. However, he felt that having a better argument in science did not necessarily mean having strong scientific findings. That is why Alex hoped that the scientists with stronger arguments also had better science behind their arguments. In order to determine the credibility of scientific studies, Alex believed that people, including high school students, needed critical thinking skills to ask the right questions and evaluate the scientific arguments. Regardless of their background, he hoped that his students were able to look at the scientific studies critically to be able to decide whether these studies were biased or not.

Beliefs about SSI-based instruction. As he expressed his beliefs about SSI based instruction, Alex highlighted the potential of socioscientific contexts in creating space for student agency. Criticizing traditional science classes, Alex believed that teachers usually assumed students had an interest in science content,

> *Telling the kid that you have an interest in something is not gonna work either. That used to be like what do you mean I am in interest something. They are actually be forced to have an interest and it sometimes fake to make it a little bit too. #Semi-structured teacher interview I*

In order to address issues of student interest in science, he believed that teachers needed to help students figure out their interests, and then make the necessary connections within the context of sociosicentific issues. Based on his experiences in the

Environmental Ethics class, Alex believed that this was a challenging, but effective way of teaching. He described the role of teacher in those situations as,

> *I am really, really, really, this year especially really, liking the idea of kids learn more when they are interested in the topic. And, it is a challenge, but our job then is to figure out those topics and then have them somehow produce knowledge on that. And, that's a difficult thing to do. #Semi-structured teacher interview II*

In addition to giving students the freedom to figure out their own interests, Alex also added that students could learn better if they investigated the issue themselves. As long as students were given opportunities to control their own learning processes, they could become experts on the particular topics related to their interests,

> *For kid to really learn a lot about it, and really best strategy is the kid does it himself. The kid goes, and does the research, does their project on their own. They are really gonna know a lot. And, they are gonna be an expert, and they are gonna have a great understanding about what's going on with the Minnesota River. #Semi-structured teacher interview I*

Alex also addressed how students perceive socioscientific issues. In terms of judging the trustworthiness of information, he criticized his students for not being critical and skeptical. Therefore, Alex stated that his main objective was to have students think critically and be skeptical about socioscientific issues.

> *Most students just accept what they see. If it's written, it's golden. My criteria would just be having them think critically and try and question. #Semi-structured teacher interview I*

However, he added that people underestimated how hard it was to be critical and skeptical. In order to think critically about the controversial socioscientific issues, he emphasized the fact that students needed to know about the issue and gain a broad perspective on it.

Portrait II. Dirk is a social studies teacher with 20 years of experience in his current school. Even though he teaches different social studies content, such as history, microeconomics, and the humanities, Dirk and his students often described Dirk as an economics teacher due to his BA degree in Economics. Correspondingly, he encourages his students to examine various issues from the economics perspective. In his social studies classes, Dirk strongly encourages his students to think critically and determine their own positions. As a social studies teacher, Dirk often makes references to citizenship education in the context of environmental science classes. In one of his interviews, Dirk stated that "you talk about immersing and connecting the kids to where they live, and then you have an active citizen on your hands". Despite his social studies background, Dirk takes advantage of his outdoor interests while teaching the Environmental Ethics class.

Dirk's beliefs.

Beliefs about the SSI around the river basin. While demonstrating his understanding of the issues around the river basin, Dirk expressed his struggle to understand the science related to these issues. He was also disappointed about the disagreement among scientists as to whether agriculture or erosion was the main contributor of river basin issues. That is why he rarely attempted to explain the science behind these issues. On the other hand, Dirk was well aware of the social factors which, he thought, made these issues more complex. According to him, the social dimensions of the issue required people to take different lenses while investigating the issue,

> *We have to understand those lens ideas, social, environment, economic. I think it is hard. Sometimes it is a situation that all three are engaged…I think you have to be willing to hear all points of view, but you can't take one as the truth. #Semi-structured teacher interview I*

Dirk also addressed the decision-making processes in dealing with the issue. He stated that he personally preferred listening to extreme points of view first, and then trying to find the consistent ideas from both extremes that can be centered to bring a more moderate view. Dirk believed that the complexity of the issue, as well as the involvement of groups with different vested interests, required people to make their decisions based on critical thinking. However, he was concerned that most people made up their minds based on their initial thoughts which were more emotionally driven than logical,

> *People see the view they want, and they hold on to that with their heart. They believe that way. That's the scary thing, when people decide their first initial thought was the best, and it becomes more of an emotional component than a logical, thought out component. That's the fear I have. I wish more people would wait a little bit before they made up their mind, but I think it's emotionally driven; especially something as precious as Lake Pepin, with the value of the land and the value of the resource. I think it becomes more emotional than thought-provoked ideas. #Semi-structured teacher interview I*

He added that people did not make decisions unless the consequences impacted them directly. Therefore, the closer people were to the issue, the more they were engaged but also this proximity caused them to follow their emotions rather than logic.

Beliefs about scientific studies around the river issues. Even though he rarely addressed the science in his interviews, Dirk frequently addressed the bias factor in science. Despite the fact that he expected researchers to be less biased, he added that funding played a significant role in presenting the reality,

> *I would always hope that the researchers would be less biased. But you never know who is paying for the study. #Semi-structured teacher interview I*

In addition, Dirk believed that the scientific data itself did not necessarily tell the truth because the data could be fit into the lens that people held based on their vested interests,

> *I think you can make the data and research fit what lens you want to see it incorporated into. That's where I get nervous about who is doing the right study. I always try to remain objective to see what's their bias, what's their slant on the issue. #Semi-structured teacher interview I*

In order to decide who had bias in their study, Dirk suggested taking an objective look at the scientific studies. He added that if he had a chance to ask questions of those scientists, he would probably ask them to reveal their own biases, as well as to defend each other's positions.

Beliefs about SSI-based instruction. Similar to Alex, Dirk highlighted the necessity of helping students find connections to their interests while exploring socioscientific issues. Dirk believed that in order to be fully engaged in an issue, students needed to see the connections to their lives. In order to do that, he suggested taking students to the places where they could see the parallels to their own experiences,

> *I think ultimately, getting them to apply it, and making a complete connective parallel to their life. So if they went from Lake Pepin to Lake O'Dowd in our town or something like that, then I can see that they can see that the kid can see parallels. #Semi-structured teacher interview I*

One of the reasons why Dirk was so insistent on the idea of finding connections to students' lives was the fact that students did not even think about the river issues even though the river was their backyard. He believed that students needed to define their feelings first in order to ground their ethics,

> *I think big thing in here is our vested interest. And, that's a huge topic like he said I don't think some kids even think about it. Because my side of ethics, you gotta define what you feel about certain things to have any type of platform to base your ethics out of. #Semi-structured teacher interview II*

In terms of students' criteria for the reliability of information resources, he stated that students paid attention to the resources that were easier to understand. That is why they usually made inquiries about socioscientific issues via media because scientific resources were too hard to understand. Dirk also criticized his students for not having critical reading skills. He stated that if he did not lead them, his students read to complete the task instead of really understanding and critically thinking about it,

> *The way students read versus the way I want them to read is completely different. They're going to read just to get the damn thing done. They're not going to read to connect or look at a line and pull something out. I think critical reading is such a big component to being a good student. #Semi-structured teacher interview I*

In order to encourage students to think critically about an issue like the ones around the river basin, Dirk suggested pushing the extremes first in presenting the issue to the students. He believed that students could be provoked as they saw the extreme sides of the issue because students' thinking about controversial issues was driven by their emotions. Thus, the classroom discourse about controversy would be enriched,

> *Even dealing with controversial issues in my school, it seems that the emotional component, or whatever their parents have felt becomes what the kid feels, and then that drives what their thinking. That's what scares me. Personally, I would enjoy pushing the extreme. To me, that would be more enriching #Semi-structured teacher interview I*

In the context of SSI- focused instruction, Dirk focused deeply on the idea of student learning. While being critical about the SSI content traditionally taught in environmental science classes, Dirk also questioned the traditional assessment tools and what those tools actually measured. As he believed that the evaluation of knowledge, especially the knowledge about controversial socioscientific issues, was too subjective, Dirk suggested measuring students' ability to ask critical questions and creating solutions for real world problems, *How do you measure if a kid understands the problem? Isn't it just subjective? How do I really know when you say 'evaluating knowledge'? That one right there will carry me through the end of my career. #Semi-structured teacher interview I*

Instruction.

Co-designing Environmental Ethics class. Environmental Ethics was a very popular elective class in the school, and students took this class for specific reasons, such as its project-based and student-driven structure. As Alex described the student body, he stated that students do not take this class just for learning science. In fact, most students taking this class were not interested in the traditional environmental science content. He added that the class had both high and low achieving students in it. The main motivation to take this class was to go out and help the environment,

> *They just don't whatever man, I don't care. It is just a graph, it is just numbers. That's not why they are in the class. It is not what they want. It has everything in it. And, we want every kid to explore their interest. Going out and doing actual work. That's the main thing we want. #Semi-structured teacher interview I (Alex)*

While designing the class, Alex and Dirk took this into consideration. Unlike most environmental science classes, they designed a less science-driven class in order to create a space for social aspects and student-driven projects. After attending the River Run professional development program, they decided to center the course content on the socioscientific issues around the Minnesota River Basin, more specifically sediment and chemical load in the Minnesota River and its tributaries. Addressing the objectives of their class, both Alex and Dirk strongly highlighted critical thinking as the main goal. As a result, they wanted their students to be informed decision-makers, instead of blind consumers. While the teachers co-designed their class, Dirk strongly pushed the idea of *a triple bottom line* that required students to look at socioscientific issues around the river basin from social, environmental, and economic perspectives,

> *Our class is based on triple bottom line: social, environmental, and economic. So, we work hard to get the kids to see each of these...I think that just asking them to look at three different lenses really helps. #Semi-structured teacher interview I (Dirk)*

The idea of triple bottom line was a baseline for the content of the Environmental Ethics class. Alex and Dirk often emphasized the triple bottom line idea and made explicit references to it throughout the academic semester. Therefore, they required their students to examine any environmental issue from the social, economic, and environmental perspectives. As a result, Alex and Dirk aimed at educating responsible citizens of future. In their syllabus, they described their goal as "producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution". They both believed that the way to produce this citizenry was to encourage students not only to understand the science behind socioscientific environmental issues, but also to examine those issues from the three perspectives in the triple bottom line idea.

One of the main points that made the Environmental Ethics class different from other science classes was the explicit inclusion of social aspects. Dirk believed in the importance of social aspects and often criticized the traditional environmental science curriculum and textbooks. With his social studies background, Dirk's role was mostly to highlight the social aspects of environmental issues. Indicating the environmental science textbook that they were supposed to use for this class, he described how environmental science classes miss the opportunity to present the topics using different lenses,

> *Look. This is our environmental science textbook we were supposed to follow. This is the only page talking about the policy, economical, and social aspects of*

the environmental topics. This freaking hundreds of pages textbook only have one figure to show that. #Semi-structured teacher interview II (Dirk)

Therefore, Alex and Dirk decided not to use the environmental science textbook. Instead, they enriched their environmental ethics curriculum with outside resources, such as documentaries, newspaper articles, and outside experts in order to fully address both scientific and social aspects of environmental science content.

Agency and student-driven projects. As mentioned before, Alex highlighted the idea of place-based education and project-based learning in teaching environmental science content. Dirk strongly believed in the premise of citizenship education and the triple bottom line as a framework for environmental science teaching. Therefore, Alex and Dirk decided the main premise of the class was to challenge students to do projects that helped their communities. Besides being critical thinkers and informed decision-makers, Alex and Dirk strongly encouraged their students to improve the quality of the environment surrounding them. They believed that the way they structured the class "challenged students to produce something" during the semester,

Our goal is to challenging them to produce something. And, that what we hope our service learning projects can make. #Semi-structured teacher interview I (Alex)

In deciding the objectives for those student-driven projects, they assigned two different goals: "learning goals" and "content learning goals". The content learning goals involved the usual environmental science content, such as "wildlife, water quality, aquatic life, soils, bio-geochemical cycles, pollution, interconnected systems, bio indicators, and human interactions with the environment". They also explicitly stated that each content learning goal needed to be tied to socioscientific issues around the Minnesota River Basin, especially the sediment and chemical load issue. The learning goals were built on the “triple bottom line idea that required students to solve community-based problems through the perspectives of social, economic, and environmental”. Therefore, it is fair to say that the content learning goals had more of Alex’s influence, whereas Dirk’s expertise and interests were more apparent in the broader learning goals.

Alex and Dirk strongly highlighted student agency in the Environmental Ethics class. “Vested interest” was the word both teachers frequently stated in order to address the personal reason for students wanting to work on an issue. Indeed, the first assignment they gave was asking students to determine their own vested interests. In their first class, Dirk described a person with vested interest as “an individual with strong interests in the outcome of a decision that results in gain or loss for that individual”. Presenting the service learning projects as broadly as possible, Alex and Dirk aimed at uncovering the different vested interests of their students. In addition, Dirk believed that by looking at environmental problems with diverse perspectives based on the triple bottom line idea, students would be able to make connections more easily regardless of their interests and backgrounds,

> *If they don't feel passion towards or connect it, it might not register. But, at the same time, maybe they are getting it as they begin to present many of these different diverse ways to look at different topics. #Semi-structured teacher interview I (Dirk)*

In addition to the teachers’ own efforts, the SSI-focused content also helped them to give students opportunities to find their interests. Like most SSI-based content, the issues around the Minnesota River Basin are multifaceted and incorporate the interests of different groups of people with a variety of different perspectives. Therefore, it creates a wide space for students to focus on their own interests within their projects. Alex believed that as long as they stayed in the big picture of the watershed, students could not only focus on different socioscientific issues around the river basin, but also employ the perspectives of the groups in those issues that they felt passionate about. Hence, the content itself became one of the factors motivating students in the class. In the following quote, Alex provided the example of a potential student project and how it could be connected to the big idea:

> *It is gonna be hard for every kid to buying the Minnesota River really understand completely the Minnesota River. If they don't get, if they wanna do something then, bees, you know we also talked about bees. Let's get kids find more about the bees. And connect it to the idea of watershed ecosystem. #Semi-structured teacher interview I (Alex)*

SSI-based instruction. At the beginning of the semester, the class started with an overview of environmental issues. That was where Dirk emphasized the necessity of looking at socioscientific issues with the triple bottom idea. During that period, Alex and Dirk showed their students a documentary called *Straw* to introduce the idea of students taking action to restore a watershed. In addition, they showed another video, *Troubled Waters,* which highlighted the overall problem within the watershed as a springboard for discussions. They also had field trips to different places, such as a tributary of the Minnesota River on a Native American reservation. On those field trips, Alex was usually the one who lectured students about the environmental science content. Then, Dirk promoted a discussion about ethical, economic, cultural, and social contexts. To illustrate, in their field trip to one of the tributaries of the river located on a Native land, Alex first addressed the ecosystem around the river, discussing the health of the river and surrounding vegetation, and then Dirk raised questions about land ethics and Native culture.

In the first few weeks of the semester, Alex and Dirk highlighted the content in which they had expertise. Alex explained the scientific method and the ways to use it in student-driven projects. For instance, in the first class, he introduced different chemicals that existed in the river, and then promoted a discussion about the ways to investigate river basin issues. In another occasion, when he was leading the water analysis activity with Vernier probes, students struggled to figure out if they had the right values on their screen. Therefore, Alex led a conversation about what an acceptable value was in science.

On the other hand, Dirk frequently highlighted ethics and economics in environmental studies. Using a PowerPoint presentation for whole-class discussion, he introduced the concepts of cultures, worldviews, ethics, economics, and sustainability in the context of environmental science. Dirk also made references to specific terminology for ethics and economics, such as anthropocentrism, biocentrism, ecocentrism, preservation, conservation, land ethics, deep ecology, ecofeminism, and environmental justice. Using the sediment load issue in the Minnesota River as a context for these terminologies, Dirk tried to make sense of each concept for his students. In addition, when Alex introduced the science around the river basin, Dirk intervened several times to address the role of bias in scientific studies.

As they moved further into the semester, students started spending more time outside of the classroom for two sequential projects. The first project was called the MN-based project. The goal for this project was to make a public service announcement or an informational video that "was informative and reflects the goal of seeing the chosen topic through the triple bottom line, the different lenses of social, economic and environmental". The second project, which the teachers called a service-learning project, required students "identifying a river-related issue in their community, research the problem, examine possible solutions, and take action/perform a service".

In these two projects, Alex and Dirk had to grapple with a dilemma related to their choices of content and pedagogical approaches. One of the requirements of both projects was to focus on socioscientific issues around the river basin. However, Alex and Dirk strongly supported the idea of student agency. Thus, they decided to ask their students to focus on the community-based environmental issues that they had "vested interest" in, as long as they stayed in the big picture of the watershed. Therefore, there were projects directly related to the socioscientific issues around the river basin, such as preventing farm runoff in the river, installing filter strips to prevent nitrates from entering rivers, and building ripraps to prevent riverbank erosion, whereas there were other projects out of the SSI context the class focused on such as designing loon nests on lakes and ponds, studying the impacts of hormone pills on fish reproduction, and building a rain garden. However, regardless of their topic, students made an effort to connect the issue they chose to socioscientific issues around the river when they presented it.

The role of teachers. Due to the mostly student-driven structure of the Environmental Ethics class, the roles teachers took were quite different from those of traditional settings. As they presented the community-based socioscientific issues, each teacher used his own content expertise to promote students' understandings of those issues. Alex often presented the ecological, biological, and environmental aspects of those issues, while Dirk added the social, cultural, economic, and ethical influences. To illustrate, when they introduced the sediment and chemical load issue in the river, Alex's role was mainly addressing the science behind the issue, such as ways to measure the sediment and chemical level in the river, the acceptable and extreme values in scientific data, and potential impacts of sediment and chemicals on the river system. Then, Dirk added the economical factors that forced farmers to keep their existing practices, the vested interests of the various groups, the ethical standards people needed to have while exploring solutions, and the consequences of the sediment and chemical load on social lives in surrounding communities. As they presented their expertise by approaching the socioscientific issues from multiple perspectives, Alex and Dirk strongly encouraged their students to take similar approaches while investigating different community-based issues for their projects. In this way, they modeled multidisciplinary thinking.

As mentioned before, although he was not confident about the science behind the environmental topics, Dirk was quite critical about science itself. When Alex made references to scientific processes while talking about the environmental issues, Dirk played a key role in being critical about what scientists say. He frequently addressed the need for taking multiple perspectives in order to fully understand socioscientific issues around the river basin.

For the community-based service learning projects, Alex and Dirk decided to take a unique role in order to promote student agency in their classroom. Instead of taking usual teacher roles, Alex and Dirk consulted their students on the pathways they chose to follow for their projects. They believed that it was an effective way to help students choose their projects based on their interests,

> *Our job is it is almost like you need with them you are just consulting you are always consulting with them to see that they are going down that pathway choosing, you know, follow that interest. That's really weird but it is an*

interesting way to teach I think. #Semi-structured teacher interview I (Alex)

Alex and Dirk used particular approaches to keep students on track while working on their projects. Considering that students spent most of their time working in their communities, the teachers worked hard to find a balance between too much control and leaving them alone. Hence, they decided to consult students on the path they chose and to have regular check-ins with students to see where they were in their projects. They met students both in and after class hours to see their progress in their work. Both Alex and Dirk explained their strategies by saying,

> *Our job is it is almost like you need with them you are just consulting you are always consulting with them to see that they are going down that pathway choosing, you know, follow that interest. That's really weird but it is an interesting way to teach I think. #Semi-structured teacher interview I (Alex)*
>
> *You know we have regular check out spot ultimately you are doing constant check ups throughout the semester. #Semi-structured teacher interview I (Dirk)*

While consulting their students, Alex and Dirk encouraged their students to present the environmental issues from the perspectives of different actors, thus including the voices of different groups of people. Hence, students could examine those issues from different perspectives to figure out their own position. Dirk frequently asked their students to be true to the triple bottom line idea. Since they introduced the triple bottom line as a basis for any student work, both teachers constantly reminded their students to adopt those perspectives in any stage of their projects, including investigating the problem, creating solutions, and presenting their work.

Discussion

This study investigated the experiences of a science and a social studies teacher co-teaching an SSI-based environmental ethics class. Using the themes that emerged through the case analysis, this section generates discussion around each of the research questions.

RQ1. How do a science and a social studies teacher experience co-teaching an SSI-based environmental ethics class. The literature indicates that the science curriculum itself is unable to address all of the concerns surrounding socioscientific issues (Ryder, 2001) because those issues are subject to various social domains, such as politics, economics, and ethics (Klosterman, Sadler, & Brown, 2012; Sadler, 2011). There were several occasions where both Alex and Dirk criticized the environmental science curriculum and textbooks for not being able to address every dimension of socioscientific issues. Therefore, they structured their environmental ethics class based on the 'triple bottom idea' in order to look at those issues from social, economic, and environmental points of view. Similar to Sadler's (2011) argument that teaching science content was not enough for students to be able to negotiate the real world problems, Alex and Dirk dedicated a significant part of their environmental ethics curriculum to social studies content (e.g. ethics, culture, economics) in order to help their students become better able to deal with the environmental problems in their community. Addressing both scientific and social dimensions of the community-based river issues, Alex and Dirk intended to help their students to make informed decisions, as well as taking active roles in those community-based problems. When students are exposed to different perspectives and alternative viewpoints, they are more likely to make informed, critical, and democratic choices (Hyslop-Margison & Graham, 2004). The teachers presented the community based river-related issues from the viewpoints grounded on social, economical and cultural contexts in order to prepare students being critical and informed decision-makers who are able to examine those issues from multiple perspectives, instead of blind consumers.

As Alex and Dirk designed their environmental ethics class, more than half of the academic semester was dedicated to student-driven community based projects. As they prepared their students for those projects, Alex and Dirk decided to use external resources, such as documentaries and Op-ed articles, because they strongly believed that those external resources were more appropriate to inform and encourage their students to explore socioscientific issues around the river basin. The literature in SSI indicates that teachers have complained about lack of useful curricular materials and textbooks in enacting educational innovations, particularly SSI-based instruction (Sadler, Klosterman, & Topcu, 2011). Zeidler's (2014) extensive review on SSI suggested that "research on how teachers can use and modify existing resources shows promise for allowing teachers to best match their curriculum to local needs and student interests" (p. 705). After deciding that the traditional environmental science curriculum and textbooks did not meet their expectations for the community-focused class, Alex and Dirk dedicated their time to design their environmental ethics curriculum based on the resources that specifically addressed the local environmental issues from multiple perspectives.

Alex and Dirk described their role in the environmental ethics class as *consulting* which was different from traditional settings. Therefore, they were not the providers of content anymore, but consulted their students to explore their vested interests. Their students considered their projects as a passion to improve the quality of their lives, as well as people around them, instead of an assignment. Thus, the students were able to act as individuals in making their own informed decisions and become proactive in issues of environmental sustainability in particular, as literature suggested (Bencze, Sperling, & Carter, 2012; Mueller, Zeidler, & Jenkins, 2011; Simmonneaux & Simmonneaux, 2009; Tytler, 2012). In the classroom, the teachers shared the roles based on their pedagogical and content-related strengths and expertise, as suggested by co-teaching practices (Bauwens, Hourcade, & Friend, 1989; Walsh, 1992). Hence, the environmental ethics class covered both science and social studies content. Moreover, because of the expertise of each teacher, the pedagogical strategies employed met the demands of providing the multidisciplinary content, as well as filled the needs of the diverse student body.

RQ2. How do a science and a social studies teacher promote student agency in an SSI-based environmental ethics class. One of the highlights of their Environmental Ethics class was the opportunity given to the students to work in the projects they felt passionate about. Science in formal school environments has usually been described as authoritative and monolithic (Fensham, 1997; Yager, 1992). In contrast, Dewey's (1929) ideas highlighted the autonomous capacity of individuals to participate in shaping their social and cultural experience by achieving goals through their own interests. Giving students power to choose their own project topics, the teachers aimed at enhancing the motivation of students in taking pro-environmental actions, as well as having their own perspective about controversial socioscientific issues. As a result, students were likely to gained greater ownership of their own learning experiences throughout the academic semester. The sense of agency in the environmental ethics class empowered students to use the class to make changes in their lives and surroundings. The literature supports that by indicating that a sense of agency help students identify themselves within science in ways that advance participation in their community by taking actions at both individual and community levels (McNeill & Vaughn, 2010; Basu et al. 2009; Calabrese Barton 2008).

The literature indicates that teachers' personal beliefs have great impact on their classroom instruction (Berkman et al., 2008; Rutledge & Mitchell, 2002). The findings of this study revealed that both Alex and Dirk believed in the idea of agency as a strong pedagogical approach. Therefore, their practices in the Environmental Ethics class were strongly influenced by their beliefs. Alex and Dirk provided their students with opportunities to explore their own interests, and centered their projects on those interests.

In addition to deciding their own topics for service learning projects, students were also given the opportunities to decide the ways they used different technologies in their investigation of the problems, such as use of Vernier probes for water quality analysis and tablets for documenting their experiences. Despite the criticisms of classroom technologies for promoting simple information transfer and instrumental learning (Robertson, 1998), those critiques of educational technology ignore the considerable student agency on shaping related learning outcomes (Hyslop-Margison, 2004). Giving their students ownership on different technology tools, Alex and Dirk created a learning environment where students made inquiries, documented their experiences, and presented their work to wider audiences via technology. Thus, students made their projects more meaningful for not only themselves, but also for their community.

Holland (1998) described agency as the acts of individuals upon, modify, and give significance to the world in purposeful ways in order to create, impact and/or transform themselves and/or the conditions of their lives. Similarly, critical science agency is defined as students identifying themselves within science in ways that advance participation in their community by taking actions at both individual and community levels (McNeill & Vaughn, 2010; Basu et al. 2009; Calabrese Barton 2008). Considering the community involvement of Alex and Dirk's students, this missing piece of agency in most educational settings was strongly present in the environmental ethics class. The more students took control on their own learning processes, the more their community involvement increased because they sought the information from the experts in real world settings.

Freirean pedagogy aims at liberating students to view themselves as capable of taking action in their world in order to change it (Freire, 1970; Freire & Macedo 1987). Agency can be seen as "purposeful action taken by an individual, or group of individuals, to facilitate the creation of counter-hegemonic practices" (Pruyn, 1999, p. 20) such as actions directed against any given society's normative cultural and political practices. Therefore, challenging authority or power is an essential piece in agency. In taking pro-environmental actions via community-based projects, Alex and Dirk strongly presented a variety of different beliefs to their students, as well as encouraging them to challenge the beliefs and practices of their communities in order to make a change. As a result, despite living in a farm-based community, there were community-based projects that criticized the existing farming practices and prevented the negative impacts of those farmlands on the river.

Chapter 4: Secondary School Students' Understanding of Science and Their Socioscientific Reasoning

One of the essential outcomes of K-12 science education is to enable students to use their understanding of science to contribute to public debate and make informed decisions about socioscientific issues (SSI) that impact their lives (Dawson & Venville, 2008). Students need to be able to assess the risks and benefits of alternative solutions, pose questions, and evaluate the integrity of evidence and counter evidence in order to make well-informed decisions. Science is a discipline that relies on empirical evidence, but when addressing socioscientific issues, the data must be interpreted in a creative fashion (Sadler, 2004). Formal reasoning depends upon logical and mathematical concepts and the processes of induction or deduction, thus the results of formal reasoning are fixed and unchanging (Sadler, 2004). In the context of SSI, variations in scientific reasoning are not fully able to explain conclusions reached (Grace & Ratcliffe, 2002) because "the true explanation lies in a reality, which is much less objective" (Parr, 2013, p. 35). Moreover, the decision-making processes in SSI are different from those processes in reaching conclusions regarding purely scientific questions (Braund et al., 2007), because these processes in the context of SSI are more complicated than a reflection of the level of content knowledge (Lee, 2007). In response to the need for a tool to more effectively operationalize and assess the practices in which students engage as they negotiate SSI, Sadler, Barab, and Scott (2007) introduced socioscientific reasoning (SSR) as a construct, capturing practices of negotiating socioscientific issues.

The literature indicates that research in SSI-based interventions is relatively new (Sadler, 2004; Zeidler, Sadler, Applebaum, & Callahan, 2009), and there is a need for understanding more about the effects of SSI-based learning environments (Sadler, 2004). Despite the growing body of literature in SSI, only a few researchers have gathered empirical data on the effects of SSI-based learning environments (Schalk, 2009). This number is even smaller when examining the effects of SSI-based learning experiences on students' socioscientific reasoning. Lee and Witz (2009) highlighted the need for detailed case studies that would focus on how students respond to teachers' practices of teaching SSI. In response to these calls, this study aimed at exploring secondary school students' understanding of science and their socioscientific reasoning through SSI-based science classes. The following research questions were addressed in this study:

- How does secondary school students' understanding of science around SSI develop through SSI-based science classes?
- How does secondary school students' socioscientific reasoning develop through SSI-based science classes?

Literature Review

In the context of science, reasoning traditionally referred to formal reasoning characterized by rules of logic and mathematics. However, Thomas Kuhn (1962) challenged the dominance of formal reasoning in science by proposing a new way of reasoning called informal reasoning (Sadler, 2003). Zohar and Nemet (2002) described informal reasoning as

> reasoning about causes and consequences and about advantages and disadvantages, or pros and cons, of particular propositions or decision alternatives. It underlies attitudes and opinions, involves ill-structured problems

> that have no definite solution, and often involves inductive (rather than deductive) reasoning problems. (p. 38)

Kuhn (1993) believed that although formal reasoning has contributed to scientific discoveries, informal reasoning often holds a more prominent role in science. Formal reasoning methods depend upon logical and mathematical concepts and the processes of induction or deduction, and the results of formal reasoning are fixed and unchanging (Sadler, 2004). Science is a discipline that often relies on empirical evidence. However, the data in SSI scenarios must be interpreted in a creative fashion (Sadler, 2004). Therefore, the topics lacking a definite solution with the currently available data are more appropriate for informal reasoning than formal reasoning (Sadler, 2004). Socioscientific reasoning was proposed by Sadler, Barab, and Scott (2007) for effectively operationalizing and assessing the practices in which students engage as they negotiate socioscientific issues. Their study theoretically situated four aspects of socioscientific reasoning: complexity, perspectives, inquiry, and skepticism. Conducting interviews with 24 middle school students from classes engaged in socioscientific inquiry, their results suggested that "the complexity and inquiry aspects could be used to develop a composite measure of socioscientific reasoning, but such a measure is unlikely to capture the full range of practices associated with the negotiation of SSI" (p. 388).

After they introduced the socioscientific reasoning construct, different studies investigated students' socioscientific reasoning through SSI-focused curriculum implementation. Barab et al. (2007) examined students' socioscientific reasoning patterns by using a multi-user virtual environment, *Quest Atlantis*, to embed fourth grade students in an aquatic habitat simulation. They found that students showed high socioscientific reasoning in balancing ecological and economic concerns, presentation of strengths and weaknesses, consideration of scientific data, and consideration of multiple lines of evidence. In contrast, students had lower socioscientific reasoning in inconsistencies between conclusions and solutions, inaccurate scientific assumptions, and underestimations of social impacts. Sadler, Klosterman, and Topcu (2011) attempted to explore the change in students' socioscientific reasoning associated with an SSI-focused unit, *CATSI*, by using an online SSI Questionnaire (SSIQ) survey. The data based on paired t-test (pre vs. post) for each of the socioscientific reasoning aspects revealed no significant differences in pre- and post-test performances of these students. Simonneaux and Simonneaux's (2009) study found that students did not perform the operations of inquiry and complexity, while the other two operations, perspectives and skepticism, were performed only partially. Laius and Rannikmae (2011) examined the impacts of science teachers' professional change, as a result of participating in longitudinal in-service courses, on their high school students' socioscientific reasoning and scientific creativity skills. They found that the degree of teachers' professional level in promoting problem solving and decision making teaching made a significant impact on their students' improvement in skills associated with socio-scientific reasoning. Lastly, Testa (2013) investigated Italian high school students' use of content knowledge in socioscientific reasoning through the introduction of laboratory activities in SSI teaching interventions. He found that this intervention promoted students' use of content knowledge in their reasoning about science-related social controversies. While the relationship between SSI interventions and students' socioscientific reasoning has been researched in these studies, the empirical evidence has provided mixed results.

Theoretical Framework

The unsteady nature of information and evidence in socioscientific issues causes shifts in reasoning as new information becomes available (Perkins, Farady, & Bushey, 1991). This results in a need for a new type of reasoning that incorporates the aspects of practices and skills associated with the negotiation of socioscientific issues. In response, socioscientific reasoning was proposed by Sadler, Barab, and Scott (2007) for effectively operationalizing and assessing the practices in which students engage as they negotiate socioscientific issues. Based on their previous studies, the most significant practices for reasoning in SSI contexts were: "(1) Recognizing the inherent complexity of SSI, (2) Examining issues from multiple perspectives, (3) Appreciating that SSI are subject to ongoing inquiry, (4) Exhibiting skepticism when presented potentially biased information" (p.374). Even though the individual aspects of this framework are not unique to socioscientific reasoning, "socioscientific reasoning is presented as a theoretical construct designed to uniquely capture the array of practices fundamental to the negotiation of SSI" (Sadler, Barab, & Scott, 2007, p. 377). Each of the four SSI contexts in the framework are detailed in the following sections.

Recognizing the complexity of the issue. Socioscientific issues are described as complex and subject to various knowledge domains (Klosterman, Sadler, & Brown, 2012). Dealing with these ill-structured problems requires students to recognize their complexity (Sadler, Barab, & Scott, 2007), which informal reasoning tends to feature. "Many practical, socioscientific problems are not conducive to being decomposed and handled one dimension at time, but rather must be considered in all of their systemic complexity" (Hogan, 2002, p. 364), and understanding the behavior of complex systems is a necessary basic literacy in environmental science education (Hogan, 2002).

Examining the issue from multiple perspectives. The complex structure of socioscientific issues involves a multiplicity of participant roles, the interpretation of scientific and public discourses, and the potential tensions between public and scientific perspectives and reasoning (Goodnight, 2005). Socioscientific issues involve a realm of reasonable disagreement, where opposing positions exist with both sides appealing to some form of logic that is not necessarily flawed (Levinson, 2006a). Different views and opinions of those issues are a major dynamic in describing opinion differences (Levinson, 2006b). That is why individuals dealing with socioscientific issues need to employ multiple perspectives in order to be able to fully understand these issues. Sadler, Barab, and Scott (2007) stated that several studies (e.g. Erduran, Simon, & Osborne, 2004; Kuhn, 1991; Sadler & Donnelly, 2006; Zohar & Nemet, 2002) in scientific and socioscientific contexts have highlighted the formation of positions, counter-positions, and rebuttals to reveal participants' abilities to consider multiple perspectives.

Appreciating that socioscientific issues are subject to ongoing inquiry. Scientific knowledge and claims change "as new evidence, made possible through advances in thinking and technology, is brought to bear on these claims, and as extant evidence is reinterpreted in the light of new theoretical advances, changes in the cultural and social spheres, or shifts in the directions of established research programs" (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002, p. 502). Latour (1987) expressed the distinction in terms of ready-made science and science-in-the-making. In contrast to ready-made science, where knowledge is assumed independent from contexts and controversies, science-in-the-making proposes scientific knowledge as claims which are context-bounded, contestable, and subject to revision (Bingle & Gaskell, 1994). “When uncertain knowledge associated with science-in-the-making is a part of a social issue, a socioscientific dispute results because there is no consensus as to the scientific facts” (Bingle & Gaskell, 1994, p. 187). The science behind current socioscientific issues is often ‘science-in-the-making’ and involved tentative results from frontier science (Bingle & Gaskell, 1994; Kolsto, 2000). Thus, students need to be able to deal with the tentative and ongoing nature of socioscientific issues (Kolsto, 2001).

Exhibiting skepticism when presented potentially biased information. One of the reasons for the argumentativeness of socioscientific issues is the inclusion of well-reasoned positions offered by interested parties with the differences in personal priorities, principles, and biases (Sadler, Barab, & Scott, 2007). Geddis (1991) argued that when “dealing with controversial issues, it is important to uncover how particular knowledge claims may serve the interests of different claimants” (p. 171) because “to some extent the epistemology interacts with the interests of the stakeholders” (p.180). The actors engaged in a socioscientific issue often possess vested interests that potentially affect the focus and process of their inquiries (Sadler, Barab, & Scott, 2007). Encouraging students to try to interpret statements, to look for bias and underlying ideologies and values, and to judge the evidence in socioscientific scenarios is a powerful tool for educators (Kolsto, 2000).

The Study

The purpose of this study is to understand and describe how secondary school students’ understanding of science and their socioscientific reasoning were developed through SSI-based instruction around a local river basin. This study utilizes Sadler, Klosterman, and Topcu's (2011) definition of socioscientific reasoning as the set of skills capturing the practices in which citizens are expected to engage across multiple socioscientific issues. Specifically, the following research questions were addressed in this study:

- How does secondary school students' understanding of science around SSI develop through SSI-based science classes?
- How does secondary school students' socioscientific reasoning develop through SSI-based science classes?

Research Context

The Minnesota River Basin (MRB) is a watershed where natural and human-induced changes have converged within a central landscape to exhibit a large and diverse set of water, sediment, and biotic responses to change. The Minnesota River Basin has long been a site of focus for researchers seeking ways to stem the erosion that degrades water quality while being responsive to agricultural needs. The effective remediation actions require a predictive understanding of the cascade of changes and local amplifications between climatic, human, hydrologic, geomorphologic, and biological processes. A large Water Sustainability and Climate (WSC) grant from the National Science Foundation (NSF) is funding a multi-institutional science team study of how climate, water, and human land use interact in the watershed. The primary goal of this study is to develop tools to study similar situations nationwide with potentially global applications. A secondary goal is to model community-based K-12 educational initiatives designed to heighten awareness of environmental social sustainability issues. The project calls for the development of a socioscientific issue based watershed curriculum to implement in technologically enriched learning environments and establish a framework for water sustainability studies. The developed methodologies, framework, and curriculum are, however, generic and apply to any basin where effective remediation actions require a predictive understanding of the cascade of changes and local amplifications between climatic, human, hydrologic, geomorphologic, and biologic processes.

Participants

The participants of this study included secondary school students from four schools located along the Minnesota River. Participant students of this study were chosen based on their teachers' involvement in a National Science Foundation (NSF) funded WSC project. Twelve students (male=7, female=5) from four different schools participated in this study (see Table 4.1). Three students from each participant teacher's classroom were chosen randomly. The information about the participants is listed in Table 4.1 below.

Table 4.1.

Information about participant students

Cases	*Subject*	*Grade Level*	*Gender*	*Demographics*
I	Environmental Science	11-12th	2 male, 1 female	2 Caucasian, 1 Hispanic
II	Biology	10th	3 male	2 Caucasian, 1 African American
III	Biology	10th	3 female	2 Caucasian, 1 Hispanic
IV	Environmental Ethics	10-12th	2 male, 1 female	2 Caucasian, 1 Asian

Research Design

This case study was designed to gain insights into secondary school students' understanding of science and their socioscientific reasoning developed through SSI-based science instruction. Yin (2003) defines a case study as investigating a phenomenon (secondary school students' understanding of science and their socioscientific reasoning) which occurs within authentic contexts (SSI-based science classrooms), especially when the boundaries between the phenomenon and context are unclear. The type of case study implemented for this research is considered a multiple case study having embedded units of analysis. The reason why a multiple case study approach was chosen instead of a single case study is that the context (community, school, instructor, grade level etc.) was different for each of the cases. A multiple case study allows the researcher to analyze within each setting and across settings (Baxter & Jack, 2008). Yin (2003) argued that multiple case studies can be used to predict similar results (a literal replication) and/or to predict contrasting results but for predictable reasons (a theoretical replication). Overall, the evidence created from this type of case study is considered robust and reliable, but it can also be extremely time consuming and compelling (Baxter & Jack, 2008; Yin, 2003). Considering each classroom as individual cases in different contexts and the students as embedded units in cases, this study provides the similarities and differences between cases, as well as the potential sources of these similarities and differences.

Data Collection

The data collected for this case study took on three different forms: interviews, observational field notes, and reflective journals. Interviewing is described as "the best technique to use when conducting intensive case studies of a few selected individuals" (Merriam, 1998, p. 72), and useful to reveal the insights of participants' beliefs and understanding (Davis, 2003; Irez, 2007). A semi-structured interview protocol was designed to explore participant students' understanding of science and their socioscientific reasoning in the context of a large river basin (see Appendix E). Before the interview, each participant was provided a short article about the sediment load issue from a local source in order to create a context for the conversation (see Appendix D). In addition, the observation data from each classroom with the complementary reflective journals was included in order to describe the classroom context and SSI-based instruction that participant students received prior to the SSI interview. Each school was visited 3-8 times during the academic semester for observations. The researcher had been informed by the teachers about the best times to visit their classrooms in advance in order to observe their SSI-based instruction. The researcher recorded his observations during the class, as well as before and after the class. In addition, the researcher wrote reflective journals after each observation to complement the observation data in order to find a reflective balance (Clandinin & Connelly, 2000).

Data Analysis

The thematic analysis of qualitative data was done through the use of NVivo 10.0 software. Spradley (1979) discussed several techniques to identify themes which include examining dimensions of contrast for several domains to find similar dimensions, doing a componential analysis using cover terms of all the domains uncovered, and making a schematic diagram of relationships among domains. The data analysis procedure in this study occurred in three stages: (1) open coding, (2) identification of patterns and categories, and (3) building themes. In the open coding process, a selective reading approach was used by reading the data several times in order to explore the codes that were particularly essential or revealing about the phenomenon being described (van Manen, 1990). After gathering all the open codes, main ideas emerged as patterns. Lastly, the researcher examined the patterns in each individual case to find common themes based on the theoretical framework.

The Cases

In this section, each case is presented in order to portray participant students' understanding of socioscientific issues around a local river and their understanding of science in the context of those issues. Cases are presented by classroom starting with a description of the SSI-based instruction each group of students received.

Classroom I.

Instruction. Thom taught an elective Environmental Science class for 11-12th graders. He divided his year-long environmental science curriculum into two parts: i) building a conceptual scientific understanding about community-based environmental issues and ii) student-driven service learning projects. Thom's curriculum dealt with a wide range of different environmental issues in the following nine units: (1) Introduction to environmental science and the scientific method; (2) Organization of ecosystems; (3) Aquatic ecosystems; (4) Storm water management; (5) Atmosphere and climate; (6) Land use and agricultural practices; (7) Human population patterns; (8) The environment and human health; and (9) Economics, policymaking and the future. Following the River Run professional development, Thom decided to integrate content related to issues around the MRB into his existing environmental science curriculum instead of adding a new isolated unit. He considered the integration of community-focused river basin content critical for students' civic development. As one strategy to build conceptual understanding, Thom introduced authentic case studies in order to help his students develop their own opinions, which was the overarching objective he identified for his Environmental Science class. Thom was well aware that, in addition to the science, there were a variety of different social aspects he needed to cover in order to present the full picture to his students. Thus, he made an effort to include social aspects of river basin issues, such as economics and ethics. As he described his experiences of integrating those social aspects, Thom stated that he often “juggles between being a science teacher and social studies teacher”.

The second semester of the class was mostly dedicated to students working on their service learning projects and public service announcements. Students in each group were asked to focus on a community-based environmental issue for their projects. Even though Thom aimed to maintain a SSI focus around the MRB, he also provided students enough freedom to choose the topics that they felt passionate about. Before students started working on their projects, Thom informed his students about the expected outcomes of the projects and key deadlines. Then, students in groups of three to four identified possible topics of interest from the first semester. Aligned with the service learning projects, Thom asked his students to document their experiences, as well as incorporate an expert’s view about their topic. The service learning and complementary public service announcement projects chosen by students included: a rain garden, wood duck houses, a bio-retention area, compost barrels, rain barrels, and river sediment. In order to help them stay on track, he asked them to complete reflections at different points throughout the semester. When students completed their projects, they presented their videos in the class, and put those videos on Thom’s YouTube channel for the public. Overall, Thom’s teaching approaches were aimed at not only awakening his students’ consciousness about environmental problems, but also encouraging them to take active roles in their communities to address these issues.

Students' understanding of the SSI around the river basin. When students were asked to describe the issues around the river basin from their own perspective, they mostly addressed the sediment and chemicals going into the river due to agricultural run-off and riverbank erosion. They also mentioned the bad reputation of farmers in their community as contributors to this problem. Students frequently referred to 'people' complaining about agricultural actions and how they negatively impacted the health of the river. They noted that the discussion about the river basin issues mainly centered on whether agricultural practices or natural events, such as the amount of rainfall, were the main problem,

> *I got how I assumed it was is people are they are complaining about the farmers on like the sediment going to the river and all those bad chemicals because they farm and if it rains, the rain drives it to the river... The main discussion is who is to blame whether it is just natural, or if farmers are the main cause because farming next to these drainage ditches and stuff. #Semi-structured student interview-S1*

'Sediment' was the word all students used while describing the problem although they were not sometimes sure about what 'sediment' actually referred to. A couple of the students used the word 'sediment' as an umbrella term for anything that goes into the river,

> *Yeah. I mean I guess sediment is pretty much anything, isn't it? Pretty much anything falls down the river. Settles. It could settle. #Semi-structured student interview-S3*

In addition to agricultural actions, some students addressed different factors that could potentially impact the health of the river. For instance, one student referred to salt and sand that rain-washed from the roads and went into the river. Another student pointed out the dam removal and how it caused sediment to wash away.

Describing the changing conditions of the river over the long term, some students pointed out Native American views on the issue. Since Native Americans have been around longer than any other groups, students believed that their long-term observations were more reliable than others. Native American people in their area have been calling the river ‘Muddy River’ for a long time, so these students concluded that the sediment in the river has always been there, thus it is just nature’s course,

> *It is just the Minnesota River, the Indian’s name for it was Muddy River. That’s basically what, the original name was it for. So, that's basically they said it has been that way since they could remember. There has always been muddy like that. Murky… So, that's basically what I have learned, it is just nature's course. #Semi-structured student interview-S2*

Talking about their perspectives on the issue, students frequently stated that they needed more information to make a decision about the significance of the issue. One student said that she both needed accurate scientific data and her own observations to believe what was said about the issue, whereas another one asked for the big picture to get an idea about the future conditions of the river. In their statements, students frequently showed skepticism about the scientific data and mentioned alternative explanations,

> *To me, if they have, you can't believe every graph you see, but like if I read it and the graph is pretty accurate or else, if I see it too and see in the river too and then I would believe it or I will see, you see everything in the river, every time you pass by the river, you see the affects. #Semi-structured student interview-S1*

Describing the problems of the river basin, students addressed different actions that could potentially prevent the sediment load in the river. Most of the solutions came from what students heard or observed around them. One of the potential solutions for the issue was the use of rock bands around the river to prevent erosion. Students argued that it would especially be useful in their town because the soil was washed away due to ice melt and flooding during the spring time.

When students described the issue from their own perspective, they recognized its complexity. They believed that this complexity resulted from groups of people having different positions or the communities living up and downstream experiencing the issue differently. One student stated that there was a conflict and it was not possible to agree on one position. That is why she believed she needed to be open-minded to all opinions,

> *I think everybody has their own opinions. I think it is a conflict, because there are different people having different opinions, and you can't just agree on one, you know you cannot choose one opinion, there are many different ones, so I need to be open-minded to all of them. #Semi-structured student interview-S1*

Another student addressed the conflict of interest between the actions taken by the upstream and downstream communities. He noted that upstream communities took actions for the sake of their own benefits and interests, and those actions ultimately impacted people living downstream. He believed that this conflict of interest made the issue more complex than it seemed. As an example, he described the dam removal in his community a couple years ago as favorable in his location, but that it had negative impacts on communities living downstream such as higher water level. That is why he believed that despite the fact that the issue did not seem that complex in one community, the whole thing got more complicated on a bigger scale.

The issues around the river basin, like any other socioscientific issue, involve different interest groups with a variety of different positions**.** The students revealed their perspectives about the different groups involved in the issue, as well as the positions of these groups. In describing the role of farmers, students mostly showed a strong empathy for them. They almost never blamed farmers for sediment load and chemicals in the river, and even criticized people for blaming farmers. One of the reasons they were so supportive of the farmers was the fact that most students had friends or family connections to the farming community. Being familiar with local agricultural practices, they indicated different actions that farmers in their community had taken in order to help prevent sediment problems. They believed that farmers used to employ practices negatively affecting the river, but they now more educated about the issues and implementing best practices in favor of the river,

> *I think before back in the day they did not know. They didn't mind, they just do what they do, but now as I say aftermath how it will affect the river and how it is getting worse. I think they are getting more educated on it, and hopefully they are trying to prevent it. #Semi-structured student interview-S1*

Also, some referred to the actions that their own family took in order to minimize the impacts of their farmlands on the river. One student stated that the river played an important role in his family's life, so they felt responsible for making an effort for positive change in their farming practices. Students argued that despite the fact that the argument was related to agriculture, people needed to understand other factors. They believed that farmers had no control over their actions because farming was their way to maintain their lives,

> *The farmers, they have to crop, they have to farm, it is their job, it is their life, and they can't control that, because they get income and if they don't get income, then what's gonna happen. And, you can't just blame the farmers, you have to see the other factors besides it is the farmers' fault. #Semi-structured student interview-S1*

Students often criticized the perspectives of farmers held by people living in cities. They believed that urban people did not really know much about agriculture, but blamed farmers for negatively impacting the river. They highlighted the contrast between the perspectives of urban and rural communities on the issue. In order to fully understand the issue, students believed that people, especially the ones living in the cities, needed to experience the issue firsthand and make their own observations.

In addition to farmers, students also shared their perspectives about the environmentalists and their actions related to the river. Most students believed that the environmental activists took a radical point of view on the issue and blamed farmers more than any other groups. They often claimed that environmental activists took a strong position against farmers and did not give them a chance to defend themselves,

> *Environmental agencies. I feel like extreme activists only show the negatives. Like they look at it and say it is the total farmers, they don't actually look at like the courses overall the years … I think that they are just hard-headed. They think they are always right. #Semi-structured student interview-S2*

Students' understanding of scientific studies around the river basin. In the interviews, students also revealed their understandings about the scientists and their research around the river basin. They specifically addressed how scientists study the river, including collecting data and making interpretations. Students believed that scientists' practices showed similarities to what they did in their class project collecting water samples in the field. In addition to sediment and chemical levels, they also mentioned the data for the flow of the river and micro-invertebrate species in the river as part of the data scientists collect.

In addition to types of data, students also addressed collecting data in different times and locations. They believed that scientists collect water samples from different points of the river basin to determine the high sediment areas and eventually the sources of sediment,

> *They first took samples along from all the river points. And then Lake Pepin, too. And then, they kind of watched to see where the high sediment areas are. And then where the low sediments areas are to actually figure out where it actually is coming from the source of it. #Semi-structured student interview-S1*

Furthermore, they added that scientists do testing in different seasons throughout the year and compare their data across the seasons.

In terms of the interaction among different scientists, students addressed the way different researchers and their studies could potentially affect each other. According to the students, comparing the data they collected or getting ideas from other studies going on in different places were two examples of how scientists could impact each other. To illustrate, one student stated that scientists could take ideas from others studying similar issues in different locations,

> *Not only us have the problem, other communities have this problem too. And, if they are doing similar study, maybe not so similar but similar to the issue, I think they take some other ideas from different places, it is my idea. #Semi-structured student interview-S1*

Sometimes, students questioned the trustworthiness of the scientific studies around the river basin. They stated that scientists needed to show their data in order to convince them and the statements of scientists are just personal opinions if no evidence was provided. In addition to data, some students asked for the information about data collection and interpretation methods in order to believe scientists. It was also interesting that students often used ‘data’ and ‘graph’ interchangeably in their statements.

Classroom II.

Instruction. Amy taught a Wild Life Ecology class in the fall and a Biology class in the spring semester. Instead of integrating SSI based content in her existing curriculum, she decided to develop a separate unit and spend a couple weeks on water analysis and related activities in order to examine the sediment and chemical load in the river. Being a strong advocate of quantitative focus in her science classes, Amy stated that she covered the SSI based content factually based on the data. Even though she recognized the different aspects of the issue such as ethics, Amy did not attempt to cover those aspects.

Amy started her unit with a field trip where students tested the water quality in two different locations, a creek in a well-maintained park and one of the tributaries of the Minnesota River. Eight student groups collected four different types of data (pH levels, turbidity, nitrate, and phosphate), so that they had two sets of data from each type of analysis unit. In addition, students also collected micro-invertebrate samples while they were out in the field. Following the field trip, students brought back their data to the media center in the school and used computer programs to create data tables and graphs. Based on their findings in the water analysis process, Amy encouraged the student groups to take an idea and argue how the chosen idea was evident in the data they collected. Based on this first experience teaching socioscientific issues around the river basin, Amy stated that she would be interested in covering the content in depth in the future. Despite the limited time she took to cover the socioscientific content, Amy believed that based on the conversations with students, her students were more aware of the issues around the river basin than they had been before.

Students' understanding of the SSI around the river basin. In Amy's class, even though all students addressed the sediment load in the river as coming from both agricultural lands, their explanations about the impacts of the issue were different for each student. Describing the issue, students often referred to the sediment load in the Minnesota River, as well as other places such as the Mississippi River and Lake Pepin. While indicating how significant the issue was, different students addressed the impacts of the sediment and chemicals coming from agricultural lands on living organisms in the river ecosystem,

> *All the different chemicals they are using on the crops running off into the river affecting all sort of stuff, plant life, animal life, water quality. #Semi-structured student interview-S2*

With widely known river issues such as sediment load, one student pointed out the heat pollution and the algae bloom that was caused by the factories located next to the river. He added that algae caused more carbon dioxide in the water, which resulted in the death of fish.

In addition to the consequences of river basin issues in their area, some students also addressed the problems on a larger scale. While most students talked about the towns upstream and downstream in describing the impacts, one student specifically pointed out the nitrogen based fertilizers from agricultural lands that went through the Minnesota River, the Mississippi River, and eventually the Gulf of Mexico. He claimed that the sediment load issue in the southern part of his state was one of the leading causes of the problem in the Gulf of Mexico dead zone,

> *Minnesota River is one of the causes of algae bloom in the gulf and the dead zone because of the nitrogen based fertilizers from farmers' fields going into the river and leading to the Mississippi and the Gulf of Mexico. And, that's a pretty big*

problem too because no one likes to see tons of square miles of ocean just dead. #Semi-structured student interview-S2

In describing the complexity of the issue, students recognized that the conflict of interests of different groups made the issue harder to resolve. They frequently highlighted the conflicting interests of farmers and others in their community. To illustrate, one student pointed out the debate between farmers and people advocating for a clean river and added that the issue was not resolvable due to the involvement of so many groups,

> *You have to pick do you want the crop or do you want the river. I feel like that's kind of the thing that's hitting people now. Some people are fighting we want the river to be clean and farmers are standing on and saying we need to raise corn and beans and stuff. And they are looking at the best rates to do that while the other people are looking the best interest in the river... yeah I definitely think it is a complex issue because there is way too many sides of it to just say one way or the other. #Semi-structured student interview-S3*

In terms of agricultural practices and the consequences of these actions on the river, students' perspectives were significantly divided. Some showed a strong sympathy for farmers and their actions, whereas others blamed the farmers for having the main responsibility. Some students believed that although it was an issue for everyone, it was the farmers' responsibility to take necessary actions to prevent that issue,

> *I think it is everybody's issue really but farmers can and should do I think a better job of making the problem better. They have more responsibility than others. #Semi-structured student interview-S1*

On the other hand, another student showed strong sympathy for the farmers about why it was hard for farmers to admit the blame they received. He added that not just farmers but other people in their town negatively affected the health of the river with their everyday actions,

> *If you are farming, I am sure you are not gonna say that it is your fault that the river is bad. But, in a way, they are affecting, but it is not just all on them.*

Everyday, people are affecting the river too. #Semi-structured student interview-S2

In terms of showing sympathy for farmers, a particular student coming from a farming background provided a concrete example for why the proposed actions to prevent agricultural impacts on the river were not fully accepted by farmers. Giving the example of buffer strips, he explained how building those buffer strips would negatively impact the farmers economically as follows:

I think when it comes on to it, there is a lot of people who don't understand the farming side of things, I grew up like that, so I do. But, they look at it and say well, we can just do this you know you take two or three acres of your land along the river and turn into a buffer zone or buffer strip, that would help the river. Well, that two or three acres is maybe six hundred bushels of corn. And that's you know 2400 dollars for the corn that farmers just lost. I predict and that's per year. How many years he has a buffer zone or buffer strip, look at the money he loses. He does not want to lose that money, but everyone else wants to save the river. #Semi-structured student interview-S3

In describing the controversy around the river basin issues, students addressed the perspectives of different interest groups. Even though the main argument revolved around whether agricultural practices or riverbank erosion was the main cause, some students argued that there were more factors negatively affecting the health of the river, such as heat pollution and ecological changes. As they referred to the argument about whether farmlands or riverbanks were the main source of sediment in the river, one student noted that neither of the factors was as drastic as it was presented. He believed that the impacts of these two factors were roughly equal, and that scientists claiming either one as the main contributor were not completely right or wrong,

I don't think either one is as drastic as they say, one says farmers' field you know like it is 80% from farmers' field, 20% from the river banks and stuff. The other one pretty much is the opposite, I think it is more compromised between the two like 50-50 … I think, I don't think either one is necessarily wrong, but I would not *say either one is 100% right either. #Semi-structured student interview-S1*

Lastly, students shared how they perceived the argument around the river basin issues, as well as the way to win the argument. According to one of the students, because there were so many different groups with different arguments, whomever described their argument best would win,

> *No one wants to be responsible for it, and therefore you could ask a dozen different people, you might get a dozen different answers. And, the person who describes the best is the one who is gonna win the argument probably. #Semi-structured student interview-S3*

While describing the problem, students also addressed the potential actions that needed to be taken to prevent the river basin issues. Even though students proposed different types of actions, such as improved agricultural practices, they still believed that it was hard to reverse already existing effects,

> *Well, I mean you know there is only one river and it is kind of hard to be able to reverse the effect has already been down out to it. #Semi-structured student interview-S1*

In describing the actions that needed to be taken, one student considered the potential cost of the solution, as well as the risk involved. In terms of the way of judging the potential solutions of the issues around the river basin, he considered the economic factors in order to decide if it was worth trying or not. He added that the only thing he needed to know about the solution was the evaluation of the cost and outcome,

> *I would have to know economically what is it gonna cost. I think at least super expensive, you know, is the cost efficient for be ending product, like what are we gonna get out of it, is it worth the cost and the risk involved…But, I think that's really all I have to know, I mean outside of I know the issue, it is hmm to make the final decision, you really have to know you know you have to cost and reward know what are you getting out of it. #Semi-structured student interview-S3*

Students' understanding of scientific studies around the river basin. Students' understanding of science was strongly impacted by Amy's instruction that specifically focused on data collection and analysis. Therefore, students believed in the significant role of data in scientific studies. All participant students agreed that scientific studies needed to be based on strong data and facts, but no opinions. In order to believe in the findings scientists proposed, students demanded the data,

> *I guess kinda if they are, kinda have to believe what scientists are saying and if they have good hard facts and data that are supporting it, then I mean scientific facts. #Semi-structured student interview-S3*

In addition, when students described what science meant to them, they described it as mostly facts and some opinions. Despite students' recognition of the inclusion of opinions in science, they still believed that science had to involve less opinion and more facts,

> *I mean science, a lot of it is facts, but there are some opinions in like saying that blaming farmers or not blaming farmers. I guess it should have less opinion. #Semi-structured student interview-S2*

Even though students frequently stated that scientists should be the ones whom people believed, while also recognizing the bias scientists could potentially hold. Students noted that scientists could have farming backgrounds, as well as having connections with different corporations. To illustrate, one student stated that he would check if a scientist had any study about which he was questioned by the scientific community before making his decisions based on it,

> *I would definitely look and see what other studies have that scientist done. I mean has he been like proven right or time period has he done a lot that are really questioned, ones that are not so correct. I would definitely do that. #Semi-structured student interview-S3*

In describing the data analysis procedures scientists followed, 'averaging' was the key word students commonly used. Students believed that scientists average the data from different locations, different time periods, different studies, or different rivers. They described averaging as part of the process for having more reliable findings. To illustrate, one student addressed averaging the data values collected from the different locations on the same river,

> *If you take a hundred samples from in town in hundred yards diameter of the river, you are gonna be able to average that out to one you know close number to as best as you can get it versus one sample, or even one sample here and one sample there. I mean you average one sample here one sample here, it is gonna be pretty vague. #Semi-structured student interview-S2*

Finally, students stated that scientists studying different rivers could work together in order to find more information. They often highlighted the necessity of collaboration among scientists. Using different contexts, scientists could use other scientists' data as well as learning from other studies,

> *I mean they have learned something from another river and they can try to use it while doing research in here. They could possibly find connections between the two. They can use each other's data sometimes…So, communicate through the river to find out what can we do to prevent rivers going bad. #Semi-structured student interview-S2*

Classroom III.

Instruction. Because of the extensive standards in biology to be covered in his yearlong biology class, Jonny planned a single week-long SSI unit that involved water quality analysis and debate around the issue of sediment load in the river. During water analysis along the river, students working in groups of 4-6 were assigned different kinds of data sets from each aspect such as pH levels, turbidity, nitrate, and phosphate. He also led individual students to collect more simple data, such as temperature. In addition to all these water quality variables, Jonny included micro invertebrate species in his data collection agenda. After the field trip, students brought back their data to the classroom for analysis, and then presented their findings to the whole class. Jonny stated that the water analysis activity in the field helped his students to become aware of the sediment and chemical related issues in the river, as well as the connection between different water analysis units such as sediment, nitrate, phosphate, temperature, and turbidity levels in the river.

The in-class activity that followed the water analysis was a debate around the sediment load issue in the river. Jonny assigned each group of 4-8 students to one of the interest groups in the issue, such as farmers and environmentalists. Spending the first day on doing research, collecting information, and preparing presentations for their arguments, students did the actual debate on the following day. According to Jonny, students in debate groups were very motivated and engaged during this particular activity. Jonny also addressed the history of the Minnesota River in his class via readings and stories he shared during the academic year.

Students' understanding of the SSI around the river basin. When Jonny's students talked about the issues around the river basin, they mostly pointed out the sediment load issue in the river. Furthermore, they addressed the controversy around the issues caused by the involvement of different actors,

> *The problem is the sediment levels are way too high and there is a lot of hmm pollution whether that would be from farming or other sources as yet to be decided officially. #Semi-structured Student Interview I*

In addition to the sediment load, students also addressed other kinds of pollutions going into the river. Some students believed that pollutants were a bigger problem than sediment. To illustrate, one of the students mentioned the pollution coming from the farmlands around the river,

> *(S) I think the pollution is more of a problem than the sediment is. (I) How do you mean? (S) Because pollution is bad. (I) Simply put. I like it. So, like what is the pollution? (S) Like waste from barns like pig barns or something. That's bad, he could get like poop and pee like bunch of like stuff in there and that's bad. Kids could be swimming there, that would be gross. #Semi-structured Student Interview III*

As they addressed the impacts of sediment and chemicals on living systems in the river basin, one of the students mentioned that although high nitrate and phosphate levels negatively impacted fish and other animals in the river ecosystem, they were actually good for the algae and other plants.

In terms of its scale, some students considered the sediment load in the river a national issue that everyone in the country needed to be worried about, whereas others thought that it was Minnesota's own problem. Students who thought that it was a national problem highlighted the connection between the Minnesota and Mississippi Rivers and the potential impacts of sediment load in the Minnesota River on the communities downstream,

> *Really the issue is sediment and how the Minnesota is a tributary and it is gonna run into the Mississippi eventually and could cause problems downstream for the rest of the US. That's a problem because not only are we hurting our state and our communities, we are starting to hurt other people downstream. #Semi-structured Student Interview I*

On the other hand, another students stated that people in Minnesota should be worried about this issue, as well as working on solutions more than other states because she believed that every place had its own problems,

> *I am sure someone in like South Dakota would say 'it is in Minnesota, why would we care? Because that does not affect us.' Every place has its own problems, but I feel like people in Minnesota should be more worried about it, like trying to fix it because if you go somewhere else, people would say yeah it is Minnesota's*

problem, we have our own problems. #Semi-structured Student Interview III

In defining the complexity of the issue, students often addressed the economic aspects, such as the financial consequences for farmers. Students stated that farming was the main economic driver of not only their community, but also the whole state. That is why if actions taken to prevent use of nitrates damaged the farming business, it could potentially impact the whole economy of the state negatively. As one student stated,

> *If we solved the problem by taking out the farming or limiting the use of nitrates. Farming is the economy of the Minnesota whether we like it or not. So, we have to we have to have that if we limit that, it completely throws out the whole economy. #Semi-structured Student Interview I*

On the other hand, another student mentioned that the actions that farmers were asked to take in order to prevent runoff were expensive. Therefore, the proposed actions would eventually cause an increase in the prices of agricultural products. She added that another contributor to the issue, which was erosion, was not possible to control. That is why she believed that it was a complex problem to deal with,

> *I do think it is a complex problem because farming is the economy of Minnesota, so we cannot just stop doing that and like erosion is a thing, it happens. Hmm. And, you also have to like you have to consider farmers don't want their top soil and their nitrates whatever the runoff. That stuff is expensive. #Semi-structured Student Interview II*

In terms of the contributors to the issues around the river basin, students often recognized the role of agricultural practices. However, they also frequently addressed the other causes such as erosion. For instance, one student stated that even though the statistics showed that agriculture is the main contributor in the issue, there were other factors that the public needed to see. She added that agriculture caused problems in the river that people could stop, but erosion also happened naturally. Therefore, people needed to see both sides,

> *Right now, statistics show the farmers are the main cause, so if we brought that down to make it leveled out a little bit, and, the general public could see things that are going on, that are causing, not just the farmers. So, you can't blame them for everything when it is happening naturally and artificially. #Semi-structured Student Interview I*

Students from farming families or working in farms often showed a strong sympathy for farmers. They appreciated the efforts farmers made in order to prevent their negative impacts on the health of the river. Referring to her conversations with her coworkers, one student stated that farmers were already aware of their impacts on the river and were trying to do their best to help,

> *The farmers are a major problem with it, but I think we also need to step back and look at it from farming perspective. And, look at what the farmers are already trying to do to help it. I think, I mean, I know as a person who just raises a lot of livestock and does a little bit debils and crops, I don't know I think I should know, but I know that the farmers like at lunch when we harvest, that's what they are talking about lately. #Semi-structured Student Interview II*

While addressing the role of farmers in this issue, students sometimes provided their perspectives about the characteristics of farmers. Considering herself a farmer, one of the students described farmers as stubborn people who wanted things to happen in their own way,

> *I think other groups notice that but it just takes a while and actual farmers, other farmers will disagree with the statement, but farmers are stubborn. They don't like to give in, they like things their way and only their way. #Semi-structured Student Interview II*

Despite considering farmers stubborn people, she was also aware of the fact that farmers care about their personal images in their communities. In order to manage their image in public, students believed that farmers tried to improve their existing agricultural practices,

> *I think they care because then it comes people fall back on the farmers, you know what I mean like. The general public is gonna fall back and say the farmers, their fault. So, I think the farmers care about their personal image compared to what public thinks. They care about their personal image enough to say we are going to do something about it. #Semi-structured Student Interview II*

In addition to demonstrating their own perspectives about farmers, students also touched upon the perspectives different groups held about farmers and their actions. Scientists and environmental agencies were two groups students talked about. Students believed that scientists were not able understand the issue from the perspectives of the farmers. When they dealt with the issue, scientists usually ignored the economic consequences for farmers, according to the students,

> *The scientists like they did not understand I don't think enough about the whole farming issue about the cost and stuff. And, I think in the farmers' perspective, we look at what's gonna cost us because we have a set budget that we can spend per year. #Semi-structured Student Interview III*

In general, students were most critical about environmental agencies. To illustrate, students believed that the fact that environmentalists were too critical of farmers and not willing to cooperate with them caused farmers to get mad. As a result, students considered environmentalists part of the problem due to their strong criticisms of farmers,

> *Well, you have the environmental activists who basically almost wanna make it sound like it's completely the farmers' fault, but yet they give a little way to compromise a little bit because they realize that if you don't compromise with farmers, the farmers just get mad… people are to blame even though they are in the group of people who buy stuff at Wal-Mart and they eat groceries #Semi-structured Student Interview II*

Students were also critical about the way environmentalists presented themselves to the public. For instance, one of the students stated that environmentalists tried to have a better image, like being sent by God to save the Earth, instead of actually trying to fix the problem,

> *Environmentalists wanna look like the God send. They wanna be like we are gonna save the world by fixing the problem when they are not actually out to fix the problem, they are just out to make themselves look better. I mean they might not think that like consciously, but you know. #Semi-structured Student Interview II*

Lastly, students believed that the actors already involved in the issue were not capable of deciding who had the main responsibility or which actions need to be taken because their biases prevented them from determining a solution. Thus, one of the students offered bringing an outside party to investigate the issue,

> *I think that there is a solution potentially and there needs to be somebody maybe an outsider party come like different groups of scientists in and look at the issue. And, make a solution because obviously the bias here is very high. #Semi-structured Student Interview III*

Students' understanding of scientific studies around the river basin. When students demonstrated their understanding of science and scientists, their statements revolved around the terms bias and credibility. They frequently shared their opinions about the bias and credibility of scientists and their work. According to the students, bias referred to opinion-based information, but not fact-based,

> *Bias can come from almost anywhere and it is just based on your opinions. Because it is an opinion, not a fact. #Semi-structured Student Interview I*

In terms of their judgment of bias, they separated science and scientists intentionally. Most students insisted on the idea that science is supposed to be unbiased, while they also believed that scientists usually held bias at certain levels, *Science is supposed to be unbiased but we are human beings. It is our tendency to make it be what we want it to be. …Human error happens. Science has to be unbiased, but it is fair to say scientists are biased. #Semi-structured Student Interview II*

Even though students stated that scientists often held bias, most of them still believed that scientists had credibility in providing information. For instance, one student considered scientists credible sources just because they were smart,

I don't believe something until I know someone, I guess the credible source to see in it. (I) Who is the credible source? (S) Scientists. They are smart, they should be credible. #Semi-structured Student Interview III

Students' understanding of how scientists work varied significantly. Some were able to describe the way scientists study the river in detail, whereas others held naïve views. To illustrate, one of the students demonstrated how scientists study the river by addressing the data collection, analysis, and interpretation processes,

They would take soil samples and water quality samples, they would look at how much sediment is in the samples and how much nitrates, phosphates, and other things in the water samples, they would look at nitrate, phosphate, and they would look at the life that was able to live there. The plants that were able to survive along the banks. #Semi-structured Student Interview I

On the other hand, another student viewed scientists as the ones who spent their time in a lab. She mentioned the words associated with the traditional view of scientists such as laboratory and microscope,

They sat in a lab all the time and then pull out some microscopes and some pen and paper. And then they go like bus or car to like get samples if necessary. #Semi-structured Student Interview III

Comparing their work from the field trip with the actual scientists' work, she also stated that data collection methods that scientists use must have been more "sterilized and accurate" than what students did in the field. She expected scientists to be more careful about the sterilization of their samples and the organization of their data, *Well, scientists' are probably more accurate, more sterilized than ours were. I am sure theirs is more sterilized, more like written down and stricter than some going out, getting some water and coming back or just dipping the thing in the water taking pH something like that. Because they are scientists. I just think of them all cleaned. #Semi-structured Student Interview III*

When students talked about the representation of data in scientific studies, they stated that scientists use numbers and graphs in order to show their findings. Most students noted that there needed to be more student friendly presentations of data in order to help the public understand scientific studies. To illustrate, one of the students, who was really into science, and had career plans in science, explicitly stated that she did not want to read those studies because she thought that they were not interesting:

I think that if you want high school students to get into your data, there needs to be a different presentation point because it is often really hard to get in to a science paper that is just graphs and mathematical equations and big long words often that times it is not interesting and sure your teacher can had it out and say 'well, read it' and you need to get points on it by reading it, but I don't want to do that. #Semi-structured Student Interview III

Classroom IV.

Instruction. Alex and Dirk co-taught an elective Environmental Ethics class. It was a popular class because of its student-driven structure and the opportunities given to students for improving the quality of the environment in their community. When they designed this class, Alex and Dirk decided not to follow a traditional environmental science curriculum and textbook. Instead, they designed the course content around community-based environmental problems. At the beginning of the semester, the instruction started with an overview of environmental issues. During this time period, the teachers strongly emphasized the necessity of looking at socioscientific issues with the triple bottom idea: social, economic, and environmental. They enriched the course content with several external resources, such as documentaries, Op-ed articles, and field trips.

As they moved further into the semester, students started spending more time outside of the classroom for two sequential projects. The first project was called the MN-based project for which students were asked to find an issue in their state, to collect information from the people directly involved in the issue, and to share it with the public in a Public Service Announcement (PSA) format. Some of the topics covered in these projects were the wolf population in Minnesota, composting sites, overfishing, impacts of hormone pills getting in the water streams on fish reproduction, and farm run-off in the river.

Following this project, students started another project that required them to develop a solution to a real problem. Students took actions to prevent an environmental problem in their community. The overall goal of the second project was to challenge students to create solutions for their communities. Some of the actions taken for these projects included collecting information about the problem, finding connections to experts, getting the necessary permissions, doing the project, and presenting it to the public at the end of the school year. These projects included building a rain garden, designing loon nests on lakes and ponds, organic composting, educating younger kids about bees, and installing filter strips to prevent nitrates from entering rivers.

Students' understanding of the SSI around the river basin. When students described the issues around the Minnesota River Basin, they usually addressed both agricultural runoff and riverbank erosion. Some believed that agriculture was the main contributor to the issue, whereas others believed that erosion was a more significant contributor than agriculture. In general, students' descriptions of these issues were driven by the perspectives they held. However, they were also aware of the different perspectives people held about these issue,

> *Different perspectives would be like the people blaming just the farmers themselves because of lack of buffer strips or too much fertilization, and the run-off from their farms going into the river creating more sediment. Or, you can also look at the increased rain and how that is creating a water power and eroding the banks. Otherwise, you can look at both of them and combine them. Those are the three I think that the most important perspectives. #Semi structured student interview S2*

Expressing their opinions about the sediment and chemical load issue in the river, students often recognized its complexity. They believed that this issue had become more complex over time. To illustrate this, one student used the 'snowball effect' analogy in order to describe how this issue had become more complex and hard to prevent. One student noted that the issue would already be agreed on and resolved if it were not complex. Most students stated that the multiple contributors, different perspectives, and involvement of different groups made it more complex. While explaining different views about the river issues, they addressed the economic, social, and environmental standpoints that they learned in the class. The economic consequences for farmers made it especially hard to take actions to prevent the issue, as the following quote indicates:

> *I think it is really hard because if you, there is a lot of sides you can come from. Farmer side say I need this nitrate make my living. Then, you go to somebody who is a conservationist and they are like no way there is totally another option, but to keep this living we have. There is a lot of view that come from like economic, social, and environmental kind of way. #Semi structured student interview S1*

Students' arguments about the role of agriculture in causing sediment and chemical load in the river mainly centered around the economic standpoint. Even though some students believed that agriculture was not the main contributor to sediment and chemical load in the river, all students recognized the role agriculture played. Unless farmers decided to change their practices in favor of nature, students believed that the issue and the controversy around it would not be settled. Referring to the conversations they had heard in their community, students believed that farmers were the ones whom people blamed. However, most students showed sympathy towards the farmers in their statements. They strongly argued that farmers' best interest was money, and that the proposed actions for farmers would significantly impact their livelihood,

> *I think they don't really have another option that is in, like their best interest is money because if I mean if they stop using fertilizer or give up their lands for buffer strips, then they are not gonna make as much, their money just gonna go down. It is unfair if you would just take away their livelihood for the sake of the river. #Semi structured student interview S2*

In addition to their own point of view, participant students also addressed the perspectives of 'people' in order to provide a full picture of the issue. Students believed that people needed to blame someone when dealing with issues similar to ones around the river. For instance, one student stated that people did not believe in the natural contributors, so they instead chose to blame human actions,

> *I mean I think people are so stuck in the ways that if it is natural, it is not causing the problem. Like the river banks people can just say oh, ok the river banks are natural, they are causing the problem, they are more blaming the next guy. #Semi structured student interview S3*

Students also noted that people needed both information and experience to be opinionated about the issue. Therefore, they criticized the fact that many people who gave opinions about the river basin issues never experienced it firsthand. They added that if those people actually went out and saw the river, they would not have such an extreme opinion. Lastly, students addressed people's lack of attention to what was happening downstream although their actions were the cause of the problem happening there, *I don't think this way, but I think some people could think that since it was not clean for them, why should they keep it up clean for other people down the road. #Semi structured student interview S1*

In terms of geographic scale, students had a broad perspective about the sediment load issue. They often compared and contrasted how upstream and downstream communities experienced it. Instead of calling it a local issue, students highlighted the fact that the sediment and chemical load in the Minnesota River converged to the Mississippi River. Thus, they connected problems in the Gulf of Mexico to the actions taken in their local community,

It is not really just the Minnesota River, like if you do something here, it's gonna affect other places because all the water is connected, Minnesota River is connected to giant Mississippi River which runs through the nation, all way down to Mexico. So, it is not something just local like if you mess up here, it is gonna be carried all the way down through the nation all the way down to Mexico. #Semi structured student interview S2

When addressing the issue at a national scale, students mentioned how people downstream were negatively affected, both socially and economically. To illustrate this, one student mentioned how the fishermen in the dead zone struggled because of the problems downstream. Students also criticized people in upstream communities for not being able to sympathize with those people who experienced an issue that actions of the people in upstream communities were responsible for.

One of the most common words participant students used was ‘dirty’, while demonstrating their understanding of the issues around the river basin. However, students’ understanding of dirty varied. The differences in their use of the word dirty were mainly caused by their varied experiences in nature. Some students explained dirty as the observable materials on the river such as trash, whereas others believed that sediment and chemicals in the river were dirty because these affect the natural state of the river. Moreover, some students stated that their understanding of dirty had changed from trash to sediment and chemicals as they learned more about the issue in the class,

> *Dirty to me, before I learned about what it was, was people not taking care of trash, people playing in parks tossing their picnic kind of trash just letting be in there going to the river, but now as I learned what dirty is, it is more like the pesticides and all that kind of stuff that gets into the banks and the sediment that sits with it that washes down and contaminates and builds up in the river. #Semi structured student interview S3*

Students' understanding of scientific studies around the river basin. In terms of how scientists study the river, students mainly focused on how scientists collected data from different locations on the river where farming runoff and riverbank erosion occurred significantly. They added that scientists looked for the patterns on data collected over years. In addition to water sample collection, some students reported that scientists looked at the historical pictures of the river that showed the changes in its conditions, as well as asking locals to provide information about those changes.

When they were asked about the possibility of collaboration among the scientists studying different rivers, students mostly believed that every river had its own features depending on local context. Therefore, they suggested that scientists needed to stay in the context they were familiar with. For instance, one student addressed social values of the communities as a part of the contextual factors that significantly impacted the river body,

> *It is gonna be like really different, and I think you just you kind of have to for the most part I would say stay in your own country because your soils are gonna be different, I guess I am sure Irelands' runoff is gonna be so much more different yet they still have farmlands, I am sure it is gonna be a lot more different than ours just because of like the outside factors and what we find to be socially acceptable. #Semi structured student interview S1*

On the other hand, some students still believed that studies from different contexts could give scientists a sense of reference for their own studies.

In terms of the disagreement among the scientists studying the river, most students had negative attitudes about the controversy. Most students believed that it was a waste of time, and that scientists needed to combine their efforts in order to reach one conclusion that everyone agreed on. They added that scientists who disagreed on the issue did not look at the issue from different perspectives, so they were not able to understand the full story. To illustrate his point, one student stated that scientists, as well as people following their argument, were split like political parties. Describing the possible reasons that scientists went against each other, one of the participant students described scientists as stubborn people who wanted to have their own theories, instead of contributing to someone else's. Unlike most, one student argued that scientists used different languages, which resulted in them not fully understanding each other,

> *I feel like in any field there might be a lack of consensus, otherwise you know there wouldn't be so many problems in the world, but scientist to scientist sometimes they might speak maybe different languages, not literally, but scientifically speaking, and maybe just like people in the world, they don't understand each other, or maybe sometimes they don't take the effort to understand each other and then that causes turmoil and different feelings, and then become with the information. #Semi structured student interview S2*

In terms of the bias factor in science, students provided different opinions about scientists. The mainstream argument was the assertion that scientists had no bias, as long as they remained truthful to the facts. To illustrate this, one of the participant students believed that scientists were least biased because they had no stake,

> *I think scientists are the less biased people because they are not really benefiting one way or another, they are just finding out the facts about things. #Semi structured student interview S1*

On the other hand, there were also other students who argued that scientists held bias as much as the other actors in the issue. Describing the sources of bias scientists could potentially hold, students stated that the background of the researchers, as well as their personal connections, could be factors affecting their research. Students also believed that it was hard to keep research unbiased because of different ways of thinking scientists had. In contrast to others, one of the students had a more extreme opinion about scientists' trustworthiness. She stated that scientists gave the public what they wanted them to see. Lastly, some students argued that science itself contained bias, instead of individual scientists. A couple of students believed that the numbers themselves could make the problem seem huge although the problem itself was not significant. It was important to note that these particular students were the ones who claimed that scientists were the least biased group. The following quote demonstrates it:

> *They can give you a chart on some numbers, and it could be a very minor problem, but the numbers make it seem like it is a huge problem. #Semi structured student interview S2*

Cross-case Analyses

Using the themes that emerged from each case, the similarities and differences across the four cases were explored to build themes for the cross-case model. The six themes developed through the cross-case analysis are shown in Table 4.2. Based on the theoretical construct of SSI reasoning (Sadler, Barab, & Scott, 2007), the cross-case themes are discussed in detail below.

Table 4.2.

Cross-case themes

Understanding of Science	The way scientists study the river
	Trustworthiness of science and scientists
	Recognizing the inherent complexity of SSI
Socioscientific Reasoning	Examining issues from multiple perspectives
	Appreciating that SSI are subject to ongoing inquiry
	Exhibiting skepticism when presented potentially biased information

Understanding of science.

The way scientists study the river. In demonstrating their understanding of scientific studies around the river basin, students across cases often made references to their own data collection experiences on the field. 'Averaging' and 'comparing' were the two words that students frequently used while describing how scientists made sense of their data. Some students highlighted the idea of 'averaging data' from different times and locations, whereas others more frequently noted that scientists 'compare data' across different times and data points, as well as across different studies. In addition, when students addressed data collection over a certain time period, they considered it across seasons, over years or even decades. When students revealed their understanding of data, most students considered data in a numerical form. However, a few students in Alex and Dirk's classroom addressed different forms of data scientists collected while studying river basin issues. These forms included historical views and interviews with the local people.

Students also addressed how scientists get ideas from other studies conducted in different contexts. Furthermore, some believed that scientists even used each other's data in order to get a broader perspective about the river issues. In terms of collaboration among scientists, most of the participant students noted that scientists studying different rivers worked together to find out more information. However, Alex and Dirk's students were hesitant about this idea. Even though one of their students believed that different studies could give scientists a sense of reference, the major opinion was that collaboration among scientists studying different rivers was impossible due to the contextual differences that included cultural, geographical, and social factors affecting the conditions of the rivers.

Trustworthiness of science and scientists. Participant students' beliefs about the trustworthiness of science and scientists differed based on the characteristics of the instruction they received. To illustrate, the data-driven SSI focused instruction in Amy's and Jonny's classrooms led their students to have strong faith in science and scientific data. These students believed that science was all about data, and that these data and facts were objective. In addition to data, most students in these two classrooms highlighted the credibility and trustworthiness of scientists. By contrast, in Thom's classroom, students argued that scientific studies involved both facts and personal opinions of scientists. His students stated that science was supposed to be unbiased, but opinions were also involved which could generate bias. They believed that the data itself was not enough to eliminate bias because a scientist could manipulate numbers and graphs. Lastly, Alex and Dirk's students showed a strong skepticism about both scientists and their studies. These students recognized that bias could impact not only scientists' interpretations of data, but also their data collection and analysis procedures. To illustrate, one of the students stated that scientist gave the public what they wanted the public to see. Another student argued that numbers themselves were capable of presenting information as more significant than it actually was. Unlike students in other classes, students in Alex and Dirk's classroom did not separate data and facts in describing bias in science.

Socioscientific reasoning.

Recognizing the inherent complexity of SSI. Dealing with socioscientific issues requires students to recognize their complexity (Sadler, Barab, & Scott, 2007). While demonstrating their understanding about the issue of sediment and chemical load in the river basin, students frequently highlighted its complexity. However, the factors students believed made the issue complex were wide-ranging. One of the most commonly stated factors that made it complex and hard to resolve was the involvement of different groups with divergent values, interests, and perspectives. In addition, some students addressed the conflicting interests of communities upstream and downstream while addressing the complexity of the issue. Most students pointed out the impacts of actions taken upstream on a large scale through the Mississippi River and Gulf of Mexico, except for Thom's students, who addressed more local conflicts, such as a dam removal in their town and the impacts of this action on downstream communities.

Students also believed that the economic aspects of the river issues increased the complexity because any action taken for the sake of the river created economic consequences for the farmers living along the river. In addition to the economic consequences of proposed actions for farmers, some students also addressed the potential impacts on the state's economy in case of any restrictions in existing agricultural practices. Students stated that all these economy-related aspects made it hard to resolve the issue.

Lastly, students expressed that the multiple contributors in the scenario, both human-made and natural ones, made the issue hard to resolve and complex. The students who were aware of natural contributors to sediment load in the river, such as increased precipitation, believed that it was hard to control those natural contributors. In addition, students perceived that the public discourse around the issue had become more agriculture-focused although this was not enough to resolve it. Therefore, those students argued that natural contributors to the issue made it more complex.

Examining issues from multiple perspectives. In socioscientific issues, no single perspective is necessarily privileged, and the SSI literature emphasizes "the importance of students coming to recognize perspectives other than their own particularly when other perspectives directly challenge the ideas they hold" (Sadler, Barab, & Scott, 2007, p. 376). As students investigated the sediment load issue in the river, their argument mainly centered around whether agriculture or erosion was the main contributor of the issue. Therefore, their examination of the issue was strongly affected by the position they held on this controversy. To illustrate, students who had a solid position about the causes for sediment load in the river usually took a single perspective and addressed the scientific studies and personal experiences to support their argument. On the contrary, students having a more neutral position on the issue were able to address the perspectives of different groups while explaining the issue. These students believed that the complexity of the issue required them to understand all different perspectives while dealing with the controversial river issues.

Perspective taking is an important skill to understand the cognitive and emotional perspectives of others (Khan & Zeidler, 2013). In Amy and Jonny's classrooms, students coming from farming families or working in farms strongly sympathized with farmers while discussing the sediment and chemical load issue. These students often made arguments about the economic conditions for farmers while exploring the sediment load issue. On the other hand, regardless of their background, all students in Thom's classrooms not only showed sympathy for farmers, but also described the sediment load issue in the river from the agricultural perspective. They made explicit references to their observations of the positive changes on farmers' practices, as well as the restrictions farmers faced regularly. The perspectives Alex and Dirk's students took on farmers were mainly determined by the focus of their student-driven projects. For instance, students whose project was building rip-rap to prevent river bank erosion made arguments supporting farmers' point of view that erosion was the main contributor of sediment load in the river. However, another group of students who designed filter strips in agricultural fields in order to prevent chemicals from entering the river supported the perspective that farmers were responsible for sediment and chemical load in the river.

Appreciating that SSI are subject to ongoing inquiry. Ability to conceptualize SSI as subject to ongoing and open inquiry is an important aspect of socioscientific reasoning (Sadler, Barab, & Scott, 2007). When students addressed the scientific inquiries about the river basin, they all stated that scientists constantly collected data on different locations and time periods. They were also aware that the shifting conditions of the river required scientists to make ongoing inquiries on the river problems in order to update the information they presented to the public. Students firmly believed that scientists had to make long-term inquiries in order to find patterns in their data, thus have more reliable findings. Nevertheless, their statements about the sediment and chemical load issue in the river were quite conclusive. Even though they highlighted the continuing research around the river, some students believed that new research would not change the existing conclusions dramatically.

Students also made predictions about the next steps scientists take after collecting their data and making interpretations in order to pursue their inquiry. One common idea was scientists coming together to make more conclusive and general statements about river problems. Even though some highlighted that scientific studies were context-bound, most students believed that different studies conducted in different areas could give scientists studying the Minnesota River Basin a clear sense of reference or a broader perspective. Then, these scientists could take their inquiries further based on what they got out of those different studies.

Exhibiting skepticism when presented potentially biased information. The ability to demonstrate skepticism when faced with potentially biased information and judging the trustworthiness of information is an important aspect of socioscientific reasoning (Sadler, Barab, & Scott, 2007). Students' level of skepticism about the information presented in the context of river basin issues was varied based on the sources of information. Regardless of their view, students were less skeptical about the scientific information than any other kind of information. However, most students still recognized that scientific studies could potentially present biased information about the issues around the river. More specifically, most students considered opinions and interpretations as the sources of bias in scientific studies, whereas only few believed that data and facts presented in those studies could be biased. Students who were skeptical about the scientific information also addressed some sources of bias in scientific studies, such as funding and vested interests of individual scientists.

Specifically, in the context of Minnesota River Basin, students were even more skeptical about scientists and their studies around the sediment load issue. Despite the fact that Amy and Jonny's students who believed that farmers were responsible for the sediment and chemical load in the river supported their arguments with the scientific studies relevant to their opinions, the students who had connections with the farmers in their communities developed negative attitudes towards scientists studying the river basin. Because of the strong emphasis on the trustworthiness of scientific data in their classes, those students with agricultural connections distrusted scientists by stating that they are biased. These students thought that scientists used opinion-based information instead of facts and data. Specifically criticizing the scientists who blame farmers for their negative impacts on the river, some of these students even suggested bringing other scientists to study the Minnesota River. On the other hand, students in Thom's and Alex and Dirk's classrooms, regardless of their background, were more skeptical about science itself, instead of just scientists. When the scientific findings about the river basin issues were not relevant to their beliefs and experiences around the river, they either showed skepticism about the scientific data or referred to the alternative explanations that were not possible to be explained with the scientific data, such as the Native American perspective or their own observations around the river.

Compared to scientific information, students were more conscious about biased information presented by other actors in the context of river basin. Environmental agencies were one of those actors that students frequently blamed for dominating the discourse and overstating the facts based on their goals. Thus, students were most critical and skeptical about environmental agencies. Most students believed that economic factors were the main sources of bias in the information presented about the sediment and chemical load in the river. They stated that economic concerns significantly impacted the information presented in different resources, including media and scientific studies. In addition, the students stated that personal interests of different actors in the issue caused them to present biased information.

Discussion

Using the themes that emerged through the cross-case analysis, this study generated discussion about participant students' understanding of science and their socioscientific reasoning.

RQ1. How does secondary school students' understanding of science around SSI develop through SSI-based science classes. SSI-based learning experiences have a great potential to enhance students' understanding of how science works outside of the classroom (Burek & Zeidler, 2015). However, teachers' pedagogical approaches usually tend to guide their students' understanding, knowledge, and skills (Zeidler, 2014). The findings of this study revealed that students' understanding of the ways scientists study the river was strongly influenced by the SSI-focused units they experienced. While almost all students addressed the data collection and analysis related to the water analysis activities in the field that each teacher integrated in their curriculum, Alex and Dirk's students specifically pointed out different forms of data based on their own investigations of community-based environmental issues, such as interviews with the locals and investigating historical pictures and maps. Moreover, those students from Alex and Dirk's class also highlighted the social and cultural contexts in which scientific studies were conducted. Bingle and Gaskell (1994) highlighted that it was important to understand the importance of contextual factors affecting the scientific claims made, especially in the situations where “they are engaged in a process of deciding whether a claim would have been different if the science was conducted and evaluated by a different scientist, in a different context” (p. 191). Explicitly addressing the social factors affecting scientific studies around the river basin, Alex and Dirk helped their students become aware of those contextual factors that made scientific inquiries unique to their own contexts, while students from other classrooms denied interactions of this sort.

Students’ arguments about bias in science mainly revolved around the distinction between facts and opinions. Students from Amy’s and Jonny’s classrooms mostly stated that scientific studies needed to be free of opinions, and data and facts were enough to portray the objective truth. In contrast, students from Thom’s and Alex and Dirk’s classrooms argued that scientific studies involved both facts and personal opinions of scientists, and the data itself was not enough to eliminate bias. In their study, Zeidler et al. (2002) reported similar results that students equated subjectiveness in science with personal opinions, while highlighting the objectivity of scientific knowledge that requires proven facts and data. However, using an SSI context that was close to participant students’ home and more relevant to their lived experiences, this study uniquely revealed that participants’ understanding of bias that revolved around facts and opinions was strongly influenced by not only intellectual constructs (e.g. cognitive) but also psychological constructs, such as sociomoral considerations and perspective taking. This was evident when students’ empathy for farmers sometimes affected their evaluation of scientific information that blamed farmers for their actions.

RQ2. How does secondary school students' socioscientific reasoning develop through SSI-based science classes. In demonstrating their reasoning about the socioscientific issues around the river basin, some students attempted to reason scientifically, while others showed multiple reasoning modes in their decision-making. Liu, Lin and Tsai's (2011) study on the relationships between scientific epistemological views and reasoning processes in socioscientific decision-making revealed that non-science majors were likely to use more reasoning modes than science majors. The authors suggested that in order to actively participate in issue investigation and decision-making processes, students needed to utilize multiple reasoning modes and interdisciplinary thinking. In this study, Amy's and Jonny's students, who were exposed to data-driven SSI instruction, mostly reasoned scientifically about the sediment load issues. In addition, as both Amy and Jonny integrated SSI content in their biology classes, students also presented the examples of ecological reasoning in describing the river issues. In contrast, Thom's and Alex and Dirk's students showed multiple reasoning modes, including scientific, social-economic, ethical, and ecological reasoning modes, in their decision-making about the sediment load issue in the river. The recognition of various perspectives influencing positions taken in response to socioscientific issues was required for the display of multiple reasoning patterns (Sadler & Zeidler, 2005). Therefore, it is fair to assume that the inclusion of social domains, such as ethics and economics, and taking a multidimensional approach in SSI-based instructions in those two classrooms helped students have the reasoning modes that both science and non-science majors presented in Liu, Lin and Tsai's (2011) study. Lastly, this study showed that students who had agricultural connections showed stronger economic reasoning than others in the sediment load issue because they were well aware of the economic consequences of this issue for farmers.

In general, students from Thom’s and Alex and Dirk’s classrooms showed higher socioscientific reasoning levels than Amy’s and Jonny’s students. There could possibly be several different instructional decisions that led to this difference, such as the explicit inclusion of social domains and student-driven community involvement projects. When Sadler, Klosterman, and Topcu (2011) found no statistical difference on high school students’ socioscientific reasoning levels after the implementation of a SSI-based unit, they argued that “this non-result may indicate that an intervention of this limited time frame cannot affect change in SSR [and] changes in SSR may require longer development periods” (p. 72). In this study, Thom and Alex and Dirk’s comprehensive semester-long SSI content integration, compared to Amy and Jonny’s few-weeks long isolated units, could result in higher level socioscientific reasoning in their students.

Complexity. Recognizing the complexity of socioscientific issues is considered an important aspect in making decisions while dealing with socioscientific issues. Hogan (2002) argued that “socioscientific problems are not conducive to being decomposed and handled one dimension at time, but rather must be considered in all of their systemic complexity” (p. 364), and understanding the behavior of complex systems is a necessary basic literacy in environmental science education. Studies from different contexts (Pedretti, 1999; Hogan, 2002; Sadler & Zeidler, 2005) found that students usually recognized the complexity of socioscientific issues. In this study, participant students not only recognized the complexity of sediment and chemical load in the river, but they also appreciated it. Nonetheless, students made different arguments in describing the reasons that made the issue complex. In addition, their personal perspectives, knowledge, values, and backgrounds, as well as the characteristics of their communities, strongly impacted the way they described the complexity of the issue. To illustrate, students taking an agricultural perspective in the issue usually addressed the economic consequences for farmers that made the issue too complex to be resolved.

Perspectives. The complex structure of socioscientific issues involves a multiplicity of participant roles, the interpretation of scientific and public discourses, and the potential tensions between public and scientific perspectives and reasoning (Goodnight, 2005). That is why individuals dealing with socioscientific issues need to employ multiple perspectives in order to be able to fully understand these issues. In examining the issue, students' arguments centered on whether to blame farmers for the issues around the river basin. Students from Amy and Jonny's classrooms, except the ones having personal connections with farmers, often blamed farmers by pointing out the scientific data and findings. Due to their data-driven objectives of their instruction, those students from Amy and Jonny's classrooms approached the river basin issues with scientific knowledge and perspectives, but missed the social facets such as ethics, values, and economics. However, the literature indicates that the knowledge about the subject matter is unable to fully address the beliefs regarding SSI (Thomas, 2000), and attempts to explain an SSI with only this knowledge leads to a greater acceptance of one idea over another although a single conclusion is usually not available in those issues (Dawson, 2000). Thus, those students accepted without skepticism the idea that 'farmers were to blame' over the other positions and explanations. Though the research indicated that the empirical evidence is not enough to make decisions (Bell & Lederman, 2003; Wu & Tsai,

2007) and settle a problem (Levinson, 2006; Sadler, 2004) in socioscientific issues, the SSI instructions that Amy and Jonny designed around scientific data led their students to believe that scientific studies were enough to understand the problem comprehensively. Therefore, students ignored the economic, social, and cultural factors that significantly impacted the scenario as they concluded their thoughts. This supports Ryder's (2001) idea that the science curriculum is unable to address all of the concerns surrounding sociosientific issues.

In contrast, Thom's and Alex and Dirk's students, regardless of their background, were able to examine the sediment and chemical load issue in the river from farmers' point of view. Because these teachers covered social domains, such as economics, ethics, and culture, their students were able to describe the issue from the perspectives of different actors. In addition, those students were able to describe the issue from the perspectives of upstream and downstream communities as these communities experienced the causes and consequences of the issue differently. Khan and Zeidler (2013) refer to this as perspective-taking skills, which enable understanding of the cognitive and emotional perspectives of others, and that this is necessary to understand the multi-faceted nature of an open-ended, debatable SSI. While taking the perspectives of the actors in the issue, students from these two classrooms were also skeptical about those actors, including the scientists. Thus, they were able to have a more comprehensive perspective and understanding about the issues, as promoted by Khan and Zeidler (2013).

Inquiry. The science involved in current socioscientific issues is often 'science-in-the-making' and tentative results from frontier science (Bingle & Gaskell, 1994; Kolsto, 2000; Calik, Turan, & Coll, 2014). That is why it is important for students to be aware of the fact that scientific inquiries about socioscientific issues are ongoing. In this study, students were well aware of the ongoing scientific inquiries around the river issues. Furthermore, most students believed that scientists' long-term inquiries were necessary to identify patterns of data for stronger interpretations. However, students did not really appreciate the ongoing inquiries about the river as they sought immediate conclusions.

Skepticism. In terms of skepticism about scientific information, the literature reveals that students often take into account arguments that fit their prior beliefs and knowledge or had personal relevance to be more convincing, instead of their empirical embeddedness (Hogan, 2002; Kolstø, 2001; Sadler, Chamber, & Zeidler, 2004). In this study, the personal relevance of scientific claims about the sediment load issue in the river significantly impacted students' skepticism about scientific information. However, students' evaluation of scientific claims was not influenced by the scientific merit and empirical strength of those claims. Instead, their personal beliefs, perspectives, and vested interests strongly influenced their evaluation of scientific information. These students usually valued the evidence and data associated with the positions they supported in the sediment load issue.

Kolsto (2001) also framed the necessity of skepticism regarding the information presented in socioscientific scenarios as "in addition to the scientific knowledge offered, one usually also has to deal with the issue of trustworthiness of knowledge claims from other actors engaged in the issue" (p. 878). The findings of this study indicated that students were more skeptical about any kind of information compared to scientific information. They frequently claimed that different sources of information, such as media and environmental agencies, presented the sediment load issues more extremely than it actually was in order to get more attention. That is why most students preferred to ignore the information presented by those resources. In contrast to these resources, most students valued their personal conversations with the actors in the sediment load issue, thus being less skeptical about those first-hand information.

Additional aspects for socioscientific reasoning framework. When they proposed socioscientific reasoning as a theoretical construct, Sadler, Barab, and Scott (2007) stated it was an initial attempt to identify SSI reasoning aspects, and their work left open the possibility for identifying additional SSI reasoning aspects. This study revealed that students highlighted additional practices in which they engaged while negotiating socioscientific issues around the river basin. In addition, the findings indicated that the significance of each aspect of the socioscientific reasoning theoretical construct can differ based on the contextual differences in specific SSI that students deal with because SSI are bounded with the contexts in which they occurred.

This study proposes the inclusion of three additional aspects for socioscientific reasoning theoretical construct: (1) identification of social domains affecting the socioscientific issues, (2) making cost and benefit analysis for evaluation of claims, and (3) understanding that SSI and scientific studies around them are context-bound.

One of the most commonly observed practices in this study was the identification of social domains (e.g. economics, ethics) affecting the socioscientific issues. As they identified different social domains in sediment load issue, students had a comprehensive view about the issue, as well as being able to explain the issue from various perspectives. Supporting this observation, Aikenhead (1985) argued that there are several social domains impacting the decision-making processes, but not all social domains are relevant to every socioscientific issue. Therefore, in order to avoid simple decisions, one first needs to figure out which social domains are relevant and then "identify the social domain in which the final decision will likely be made" (p. 462).

Another practice students exhibited while dealing with socioscientific issues was making cost and benefit analysis for evaluation of claims. In dealing with sediment load issue in the river, students often considered pros and cons of the ideas proposed by different actors. To illustrate, one of the students noted that although buffer strips offered benefits for the river, the economic costs for farmers were too significant. Making a cost/benefit analysis, he decided to reject the buffer strips as a possible solution in this issue. Pedretti (1999) also highlighted the practice of making cost-benefit analysis in socioscientific issues by stating that students should be encouraged to adopt a critical thinking disposition that would allow them to investigate the pros and cons of any scientific and technological development, as well as examining potential benefits and costs.

The last practice students used in dealing with socioscientific issues around the river basin was understanding that SSI and scientific studies around them are context-bound. In SSI, scientific information is usually inconclusive (Klosterman, Sadler, & Brown, 2011); that is why it is more exposed to contextual pressures (Longino, 1990). As mentioned before, students, especially the ones from Alex and Dirk's classroom, highlighted that scientific studies around the river were strongly influenced by the social and cultural factors, as well as the geographical structure of the river basin. Therefore, the scientific claims made in different contexts were not always valid in the context of the

Minnesota River Basin. Being aware that SSI were context-bound, those students were able to address different sociocultural contextual influences on SSI.

Chapter 5: Synthesis and Recommendations

Several science education researchers have documented the significant relationships among teacher beliefs, teaching practices, and student learning (Bryan & Atwater, 2002; King, Shumow, & Lietz, 2001; Lederman, 1992). In order to explore this relationship in detail in the context of SSI, the case studies in this dissertation aimed at describing secondary school teachers' experiences of designing and teaching SSI-based instructions and their students' science understanding and socioscientific reasoning in three case studies. The first case study presented three secondary science teachers' experiences of designing and teaching technology-rich SSI classes, as well as the underlying contextual factors affecting their experiences. The second case study documented a science teacher and a social studies teacher's experiences of co-designing and co-teaching an SSI-based Environmental Ethics class. The last case study investigated secondary school students' science understanding and socioscientific reasoning developed through the instructions documented in detail in the first two studies. The studies in this dissertation confirmed the relationship among teachers' beliefs and motivation, their teaching practices, and their students' learning. However, each aspect in this relationship model was exposed to many external influences due to the significance of the context for SSI. Therefore, this relationship in the context of SSI was not demonstrated as rigid as stated in the science education literature.

Summary of the Major Findings

The first paper, *Case Studies of Secondary School Science Teachers Designing Technology Rich SSI-based Instruction*, presented a multiple case study conducted within the secondary schools located along the Minnesota River. The results of in-depth interviews and classroom observations indicated that teachers' practices of teaching SSI are strongly influenced by their backgrounds, beliefs, motivations, and experiences, as well as the conditions established in their communities and institutions.

The findings of this multiple case study highlighted that the main conflict in designing and implementing SSI-focused instructions was whether it should be free of social facets (e.g. ethics, values, culture) and controversy. Amy, one of the participants in her early years of teaching, intentionally excluded the social aspects and only focused on scientific data and findings in order to provide students the least biased information, which was her way of presenting the issue in a less controversial way. Jonny, another participant teacher in his early years, was also hesitant to teach social facets and controversy in his SSI-based classes; however, he was more encouraged and motivated to address controversy in his SSI-focused unit after his professional development experiences. Thom, the most experienced teacher among the participants, however, tried to cover multiple facets of the issue and used controversy to help his students take their own position on the socioscientific issues in the river basin. The results of this study also suggest that teachers' epistemological and pedagogical beliefs and the culture of the school and community they lived in strongly influenced their design and implementation of SSI instruction. The findings revealed that teachers' epistemological and pedagogical beliefs about science, technology, and socioscientific issues altogether drove their SSI-based instructional practices. In addition, the social and cultural conditions established in communities, as well as the trust relationship between school and community members, impacted teachers' strategies for teaching SSI.

The second paper, *A Case Study of a Science and a Social Studies Teachers'*

Experiences of Co-Teaching SSI-Based Environmental Ethics Class, presented a single case study conducted within an elective Environmental Ethics class. This study demonstrated the ways a science and a social studies teacher shared responsibilities in designing and teaching an SSI-based class based on their pedagogical and content-related strengths and expertise. The findings of this single case study highlighted that participant teachers strong believed that traditional environmental science curriculum and textbooks were not fully able to address socioscientific issues; therefore, they structured their SSI-based class on a framework called *triple bottom line* (social, economic, and environmental). In order to be true to this framework, these teachers used external resources and dedicated a significant part of their environmental ethics curriculum to multidisciplinary content and student-driven projects. As a result, the environmental ethics class provided students a broad perspective about the SSI around the river basin by covering not only traditional environmental science content, but also various social perspectives, such as economics, ethics, culture, and politics.

In addition to the co-teaching aspect of Environmental Ethics class, the results of this study also demonstrated the strategies these teachers used to promote the agency of their students in their SSI-based class. The findings indicated that when teachers give students power to choose their own focus, which they feel passionate about, in taking pro-environmental actions, students were likely to gain ownership of their own learning experiences and feel empowered to use these experiences to make changes in their lives and surroundings.

The last paper, *Secondary School Students' Understanding of Science and Their Socioscientific Reasoning*, was a multiple case study that investigated the development of students' science understanding and socioscientific reasoning through the SSI-based instructions that were addressed in the first two studies. The findings of the study revealed that students' understanding of science, including scientific method, social and cultural influences on science, and scientific bias, was strongly influenced by their experiences in SSI-based classes.

The findings of this study also indicated that multidimensional SSI instruction (Thom, Alex and Dirks' classrooms) results in students having multiple reasoning modes, such as ethical and economic reasoning, compared to data-driven SSI focused classes (Amy and Jonnys' classrooms). In addition, the in-depth interviews revealed that the personal relevance of the SSI, as well as students' backgrounds, beliefs, knowledge, and values, strongly influenced students' ability to recognize the complexity of the issue, to take multiple perspectives in examining the issue and to exhibit skepticism about the information presented. In contrary, although students found long-term ongoing inquiries around the river basin necessary, they did not appreciate those inquiries as they sought for conclusive statements.

In addition to describing how participants presented complexity, perspectives, inquiry, and skepticism aspects of socioscientific reasoning (Sadler, Barab, & Scott, 2007) in the context of SSI around the river basin, this study also proposed the inclusion of three additional aspects for the socioscientific reasoning theoretical construct: (1) identification of social domains affecting the socioscientific issues, (2) making cost and benefit analysis for evaluation of claims, and (3) understanding that SSI and scientific studies around them are context-bound. The researcher concluded that because SSI are bounded with the contexts in which they occurred, the significance of each aspect of the

SSI reasoning theoretical construct can differ based on the contextual differences in specific SSI that students deal with.

Crossroads and future directions in SSI research and practice. In the recently published *Handbook of Science Education*, Zeidler (2014) listed 16 overarching core questions in four different categories for crossroads and future directions in SSI research and practice. The four main categories were: (1) SSI as engagement of curriculum practice and teachers' pedagogical beliefs, (2) SSI as epistemological development and reasoning, (3) SSI as context for the nature of science, and (4) SSI as character development and citizenship responsibility. In this section, the finding of the three studies will be described briefly in light of these four main areas for SSI research:

SSI as engagement of curriculum practice and teachers' pedagogical beliefs.

What does the full range of scientific inquiry (including the use of technology) look like in SSI contexts. The first two studies in this dissertation presented different forms of inquiry in examining the socioscientific issues in the river basin. Those different forms of inquiries were wide-ranging as they were strongly influenced by teachers' understanding of science, as well as the objectives they decided for their SSI-based instruction. Students from the classes that were centered on data collection and analysis made their inquiries around the river basin by collecting water samples and doing analysis. However, the inquiries of students from the classes with multidisciplinary focus also included having conversations with experts and local people, exploring different social, political, cultural, and historical perspectives, and synthesizing various perspectives and arguments to reach conclusions. In addition, these case studies revealed the interrelationship between teachers' selection of different technology tools and the variations in the types of scientific inquiry that occurred in their classrooms. While the use of Vernier probes was common in collecting quantitative data, students used different technology tools based on their inquiries such as tablets to collect visual data (e.g. taking photographs from the field, recording the interviews with the experts) and document their experiences.

How can SSI curricula be leveraged to facilitate environmental commitments and related sociopolitical action. The first two studies in this dissertation also presented examples of how teachers encourage their students to take pro-environmental actions. Designing their SSI curriculum around community-based service learning projects, these teachers empowered their students to make positive changes in their communities. The first study showed that Thom's community-based projects helped students create dialogues with the members of their community while exploring those issues. In addition, through designing Public Service Announcement Projects (PSA) about community-based environmental problems, these students aimed at promoting awareness in their community about the issues they investigated in their projects. In the second study, while Alex and Dirk designed their class based on the idea of a triple bottom line, they also strongly encouraged their students to take similar approaches while investigating different community-based issues for their projects. Therefore, students took social, economical, and environmental perspectives into consideration, as well as political and cultural conditions established in their communities. These cases also illustrated the sociopolitical actions students took for these projects, such as talking to stakeholders, advocating on behalf of their projects to policymakers, and informing the public about the environmental issues.

SSI as epistemological development and reasoning.

What intellectual and psychological constructs (e.g. cognitive, sociomoral, moral reasoning, perspective taking) contribute in fundamental and meaningful ways to SSR. While the third study of this dissertation focused on secondary school students' socioscientific reasoning, it also indicated how different intellectual and psychological constructs, such as economical reasoning and perspective taking, contributed to their socioscientific reasoning. Because the socioscientific issues around the river basin were close to students' homes, psychological constructs (e.g. perspective taking) became prominent in contributing to participants' socioscientific reasoning, especially to their ability to take multiple perspectives and skepticism about the information presented. While addressing the relationship between these constructs and socioscientific reasoning, the study also revealed the underlying factors affecting this relationship (e.g. background of the students, recent conditions in the community) by highlighting the meso and micro-level contextual influences. For example, students' connections to farmers in their communities strongly influenced their perspective taking skills, thus granting multiple perspectives.

How might critical pedagogy, postcolonial, and feminist lenses, for example, empower research and practice in SSI. The second study in this dissertation reports how teachers promoted the agency of their students through student-driven projects. Participant teachers made use of the multi-faceted nature of SSI to give their students freedom to choose the topics they felt passionate about. As a result, a sense of agency empowered their students to use the class to make changes in their lives and surroundings, thus taking pro-environmental actions in their community. Considering the community involvement of students, this missing piece of agency in most educational settings was strongly present in the environmental ethics class. The more students took control of their own learning processes, the more their motivation for community involvement increased. Agency is also described as the actions directed against any given society's cultural and political normative practices (Pruyn, 1999). Alex and Dirk strongly encouraged their students to challenge the beliefs and practices of their communities in order to make a change. Therefore, the pro-environmental actions students took in their class challenged social and cultural practices in their communities.

SSI as context for the nature of science.

What explicit pedagogical strategies are effective to facilitate students' understanding of NOS within SSI strategies. The third study of this dissertation illustrates how differences in pedagogical strategies in teaching SSI culminate in variations in their students' understanding of Nature of Science (NOS), more specifically scientific methods, social and cultural influences on science, and scientific bias. Students described the ways scientists study the river based on their own inquiries in the class. To illustrate, students whose inquiries consisted of only water sample collection and analysis presented a traditional view of scientific methodology that was very quantitative-focused. However, students from Alex and Dirk's class described scientists' ways of studying the river by addressing not only quantitative data collection and analysis methods, but also other forms of data such as interviews with the locals and historical pictures and maps. In addition, these students from Alex and Dirk's class strongly highlighted social, cultural, political, and economical contextual factors that affect scientific inquiries. Therefore, they differed from the students from other three classrooms in terms of their understanding of ‘science as a social and cultural enterprise’, an important aspect of NOS. Lastly, students from Amy’s and Jonny’s data-driven SSI classes mostly stated that scientific studies needed to be free of opinions, and data and facts were enough to portray the objective truth. In contrast, students from Thom’s and Alex and Dirk’s more multidisciplinary focused classes argued that scientific studies involved both facts and personal opinions of scientists, and the data itself was not enough to eliminate bias.

SSI as character development and citizenship responsibility.

How can the SSI framework be informed by related areas of research to develop students’ sense of responsibility, civic obligation, and activism. The first two studies of this dissertation present how teachers’ pedagogical strategies, as well as their use of SSI content and context, promoted students’ sense of responsibility, civic obligation, and activism via student driven projects. Students from Thom’s and Alex and Dirk’s classrooms took pro-environmental actions via community-based service learning projects. These projects included civil works to fix problems, such as building ripraps to prevent riverbank erosion, as well as communicating with the public to build awareness about community-based environmental problems. Because the community-based issues that they addressed in their projects were close to their home, students felt responsible to take actions and be part of the solution. In addition, the third study provides an opportunity to compare the academic outcomes of the SSI classes that develop students’ responsibility, civic obligation, and activism with the content-driven SSI classes. The findings of this study indicated that students’ project focus strongly influenced not only their understanding of the socioscientific issues around the river basin, but also their opinions and perspectives about it.

Implications

The results of the studies in this dissertation have implications for a variety of audiences. In this section, the implications associated with researchers, teachers, and communities will be discussed. Beginning with researchers studying SSI, the first section will provide implications related to the methodologies to fully investigate their participants' beliefs and practices around socioscientific issues. Next, the implications for teachers concerning the types of curricular experiences that should be designed and the results that can be expected from such efforts will be discussed. Finally, implications are presented that affect the community associated with SSI curriculum focusing on local community-based issues and the potential impacts and associated opportunities.

Implications for researchers. The studies in this dissertation employed qualitative case studies for various reasons. The main intention of using the case study method was to explore the phenomena in the real life context where it occurred. Since the context played a significant role in participants' beliefs, perspectives, worldviews and experiences around the community-based socioscientific issues, the case studies methodology provided great advantages in exploring the relationship between the phenomena and its context. In addition, examining the contextual factors at different levels provided information about this relationship in detail.

Another implication for SSI-focused research was to choose interviewing methods over other types of data collection methods, such as surveys and questionnaires. There were several occasions where interviewing helped the researcher provide clear descriptions of participants' statements. To illustrate, even though students often used the term 'sediment' in the interviews, the prompting and/or follow-up questions clarified how their descriptions of sediment were wide-ranging.

The last implication for researchers was the use of interviews, observations, and reflective journals altogether in order to comprehensively portray the phenomena investigated. While observations reveal the practices of teachers in their classroom, the interviews illustrate effects of their thinking and decision-making processes on those practices. In addition to those two data sources, reflective journals incorporate the researchers' perspective about the practices of teachers, therefore providing a reflective balance. Hence, these different data sources were not only used for triangulation, but they also helped the researcher portray the phenomena in each case comprehensively.

Implications for teachers. It is also necessary to look at implications from a teacher point of view as well to get a full sense of the phenomena that occurred in the studies. Despite the significance of contexts for SSI, the attempts to teach SSI through decontextualized and irrelevant learning experiences are not unusual. In this study, by taking a context such as sediment and nutrition load in the Minnesota River, participant teachers focused on a local socioscientific issue that was relevant to students' lives. In this way, students were able to use their prior knowledge and experiences related to the issue. Therefore, contextualized and situated learning experiences around SSI helped participant students meet the academic objectives their teachers decided.

This study presented the examples of different teaching practices of socioscientific issues, as well as the reasoning behind those practices. Using a particular socioscientific issue as a context, the teachers addressed different content and standards in their science classes. Some teachers decided more science-driven content, whereas others gave more emphasis on social facets. Because of this, the objectives of SSI classes were significantly varied, as well as the academic gains of students. Based on the variation in the practices of participant teachers, it can be argued that teachers can use SSI flexibly as a context, thus incorporating the content and standards they need to address in this context.

The last implication for teachers is incorporating student-driven projects in SSI-based instructions. Two of the participants in this dissertation decided to dedicate a big part of their SSI-based curriculum to student-driven projects related to community-based environmental issues. Giving students freedom to choose their projects based on their own interests brought both advantages and disadvantages to those teachers. Because students decided their projects on the topics they felt passionate about, they were not only very motivated to complete their projects, but they also learned the content related to their project topics in-depth. On the other hand, for their projects, some students selected topics that were out of the SSI context teachers focused on in the class. Therefore, although they still gained expertise on the topics they selected, those students missed the opportunity to learn the actual SSI content as much. Teachers often indicated that it was challenging for them to find a balance between giving too much freedom and having too much control on those student-driven projects.

Implication for communities experiencing SSI. In addressing socioscientific issues in K-12 settings, the associated local communities present an invaluable resource and partner. There are organic collaborative opportunities within the community to be realized for mutual benefit between students and their communities. The bonds between schools and communities in which they are located provide students to communicate with the real actors in SSI and understand their perspectives. From this research and the associated findings, it is obvious that when students feel comfortable to go beyond the school borders and connect with the members of their communities, they get a broader understanding about socioscientific issues experienced by their communities. However, students are not the only beneficiaries in this scenario. The cases in this dissertation provide examples of how students can help preventing community-based environmental problems through service learning projects. When their motivation and efforts are responded by their communities, students are more likely to feel responsibilities and dedicate their time to help their communities.

Limitations

In this section, the limitations that emerged in this study will be addressed. Expressing the limitations of a study is necessary because each study has a unique nature that affects the types of data collected and the analysis therein (Wolcott, 1990). While the studies in this dissertation contribute to the body of knowledge on the SSI field, limitations emerged that require future investigation. There are three limitations that will be discussed. Each limitation is important to consider for the overall study because of its impact on how the study proceeded and the resultant implications for conducting the study.

The first limitation was the contextual factors affecting participants' beliefs and behaviors that were hard to explore. Even though the case study research design helped the researcher to explore the phenomenon within its authentic context, there were still limitations to fully determine how those contextual differences affected the phenomena investigated in the studies. Because the socioscientific issues are bounded with their real life contexts, participants' lived experiences outside of the school borders strongly impacted their views. Despite the fact that the study was designed to explore those impacts, there is a strong possibility that the researcher might underestimate or overlook some of those impacts that individuals experienced.

The second limitation was the researcher's proximity to the research site and the subsequent limitation of time on-site conducting research. This dissertation study involved case studies around four different schools located within a large watershed. Despite the efforts to observe significant parts of SSI-based instructions in each case, it was impossible to observe the entire implementation for each case, especially for the ones that integrated SSI content in a semester-long curriculum. However, the interviews with the participants helped the researcher get the full picture of the experiences of participants.

The third limitation was the specific context in which this dissertation study was conducted. While the results of each study in this dissertation could be transferrable to other K-12 settings having similar contexts, researchers should be cautious in applying the findings into other contexts. The particular characteristics of the SSI context in this dissertation, such as being close to participants' home, provided unique opportunities and challenges to the researcher different from many similar studies.

Directions for Future Research

The case studies presented in this dissertation work lead to some questions that need to be answered in further investigations. One future direction would be to investigate different SSI contexts that are also close to teachers and/or students' home and relevant to their lived experiences. Since this dissertation study focused on a very specific SSI topic in a specific area, it provided unique findings about the experiences of teachers and their students in SSI learning environments, but the findings may not be generalizable. Similar studies can help researchers to generalize the results this dissertation provided.

Another future direction would be to investigate what SSI can offer to address new reform movements in science education. Despite the criticisms that the use of SSI can threaten traditional science curriculum and students' understanding of basic science concepts, this study highlighted several advantages of the integration of SSI approaches in environmental science curriculum in different settings. The future research can investigate the advantages and disadvantages of infusing SSI into science curriculum designed based on the recent reform efforts, such as Next Generation Science Standards (NGSS).

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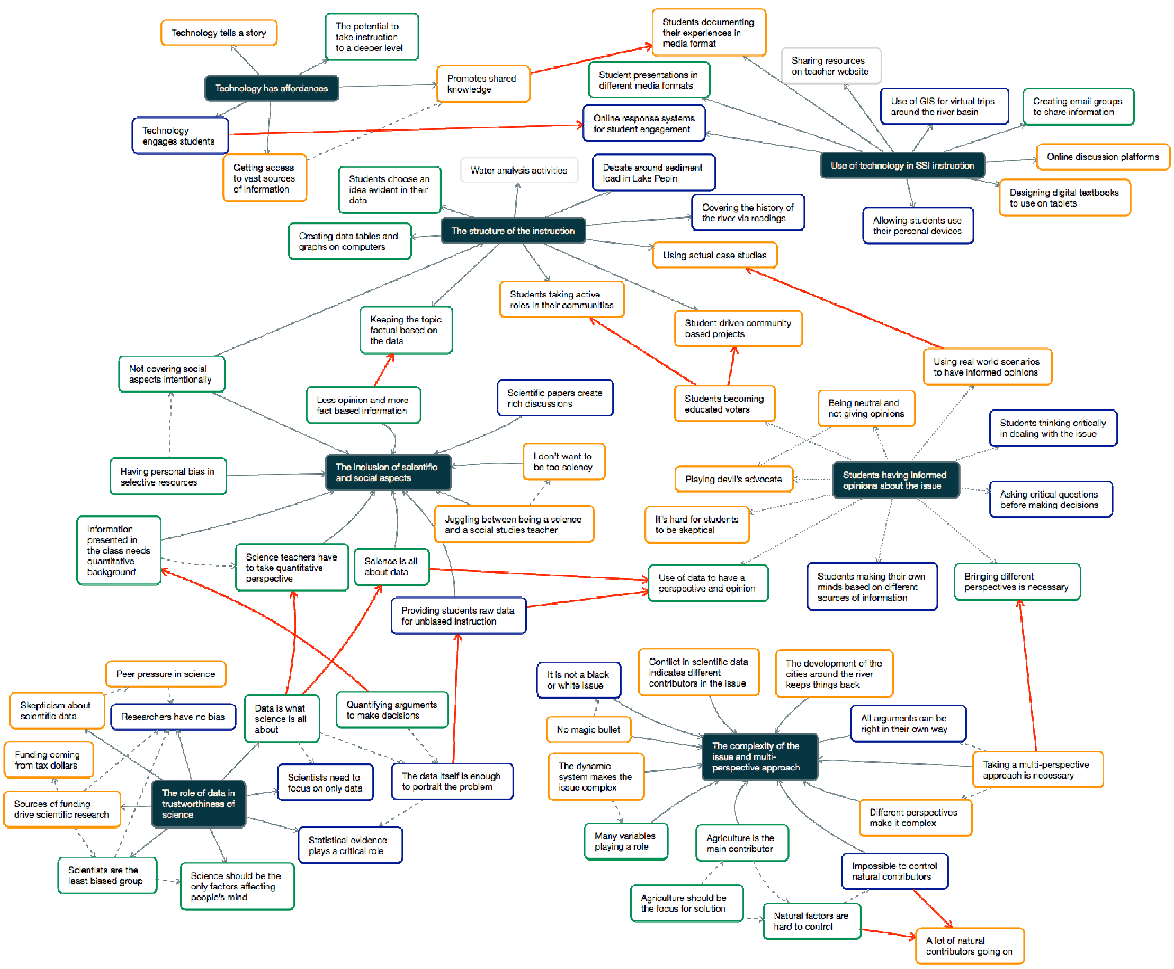
Appendix A: Cross-case model for Chapter II



Appendix B: Interview Protocol for Teacher Beliefs

- Can you describe the sediment and chemical load issues in the river basin in your own words?
- How does your community experience the issue?
- How do you think the researchers/scientists undertook their inquiries about the issue?
- How do you feel about the controversy around the issue?
- How do you feel about the disagreement among the scientists studying the river?
- What would be the criteria while evaluating a knowledge resource about the issue?
- How do you address the sediment and chemical load issue in your classroom?
- What are the specific pedagogical strategies you would use in addressing the issue?
- What would be your goals/objectives in addressing sediment and chemical load in your class?
- What are the potential challenges you could face in addressing sediment and chemical load in your class?

Appendix C: Interview Protocol for Teacher Practices

- How are issues of the MRB a community issue in your area/for your students?
- Describe your past experiences of teaching MRB in your classroom?
- What MRB content have you covered in your instruction?
  - Would there be any additional content you would have liked to cover?
- What kinds of instructional strategies do you use when you teach MRB?
  - Based on your recent experiences, would you do the same things in the future?
- What technologies do you know of that can be used to teach about the MRB?
  - What technologies have you used in class to learn about MRB issues with students
- Has technology impacted the way you teach Minnesota River Basin content? If yes, how?
- What kinds of technology tools have you used in order to make MRB content accessible to your students?
  - Has technology impacted your content choices about the issues around the MRB?
- What kinds of instructional strategies have you used in order to make MRB content accessible to your students?
  - Do you/have you integrate(d) students' interests into lessons? How?
- Based on what you had done and what you have done, what do you think you would like to do?

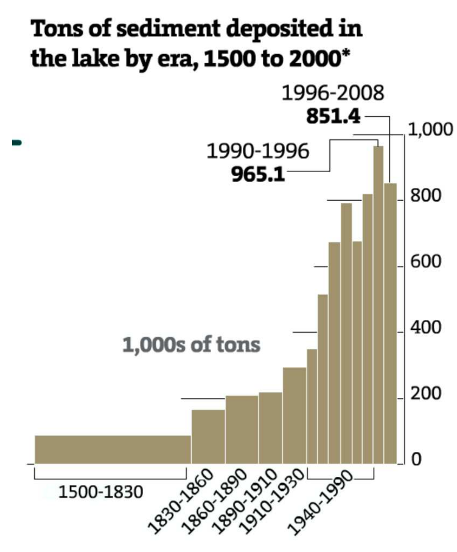
Appendix D: Local Article about Sediment Load in Lake Pepin

Who's to Blame for Sediment Choking Lake Pepin? by Mark Steil, Minnesota Public Radio

The Minnesota River's usually placid surface belies its status as a river —and a watershed—in need of help. The river is naturally prone to heavy sediment loads. It runs through rich glacial deposits, in a channel carved by a catastrophic flood at the end of the last ice age, when a large lake formed by glacial meltwater gave way.

In the last century, however, its watershed has undergone dramatic changes as human activity has added to the river's burden of sediment and nutrients. And lately, climate change has been exerting its effects— notably, shorter, more intense storms that magnify inputs from erosion.

Flanked by timbered bluffs flecked with bare rock outcroppings, the blue waters of Lake Pepin are visually stunning, even to long-time visitors.



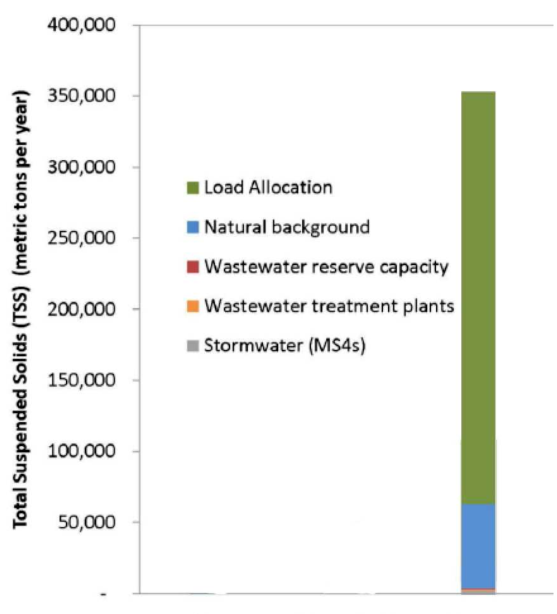
The 20-mile long wide spot in the Mississippi River is a traditional summer destination for tourists, and the spot where water-skiing was invented. But problems are brewing under the surface of Lake Pepin.

When it rains on the farmlands of southern Minnesota, rivers wash soil and sand towards the Mississippi. When the sediment reaches the slow-moving waters of Lake Pepin, it settles to the bottom, just like too much sugar in unstirred coffee.

FARMERS TO BLAME, MPCA REPORT SAYS

A new report from the Minnesota Pollution Control Agency essentially blames farmers for the growing sediment. Agency officials say agriculture has transformed the land so that more water flows into rivers, dramatically boosting riverbank erosion and sediment deposits in Lake Pepin.

The MPCA apportioned this total natural background load among basins in proportion to their relative contributions of sediment to Lake Pepin. Historical sediment core interpretation shows that the relative proportions of sediment contributed by each source area have remained stable over time (Kelley and Nater, 2000).



Sediment Loads by Minnesota River Basin

"At that rate the upper lake from Frontenac on upstream would fill in by the time this century is out," said Norman Senjem, the agency's basin coordinator for the Mississippi. "The whole lake would fill in within 300 years."

That outlook has spurred the MPCA to draft a plan to reduce the Lake Pepin sediment. But some farmers and researchers say more rain, not farming, is to blame.

Besides endangering Lake Pepin, the muddy Minnesota is also a problem for fish and other aquatic populations in the Minnesota River itself. A recent MPCA report said populations of insects, snails and mussels in the river continue to decline.

MORE TO SEDIMENT THAN FARM RUNOFF

It's easy see that the coffee-colored river carries a lot of dirt. But what's surprising is where the sediment originates. Although a third comes from farm runoff, the rest is soil washing out from bluffs, river banks and gullies.

It's the sort of erosion Glen Wilder can spot in a sandy ravine behind his home near Mankato. A few days ago, a rainstorm soaked the area, washing away more of the ravine's walls. With each storm, the ravine becomes wider and deeper, and the pace is accelerating.

The recent rain washed away an area of Wilder's backyard roughly 100 feet wide and 30 feet deep. The cascading sand toppled trees, and created more erosion trouble spots nearby.

"You can't go but a couple hundred feet and there's another big washout," he said.

Much of this soil will eventually reach the Le Sueur River, then the Blue Earth, and finally the Minnesota and Mississippi Rivers.

The fact that most of the Lake Pepin sediment comes from ravine and stream bank erosion may seem like it takes farmers off the hook. But the MPCA study has an important twist which the agency says puts the onus squarely back on agriculture.

It notes that ravines and stream banks are washing out at higher rates because more water flows through them. Agricultural drainage systems on thousands of square miles of farmland quickly route rainfall into streams.

As a result, water-absorbing grass and wetlands have nearly disappeared. Because farmers have extensively planted soybeans, which need less water than other crops, more moisture runs into waterways.

Senjem said farming practices have lead to measurable changes in the amount of water the Minnesota River carries.

"[It's] virtually doubled at Jordan," he said. "And you have comparable increases in flow in many of the tributaries."

INCREASED PRECIPITATION THEORY

Many farmers are skeptical of the MPCA's report. They're worried they'll have to pay for expensive erosion controls

based on the study's findings. They maintain most of the higher river flows are caused by increased precipitation, not farming practices.

A University of Minnesota soil scientist shares that belief.

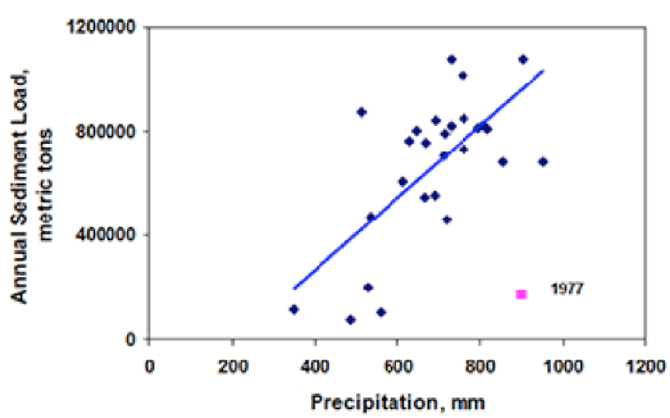
"Precip is the main driver," Satish Gupta, a professor in the university's department of soil, water and climate.

Gupta is standing on the bank of the Blue Earth River 15 miles from where it flows into the Minnesota. Across the water a sandy bluff rises 100 feet above the muddy river.

Gupta said rainfall along the most erosion-prone rivers near Mankato has increased by at least 25 percent in recent decades. He said the erosive power of that extra rainfall, not farming techniques, is causing the increased sediment.

Efforts to control the Minnesota River, such as the flood walls at Mankato, and the dredging of the last few miles of the Mississippi also have made the river flow faster.

"What we have done is we have changed the delivery system," Gupta said. "We have changed our delivery system by dredging the river, putting the levees in there."



Relationship between annual precipitation and sediment load in Minnesota River

ediment stays suspended in the iver over longer distances, rriving at Lake Pepin in greater mounts.

upta has taken a lot of flack from ther scientists for his findings. But many farmers have latched on o his conclusions, citing them as proof that they're not to blame for the sediment.

However, because agricultural groups have funded much of Gupta's research, critics of his work contend he has skewed his findings to lessen the blame on farmers, a charge he denies.

"If I am saying something wrong, my peers are going to find it out," Gupta said. "You cannot hide these things. If I am biasing it, saying one way or the other, they're going to do experiments and they will say I'm an idiot."

Gupta's work has been influential in the past. About 15 years ago, the U.S. Geological Survey estimated that 80 percent of Minnesota River sediment came from farm fields, and only 20 percent from stream banks, ravines and other sources. Gupta challenged that, saying most sediment came from ravines and stream banks, something the new MPCA study supports.

MPCA: SPRINGTIME RAIN HASN'T INCREASED

Senjem, of the MPCA, said Gupta's theory that increased rainfall, not farming, is boosting sediment rates in Lake Pepin, is wrong. Senjem said the increase in precipitation is nowhere near enough to explain the huge growth in river flows and sediment deposits. He said the only explanation is that farmland is absorbing less precipitation.

"The landscape has been altered so drastically that the response is much different today than it was in the past," Senjem said.

The agency has one more finding to bolster its argument. The most critical time for erosion is during spring downpours, but average springtime rains have basically held steady or even decreased since 1940, Senjem said. Still, spring river flows in some areas are way up, a pattern that points to farm country.

"In the highly agricultural, high row crop watersheds, there's a much stronger trend towards a higher runoff ratio," Senjem said.

The MPCA also dismisses Gupta's argument that levees and dredging force more sediment into Lake Pepin, saying research done for its draft report found those factors were negligible.

STAKES HIGH FOR FARMERS

The debate over sediment has high stakes for Wilder, whose family has owned crop fields for generations. But he has no doubt that modern agricultural practices play a big role in adding to Lake Pepin's sediment load.

As Wilder he stares at his crumbling ravine, he said there must be a dozen more washouts like it along this one gully. He said it would cost a lot of money to stop the erosion.

"We get an effect like we got here that we're looking at, it's almost unfixable in anybody's pocketbook," Wilder said.

Wilder's in a position to know. He started his own company; Wilder Erosion Control. But even he erosion expert wonders how much can be done to slow the mountains of sediment moving toward Lake Pepin.

* The images used in the article were added by the researcher. The original article provided different images.

Appendix E: Student Interview Protocol

- Could you walk me through your experiences in Mr. …'s class?
- Could you summarize what you have learned about the Minnesota River Basin this semester?
- Could you describe the best moment (learning experience) you have had in this class?

- First of all, why don't you explain the problem in your own words?
  - How would you describe the issues around Minnesota river?
- Do you think it is a complex and/or difficult problem? Why or why not?
- Why do you think we need to worry about the Minnesota River Basin problem?
- Can you tell me what you know about how scientists study this problem?
  - What kinds of data do you think scientists collect?
  - How do you think they collect their data?
- How do you think scientists came up with different conclusions after studying the same problem?
  - How do you feel about this lack of consensus?
- Can you please describe the different perspectives/positions people hold about the issues around Minnesota River Basin?
  - In addition to scientific research, what are the other factors affecting people's decisions about Minnesota River sediment load issue?
- Do you see any possible sources of bias affecting the information presented in the

scenario?

    - What would be the sources/reasons for these potential biases?

- How would you evaluate different opinions about the problems around Minnesota River or Lake Pepin as to whether they are strong or weak? What would be your criteria?
- There are other scientists investigating river/water issues in different parts of the world. How would you think these studies would impact the scientific studies around Minnesota River Basin?
- What additional information would you need before making your final decision?
- Considering our conversation and all of these different points of views about the sediment issue, what is your conclusion about the issue?
- Is there anything else you want to say?