Chapter 4
Learning Science Content and Socio-scientific Reasoning Through Classroom Explorations of Global Climate Change

Troy D. Sadler, Michelle L. Klosterman, and Mustafa S. Topcu

The goals for our research related to socio-scientific issues (SSI) have always been related to the promotion of scientific literacy (see Chap. 1) and the improvement of science learning experiences. However, the work has not always been centrally situated in classroom environments. For much of our early research, we explored students' moral perspectives (Sadler & Zeidler, 2004), reasoning (Sadler & Zeidler, 2005), understandings of science (Sadler & Fowler, 2006), and argumentation (Sadler & Donnelly, 2006) related to SSI in contexts not necessarily connected to students' experiences in science classrooms or other learning environments. We were interested in building an empirical understanding of how science learners made sense of complicated socio-scientific dilemmas, how they made decisions about these issues, and what factors influenced their thinking practices. We engaged students in reasoning and argumentation collecting data through interviews and instruments, but did not explore classroom practices or the possible effects of intervening in learning environments. In an attempt to advance the SSI research agenda and create stronger connections among theory, research, and practice we began working on projects situated in science classrooms.

To make this shift, we started to work on a large classroom-based research project focused on the implementation and study of a technology-based educational innovation. The centerpiece of the project was a multi-user virtual environment (MUVE) designed with contemporary gaming principles. The innovative teaching and learning technology, known as *Quest Atlantis*, provided opportunities for middle school learners to engage in critical thinking and explore content in several different academic areas (Barab et al., 2007). Within the MUVE, players could immerse themselves in different "worlds" each of which had unique curricular goals. One of these

T.D. Sadler (✉)
School of Teaching and Learning, University of Florida, Gainesville, FL, USA
e-mail: tsadler@coe.ufl.edu

M.L. Klosterman
Department of Education, Wake Forest University, Winston-Salem, NC, USA

M.S. Topcu
Department of Elementary Science Education, Yuzuncu Yil University, Van, Turkey

T.D. Sadler (ed.), *Socio-scientific Issues in the Classroom: Teaching, Learning and Research*, Contemporary Trends and Issues in Science Education 39,
DOI 10.1007/978-94-007-1159-4_4, © Springer Science+Business Media B.V. 2011

worlds placed students in a virtual park. The park rangers, charged with managing the park and balancing the health of the natural environment as well as the needs of several different groups of park patrons, enlisted the student players to investigate and propose courses of action to address the deteriorating health of a river flowing through the park. Various groups of park patrons relied on the river and its fish populations but these groups used the resources in different ways, impacted the health of the river in different ways, and had very different perspectives on preserving the resource. In short, this learning environment placed students in the midst of an unfolding SSI.

Our research efforts associated with *Quest Atlantis* involved case studies of classroom implementation including analyses of science content learning (Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007). We also explored ways in which students conceptualized novel SSI and the extent to which learners transferred understandings and practices developed in the context of one socio-scientific issue to other issues (Sadler, Barab, & Scott, 2007). As a means of framing transfer relative to SSI, we proposed a new construct, *socio-scientific reasoning*. Socio-scientific reasoning (SSR) was designed to capture the practices in which citizens can be expected to engage across multiple SSI. That is, socio-scientific reasoning was developed as a means of understanding student practices relative to the invariant features of SSI. (We will take up this topic in greater detail in a later section of the chapter.)

The *Quest Atlantis* findings certainly informed use of SSI by teachers and learners, but the research generated as many questions as it did answers. One important question for us related to the technology platform used to frame the curriculum. *Quest Atlantis* was a powerful teaching and learning environment, but the vast majority of secondary science classes were not well positioned in terms of using this kind of innovation. Therefore, we became interested in studying the implementation of SSI-based learning experiences in the context of classroom environments and resources that were more typical of today's schools.

Based on these experiences and the questions that they generated for us, we developed a new classroom-based study of the implementation of SSI-based curriculum and instruction. We initiated this new study, which serves as the focus of the current chapter, by first developing partnerships with two local high school science teachers. Based on assessments of the teachers' needs and interests as well as our goals for the overall project (to be discussed in the next section), we collaboratively decided that global climate change would serve as the SSI focal point for the project. As a part of the project, we created new curriculum and assessment tools for supporting teaching and learning in the context of SSI. The project became known as the Curriculum and Assessment Tools for Socio-scientific Inquiry (CATSI) project.

Project Goals

We had four goals for the CATSI project: (1) Design and implement a SSI-based curriculum in partnership with local teachers to meet the specific needs of these teachers and their students. (2) Develop an understanding of the implementation of

SSI-based instruction from an up-close perspective (i.e., from within the classroom as the learning experience unfolded). (3) Investigate how SSI-based instruction supports (or fails to support) student development of scientific content knowledge. (4) Extend previous work on socio-scientific reasoning through the exploration of how students may improve their SSR and experimentation with new SSR assessment strategies.

For the CATSI project, we were interested in creating materials and tools designed to meet the specific needs of our teacher partners. One of the consistent limitations cited by teachers interested in enacting educational innovations, particularly SSI-based instruction, was a lack of useful materials (Cross & Price, 1996; Lumpe, Haney, & Czerniak, 1998; Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006). Teachers often concluded that textbooks and other curricular materials did not meet the needs and/or interests of their students. Teachers also expressed skepticism regarding the extent to which curricula and specific learning activities embedded within these curricula could be enacted in their teaching contexts whether it be because of a lack of appropriate facilities, materials, funds or other context-dependent issues (Bryce & Gray, 2004). For these reasons, we chose to initiate teacher collaborations at the outset of the project in order to involve them in the design process with the goal of creating materials geared specifically for their use.

Our goals included not only the design of materials with collaborating teachers but also the study of classroom enactment of these materials. We took advantage of the working relationships that we had developed with the partnering teachers in order to gain an intimate vantage point from which to observe the implementation of SSI-based instruction. We sought to build understandings of how instructional materials built around socio-scientific themes would be used in classrooms with an eye toward distinctions between the intended curriculum, as shaped by our perspectives as designers and researchers, and the enacted curriculum as it unfolded in actual classrooms. By attending to these issues, we wanted to better understand how local contexts influenced the use of and results associated with SSI-based instruction.

Our third goal for the project related to the use of SSI-based instruction as a means of developing student understandings of science content. Researchers and educators have frequently cited the potential for using SSI as a means of providing meaningful contexts for learning science content knowledge (Cajas, 1999; Kolstø, 2001; Zeidler, Walker, Ackett, & Simmons, 2002). These authors (and others) have argued that SSI offered situations that connect science to the lived experience of learners thereby providing an impetus to understand the underlying science. Findings from studies of SSI have provided some initial support for the proposed link between SSI and the learning of science content (Barber, 2001; Zohar & Nemet, 2002). These studies documented content learning through comparison of postintervention assessments from students participating in SSI intervention classes and comparison classes. A possible critique of these studies was the lack of preintervention data that could have established the equivalency of groups and the change within groups. Other studies employed pre/posttest designs to document learning gains in the context of SSI (Dori, Tal, & Tsaushu, 2003; Yager, Lim, & Yager, 2006). These studies provided evidence of learning, but it was important to note that the assessments used directly aligned with the SSI intervention. In the

CATSI project, we aimed to examine content knowledge gains related to the SSI but also to the scientific generalizations that can be abstracted beyond the specific context of a particular SSI. In order to achieve this end, we adopted a multilevel assessment framework in which we created assessments at variable “distances” from the curriculum (Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002; this approach will be discussed in greater detail in a later section). Using these tools we sought to develop a more nuanced understanding of how SSI-based instruction supported student development of science content knowledge.

The final project goal was to further explore socio-scientific reasoning as a measurable construct for use in teaching and research contexts. As referenced above, we introduced SSR in our work on the *Quest Atlantis* project as a tool for conceptualizing student practices related to the negotiation of SSI (Sadler et al., 2007). We proposed four aspects of SSR that captured practices (some but not all) that are necessary for thoughtful negotiation and resolution of complex SSI. These SSR aspects included (1) recognizing the inherent *complexity* and multifaceted nature of SSI, (2) analyzing issues from multiple *perspectives*, (3) appreciating the need for ongoing *inquiry* relative to SSI, and (4) employing *skepticism* in the review of information presented by parties with vested interests. In the *Quest Atlantis* project, we explored SSR by engaging students in interviews during which they considered and discussed complex socio-scientific scenarios. In this initial work we demonstrated that some of the SSR aspects could be measured (i.e., inquiry and complexity) reliably and provided preliminary evidence that these aspects related to an underlying latent variable. In the CATSI project, we wanted to explore other SSR assessment options (noninterview based) with the aim of improving the reliability of measurement and to determine the extent to which students’ SSR practices could be improved in response to SSI-based instruction.

Setting

Before discussing issues associated with design, teaching, and research, we have chosen to discuss the settings in which the CATSI project was conducted. This decision was deliberate because the setting was a key determinant for decisions made in the design, teaching, and research. We felt it important that our work as designers and researchers fit well with the needs and interests of the classroom communities with which we worked. We prioritized classroom context in the design and implementation of the CATSI project and wanted this prioritization to be reflected here, in this description of the project.

We conducted the CATSI project in the science classrooms of two local schools. Although both schools were located fairly close to our university in the southeastern United States, they were parts of distinct communities. The first school, to which we referred to as Fields High School, served high school learners (grades 9–12) in a small, rural town. The second school, to which we referred to as Creek Academy, was a developmental research school affiliated with our university. Creek

Academy served students in kindergarten through senior high school (through grade 12) and was located in a moderate-sized city.

At Fields HS, we worked with Molly (pseudonym), a fourth year teacher who had spent her entire young career at Fields. During the year of the CATSI project, Molly taught environmental science and anatomy and physiology. Based on Molly's recommendation and the needs of her students, we developed the CATSI project for implementation in the environmental science courses (three sections). The daily schedule at Fields HS followed a traditional format in that classes met daily in 50-min blocks. Molly worked in a spacious classroom with separate areas for seated deskwork or whole-class instruction and laboratory investigations. The room was decorated brightly and displayed many examples of student work. Environmental science was a course taken primarily by 11th and 12th grade students looking to satisfy a science graduation requirement. Most of these students had taken an integrated science course in 9th grade and a general biology course in 10th grade. Environmental science students tended not to take advanced, college-track science courses including physics and chemistry. As a generalization, most of these students were considered to have average to remedial academic histories. The environmental science students tended not to exhibit enthusiasm for studying science or future careers in science and most did not plan to pursue postsecondary degrees.

At Creek Academy, we worked with William (pseudonym), a fifth year chemistry teacher. Creek Academy employed a block schedule in which each class met on Mondays for 50-min and in 100-min sessions on two other days each week. William taught multiple sections of honors chemistry and "regular" chemistry. Given curriculum constraints associated with the honors classes, we chose to implement CATSI with the regular chemistry classes (two). William's classroom was also spacious providing enough room for individual desks and a separate laboratory area. Simply stated, this classroom had the look and feel of a chemistry lab. A visitor would find various pieces of laboratory equipment, a fume hood with solutions waiting for mixture or display, and an adjoining, well-stocked storeroom. The most dominant classroom "décor" were the three large periodic tables situated so that they could be seen from any position within the classroom. According to state assessment tests, Creek Academy was a higher performing school than Field HS and a significantly greater percentage of Creek graduates matriculated to universities or community college. The highest achieving students and those who had shown strongest aptitude for an interest in school science took honors chemistry. Students who chose not to take the honors track took the regular chemistry course that William offered during their 11th grade year. These chemistry classes were best described as mixed-ability. The school's lower achieving students took the course along with high achieving students who were not particularly interested in science.

The settings in which we chose to work shared common features in that they both served students that were not the highest achieving science students in their schools. Early-career teachers interested in collaborating with university-based researchers led both classrooms, and the schools were geographically close. However, the classrooms were quite distinct in terms of subject area (environmental science and chemistry), schedule (traditional and modified block), and the communities served (rural town and university-based city). More information pertaining to how CATSI was developed for use in each of these settings will be shared in the following section.

Teacher–Researcher Relationships

We approached Molly and William with proposals to collaborate on a SSI-related project over a year prior to the initiation of CATSI. The initial conversations related to a large-scale professional development project dependent on grant funding, and the funds were ultimately not approved. However, these conversations revealed high levels of interest among all parties to collaborate on a project related to SSI-based instruction. The following year, we submitted and were awarded a small grant to partner with a local teacher to develop curriculum and assessment tools for socio-scientific inquiry, and the CATSI project was initiated. Because of the congruence between Molly's teaching focus and the principal investigator's area of expertise (i.e., biology education), we asked Molly to collaborate with us. At the time, Molly was completing an academic year teaching biology and anatomy and physiology with the expectation that her teaching assignment would remain the same in the following year. We made plans to develop the CATSI project around a unit on gene therapy to be featured in Molly's biology class. Over the summer, the project team began developing curriculum materials and creating assessments specific to the gene therapy focus. A few weeks prior to the start of the new school year, administrators at Fields HS informed Molly that she would be teaching environmental science classes rather than biology. Suddenly the focus on gene therapy was not as relevant to Molly and her students. Molly was willing to work with us such that our initial development efforts could be included in her remaining anatomy and physiology classes, but while she would have made this work for us, it was not what she really wanted for her classes. After reflecting on her plans and student needs, we collaboratively decided to shift the focus of our development efforts from gene therapy to global climate change. The new global climate change unit would fit naturally within Molly's environmental science classes and would address science content that she felt was essential for her students.

In order for students to understand the issue of global climate change, it was important that they understand several science concepts including the particulate nature of gases, combustion, atmospheric composition, and energy transformation. Because of the heavy focus on chemistry content, we decided that it was necessary to bring in a chemistry educator as a part of the project team. In addition to maintaining his classroom duties, William had begun work toward a graduate degree in science education at our university, so he became a natural addition to the team. Following an initial organizational meeting, William decided that he wanted to participate as a full-scale classroom collaborator and not just as an advisor to the project. At this point the project team consisted of a principal investigator who was a former biology teacher and had conducted a fair amount of research related to SSI, two full-time science education graduate students with a wealth of experience teaching science in secondary school and college settings, and two high school science teachers. Another graduate student joined the project team after the curricula had been developed and implemented. He assisted in the analysis of data.

The project team met regularly throughout the fall semester on the design of curriculum. Initially, the focus of meetings related to understanding the classroom contexts in which this work would be situated as well as helping the teachers understand our perspectives on SSI and goals for the research. As a part of this, we developed ideas about what our teacher partners were looking for in the collaboration and what could likely be accomplished in their classrooms. We also examined available curriculum materials related to global climate change. Ultimately, we created an instructional sequence that spanned approximately 15 h of class-time. During this timeframe, we also created assessment materials (to be described later). Whereas the teacher partners were intimately involved in the development of the curriculum materials, they played a less prominent role in the development of assessment instruments, which were specifically designed for research purposes as opposed to classroom assessment purposes.

We implemented the CATSI unit on global climate change during the middle of the following spring semester. This timing was determined by the classroom schedules of Molly and William and the curricular flow of their classes. Implementation occurred in Molly's environmental science classes first. At least one member of the research team (the PI and/or one of the graduate students) was present in Molly's classroom over the 3-week period in which the global climate change unit was implemented. Molly maintained her role as the classroom leader, but the other research team member periodically assisted with instruction particularly when students completed lab experiences or computer-based exercises. Otherwise, the research team member observed and videotaped classes without drastically altering the classroom environment. The research team collaborated with William during his implementation of the curriculum, but we were not able to be present on a daily basis.

Intervention

We designed the CATSI intervention to meet the following instructional objectives.

As a result of participation in the CATSI unit, we expected students to

1. Develop an understanding of what global climate change is and why various parties think that this is a significant issue. (Unlike some curricular efforts that originate from the environmental education community, we did not promote advocacy on any side of the global climate change debate. We did not assume a goal of pushing students to adopt a particular position on global climate change but we did intend for students to understand why different groups adopted strong positions on the issue).

2. Develop understandings of scientific principles and concepts related to global climate change. The scientific content that we focused on related primarily to chemistry and earth science including the particulate nature of gases, climate and temperature, atmospheric composition, and combustion as a chemical reaction.
3. Engage in scientific practices including creating and interpreting scientific models, conducting inquiry-based investigations, and graphing.
4. Develop understandings related to why global climate change is controversial and appreciate social factors that contribute to this controversy including economic, political, and ethical concerns.
5. Develop skills for finding and analyzing web-based resources related to SSI.
6. Formulate a personal position on global climate change that is informed by scientific principles and concepts as well as the students' own perspectives on social factors including economics, politics, and ethics.
7. Improve their socio-scientific reasoning practices in contexts beyond the scope of global climate change.

In order to achieve these objectives, we designed a 3-week unit (approximately 15 classroom contact hours) of instruction. As discussed in the section above, we worked with Molly and William to design materials that would meet their specific needs and the needs of their students. We examined published materials and found exercises within the American Chemical Society's *Chemistry in the Community* (ACS, 2006), *Chem Connections* (Anthony, Brauch, & Longley, 2007), and *Climate Change* published by the Lawrence Hall of Science (Sneider, Golden, & Gaylen, 2004) to be particularly useful. Ideas gleaned from these sources were modified and customized such that they fit our goals and classroom contexts. We also drew on the expertise of the project team to create new materials to ensure that the full range of objectives had been met.

The resulting unit was made up of nine unique, although interconnected, lessons (see Table 4.1). The lessons ranged from approximately 1 h in duration to 4 h. The actual implementation times varied between the two classrooms. The first lesson introduced students to global climate change by demonstrating the presentation of climate change in mass media. Students also explored the personal stories of several individuals with vastly different perspectives on the issue including a boy from a coal-mining region of the USA, an Inuit girl from Alaska, a US bureaucrat, a college student in the Maldives island chain, and several others. The second lesson engaged students in a jigsaw activity in which they explored the positions of various political interest groups and ultimately crafted recommendations for US policy related to global climate change. In the course of the first two lessons, we suggested that the scientific community shares general agreement (not without exceptions) that the earth's climate is changing and that human activity affects these changes. The question of whether societies should do anything in response to these changes and if so, what should be done were presented as open questions for students to explore throughout the unit.

The next four lessons were designed to help students build understandings of the science underlying global climate change. In the first of these lessons, student

Table 4.1 Overview of the CATSI curriculum

Sequence	Brief description	Approximate time (h)[a]	Target objective(s)[b]	Source[c]
1	Introduction to global climate change (GCC): Teacher presents recent media reports on GCC and provides basic overview. Student groups explore a resource that describes why various individuals are concerned by GCC or plans to address GCC.	1–2	1, 7	CATSI[d]
2	Complexifying GCC: Students worked through a jigsaw activity in which they analyzed policy recommendations of five special interest groups with distinct perspectives on GCC.	1–2	1, 4, 7	CATSI (Sadler & Klosterman, 2009)
3	Gases and the atmosphere: Student groups moved through four lab stations at which they carried out activities designed to demonstrate the particulate nature of gases. Teacher made presentation providing an overview of earth's atmosphere.	1–2	2	Sadler et al. (2005)
4	Combustion: Brief presentation on the carbon cycle and production of CO_2 through combustion. Student groups used molecular models and chemical equations to model combustion of various hydrocarbons.	1–2	2, 3	Anthony et al. (2007), ACS (2006)
5	CO_2 concentration: Student groups collected gas samples (including car exhaust) and performed titrations to determine CO_2 concentrations. Teacher prompted groups to think about CO_2 and the greenhouse effect.	2–3	2, 3	Sneider et al. (2004)
6	Greenhouse effect: Student groups created model greenhouses and measured temperature changes over time.	1–2	2, 3	Anthony et al. (2007), Sneider et al. (2004)
7	Consequences of GCC: Classroom discussion of previous activities. Students completed a worksheet that prompted them to consider possible consequences of GCC as well as proposals to address GCC. Teacher presents synthesis of the science concepts covered.	1	1, 2	CATSI

(continued)

Table 4.1 (continued)

Sequence	Brief description	Approximate time (h)[a]	Target objective(s)[b]	Source[c]
8	Graph analysis: Student groups analyzed graphs showing temperature, atmospheric CO_2, and economic trends over varying time spans.	1	3, 4	Anthony et al. (2007)
9	Webquest and position development: Student groups worked through a webquest designed to support their use of the Internet as a source of information for GCC and other SSI. The culminating activity of the webquest prompted students to create a product (e.g., website, poster, presentation) that presented their own position on national policy related to GCC.	3–4	1, 4, 5, 6, 7	CATSI (Klosterman & Sadler, 2008)

[a] Time ranges represent variation across the two teachers' implementations

[b] The numbers correspond to objectives introduced in the text

[c] All of the exercises were modified to fit our classroom contexts and instructional goals

[d] Indicates that the materials were designed by the CATSI team

groups rotated through lab stations at which they performed a series of directed inquiries designed to highlight the particulate nature of matter. At the end of class, the teacher brought all of the students back together and presented a lecture on the earth's atmosphere and synthesized the content students had seen in the lab activities particularly as it related to atmospheric conditions. The next lesson introduced combustion complete with an explosive demonstration. Students used ball and stick molecular models to simulate combustion of various fuel types. They also created and balanced chemical equations corresponding to their physical models. The teachers directed their students to carefully note variations in CO_2 production based on fuel types and amounts. In the follow-up lesson, students collected various gas samples including exhaled breath, the product of an acid–base reaction, ambient air, and car exhaust; and they performed simple titrations to determine CO_2 concentrations. The teachers then led the classes through a discussion of the links among human activity, CO_2 emissions, and greenhouse effects. The next lesson built on this introduction to greenhouse effects by having student groups create model greenhouses using glass jars and heat lamps. Students measured temperature changes over time in models with varying gas contents (ambient air, air saturated with water vapor, and pure CO_2).

Following these four lab-based lessons, both teachers used a class period to help students review and synthesize the content that had been covered and make explicit connections to the overarching issue of climate change. Teachers also prompted students to extend their thinking about the possible consequences, both environmental and societal, of climate change as well as actions proposed to stem climate change. In the next class period, students worked in groups to interpret a series of graphs displaying temperature trends, concentrations of greenhouse gases, and economic data. The graphs displayed trends over variable time frames and have been interpreted by parties with vested interests in the climate change issue in very different ways. Students responded to a series of prompts designed to help them attend to issues that can affect interpretation including graph scale and data sources. The final lesson, which extended over several class periods, was designed to help students build media and web literacy skills relative to global climate change particularly with respect to the use of Internet sources. Students completed a webquest that guided them through use of criteria for selecting and evaluating web-based media. The culminating activity for the webquest challenged students to use Internet resources as well as their experiences and findings throughout the unit to create a product promoting a particular course of action (or inaction) relative to climate change. In terms of products, students had freedom to choose their own format but were encouraged to consider creation of a website, a slide presentation, a poster, or narrative that would effectively communicate their intended message. This culminating activity challenged students to create policy positions like they had observed in the unit's second lesson. The intent was to provide an opportunity for students to synthesize all that they had learned in the unit and articulate their own perspectives on global climate change.

Research

Research Questions

Research conducted as a part of the CATSI project related primarily to the third and fourth project goals (presented in a previous section). The third goal called for an investigation of how SSI-based instruction supports (or fails to support) student development of scientific content knowledge. The fourth goal related to an extension of work on socio-scientific reasoning. More specifically, we were interested in exploring methodological improvements for the assessment of SSR. We also intended to test whether SSR could be improved among students participating in the global climate change intervention. To achieve these goals, we developed a research plan around the following research questions.

RQ1. How does SSI-based instruction support student learning of science content knowledge?
RQ2. How can the assessment of SSR be improved?
RQ3. How does SSI-based instruction support student development of SSR?

Content Knowledge

Within the science education community, there has been a long history of calls for using socially relevant issues (i.e., SSI) as contexts for teaching and learning science (DeBoer, 1991). The work of several researchers has supported the long-held contention that SSI-based instruction can support student development of science content knowledge (Barber, 2001; Dori et al., 2003; Yager et al., 2006; Zohar & Nemet, 2002), but like all studies, these had limitations. Namely, some of these researchers relied on curriculum-based tests of content and others did not employ pre/post designs. These researchers chose to focus on certain factors in the design of their research and in so doing created affordances for the investigation of some issues and limitations for others. For the design of the CATSI study, we chose to prioritize the investigation of content knowledge. In doing so, we implemented a pre/postintervention assessment strategy in order to measure gains over time. We also adopted a multilevel assessment framework in which we created content assessments at variable distances from the curriculum.

Assessing the effects, particularly content learning, of curricular innovations presents serious challenges for researchers (Ruiz-Primo et al., 2002). The designers of innovations frequently create assessments directly aligned with their interventions. These assessments, which can be thought of as close to the interventions, can be useful for classroom teachers and students as well as for formative assessment of the intervention. However, these measures are typically critiqued when used as summative assessments. Intervention-specific assessments are limited in scope, do not allow for the assessment of transfer, and do not permit comparisons among curricula.

More distant measures of content such as national exams are much broader in scope, can be used to make inferences regarding transfer, and allow for comparisons among curricula. However, assessments that are as distanced from an intervention as national exams are very insensitive to change. It is not reasonable to expect a national exam to detect significant learning gains associated with a 3-week intervention.

To address these problems, assessment specialists working in science and mathematics education have proposed a multilevel assessment framework for better understanding the effects of curricular innovations (Hickey & Pellegrino, 2005; Hickey, Zuiker, & Taasoobshirazi, 2006; Ruiz-Primo et al., 2002). This framework calls for assessment at various distances from a particular intervention. The approach calls for researchers to collect data through instruments closely aligned with an intervention, but the value of these data can be significantly improved when they are interpreted in conjunction with more distanced measures. In the CATSI project, we collected data at four unique curricular distances: immediate, close, proximal, and distal. The immediate data (classroom observations of student discourse and practices) and close data (student artifacts produced in the midst of the climate change unit) were useful as we considered the design and progress of the intervention. For research purposes, we relied primarily on the proximal (test results using items directly aligned with the curriculum) and distal data (results from a test created with items sampled from state and national exams), the sources of which will be described in the methods section.

Socio-scientific Reasoning

We introduced socio-scientific reasoning as a tool for researchers and practitioners to more effectively operationalize and assess the practices in which students engage as they negotiate SSI (Sadler et al., 2007). Science educators, including us, have argued that SSI-based education has potential to better prepare students for interacting with social issues, making decisions on complex issues, and developing character (Berkowitz & Simmons, 2003; Kolstø, 2001; Zeidler & Sadler, 2008). However, the community lacks conceptual and assessment resources to investigate the extent to which these claims are supported by evidence (Orpwood, 2007). We developed SSR as an initial attempt to address this gap in the SSI research agenda. The basic idea underlying the SSR construct was that most, if not all, SSI regardless of their specific scientific and social contexts share certain features. We hypothesized that as learners interact with specific SSI contexts, they become more aware of and better prepared to respond to the implications of the invariant features of diverse SSI. In developing a framework for assessing SSR, we sought to provide a mechanism for empirically documenting the extent to which learner practices relative to negotiation of SSI developed over time.

We explored existing science education research in order to identify the invariant features of SSI that could be leveraged to operationalize SSR. We initially identified four SSI features to serve as the basis for distinct aspects of SSR. We present the SSR aspects below with a brief sample of the literature used to identify and substantiate each aspect.

1. Recognizing the inherent *complexity* of SSI (Hogan, 2002; Pedretti, 1999).
2. Examining issues from multiple *perspectives* (Sadler & Zeidler, 2005; Zohar & Nemet, 2002).
3. Appreciating that SSI are subject to ongoing *inquiry* (Bingle & Gaskell, 1994; Yang & Anderson, 2003).
4. Exhibiting *skepticism* when presented potentially biased information (Kolstø, 2001; Zeidler et al., 2002).

Our initial investigation of SSR, within the *Quest Atlantis* project, focused on clarifying the construct, establishing assessment protocols, and documenting a baseline of student practices. In this work, we assessed SSR by providing students with two brief SSI scenarios and asking questions designed to elicit ideas and practices related to the SSR aspects. These interviews were audio-recorded and transcribed. Our analyses were based on the full transcripts. We created four-level ordinal scales for each of the SSR aspects. These scales provided a means of classifying the variability of student responses relative to each of the invariant SSI features highlighted by the SSR construct.

In order to explore the measurement properties of SSR, we conducted correlation analyses for inter-scenario aspect scores. These correlations provided a measure of how consistent student performance was for each SSR aspect. In order for an aspect to be meaningful from a measurement perspective, it would need to be fairly stable across contexts. Correlation coefficients (Spearman's rho) were relatively high for the complexity and inquiry aspects (.76 and 0.73 respectively) but low for perspectives and skepticism (.42 and 0.37). We also computed correlations among aspects within the scenarios to explore the extent to which the aspects were related. High correlations among student practices on different aspects would indicate relatedness and support the idea that SSR represented a unidimensional construct. The correlations between complexity and inquiry were relatively high in both scenarios. Correlation coefficients between all other aspects were positive but fairly low. The complexity and inquiry aspects had performed as we had expected; that is, individual student practice was measured consistently across independent contexts and the results suggested that they may both be related to an underlying latent variable that we described as SSR. The other aspects, perspectives, and skepticism, did not perform as expected in terms of inter-scenario consistency or relatedness to a common latent variable. We concluded that future research would have to approach assessment of the perspectives and skepticism aspects in different ways in order to provide useful data (Sadler et al., 2007).

To advance SSR as a useful tool for the research community, assessment of the perspectives and skepticism aspects would obviously have to be improved. We also wanted to explore other assessment formats. The interview protocol used for our initial work provided quality data but the resources required for conducting, transcribing, and analyzing interviews would likely prohibit its use in large-scale projects. Therefore, we designed the CATSI project to experiment with new data collection methods. We created an internet-based questionnaire that could vary questions based on students' previous responses. This allowed us to effectively customize prompts to which students responded, one of the advantages of interviewing, as students completed the survey. The electronic data were automatically logged to a database eliminating the need for transcription.

A primary motivation in developing SSR was generation of a tool that could be used to document student development over time. However, our initial research did not explore the extent to which SSI-based instruction improved SSR. As a part of the CATSI project we intended to address this issue. Our goal was to test the hypothesis that student learning experiences in one SSI context (i.e., global climate change) enhances SSR as displayed in different SSI contexts.

Methods

Data Collection and Analysis: Content Knowledge

We adopted a pre/postintervention design for the analysis of both content knowledge and SSR. Consistent with the multilevel assessment framework that helped to guide design of the CATSI project, we collected data related to student learning of science content at different levels of varying "distances" from the curriculum. For the research reported as a part of this chapter, we focus on two of these data sources: a proximal test and a distal test. The proximal test was aligned with the CATSI curriculum; that is, it was designed to assess student understanding of the content taught as a part of the CATSI unit. This curriculum-aligned test consisted of five open-ended questions: (1) What is global warming? (2) What is the greenhouse effect? (3) How does the greenhouse effect relate to global warming? (4) What is the controversy associated with global warming? (5) Is global warming a challenging problem? Why or why not? The curriculum-aligned test was administered electronically and student responses were collected through a database. Because of technical problems with the database, we were only able to analyze data from the curriculum-aligned test for Molly's environmental science students. The numbers of students whose data were included in analyses are displayed in Table 4.2.

Table 4.2 Number of classes and students participating in the CATSI project

Teacher (subject)	Classes	Students	Informed consent	Proximal test (pre and post)	Distal exam (pre and post)	SSIQ (pre and post)	Interview
Molly (Environmental science)	3	75	57	49	49	50	11
William (Chemistry)	2	62	51	–[a]	34	–[a]	0
Totals	5	137	108	49	83	50	11

[a]Technical difficulties prohibited access to these data

Our analysis of the open-ended student response data was guided by the constant comparative method (Strauss & Corbin, 1998) which was an inductive approach that called for iterative cycles of evaluation of interpretive hypotheses and comparisons to data. Analysis progressed in six phases beginning with two researchers independently reviewing ten randomly selected answer sets to look for general trends. By the fourth phase of analysis, the researchers had independently examined 30 transcripts and developed a coding scheme with high inter-rater consistency (<90%). The coding scheme was designed to characterize individual variation associated with each question. Categories for each question were ordinal in nature. In the fifth phase of analysis, a single researcher completed coding on the curriculum-aligned data. In the final phase, we looked for changes in student performance on the pre- and postintervention tests by testing for changes in categorical proportions. We applied a McNemar analysis, which is similar to a Chi-square test but is designed for repeated measures data.

To examine student development of content knowledge from a more distanced perspective, we developed a distal test. The distal test was aligned with state content standards that guided development of the CATSI curriculum. Therefore, it was designed to measure student understanding of the scientific formalisms underlying climate change but individual exam items were not aligned with unit curriculum. In designing the CATSI curriculum, four sets of science standards were identified. They related to the following four general areas of science: (1) climate and temperature, (2) greenhouse effects and climate change, (3) chemical principles and processes, and (4) graphing and graph analysis. We sampled items from publicly-released standardized tests used for international (e.g. TIMSS-Trends International Mathematics and Science Study), national (e.g., NAEP-National Assessment of Education Progress), and state (e.g., FCAT-Florida Comprehensive Assessment Test) assessments. We created item pools associated with each of the four groups of standards. After extensive pilot and reliability testing, we produced a 20-item, multiple-choice instrument (five items for each of the four standards groupings) and administered it to students in the CATSI project before and after the SSI-based intervention. We analyzed student responses with a repeated measures ANOVA and computed effect sizes.

Data Collection and Analysis: Socio-scientific Reasoning

One of our project goals was to experiment with a new format for assessing SSR. Our previous work suggested that interviews could be used to assess SSR but the resource-dependent nature of interviews limited their use for large sample sizes. We wanted to try an open-ended questionnaire but worried that questions designed to elicit some SSR aspects would be too leading. To address these concerns, we developed an online survey, the Socio-scientific Issues Questionnaire (SSIQ), using an adaptive questioning strategy that directed students to specific open-ended questions based on previous forced-choice responses. This strategy limited the extent to which questions were leading and yet challenged students to generate responses that could illuminate their SSR.

In its final design, the SSIQ consisted of a narrative description with an accompanying diagram of a localized socio-scientific scenario. The description was followed by a series of forced choice and open-ended questions (see Appendix 3.1 for an example). Two scenarios were developed; both related to water pollution issues with economic implications and at least three clearly identifiable parties interested in the issue. Students read and responded to one of the SSIQ scenarios prior to the intervention and the other after the intervention. The selection of scenarios (pre-versus postintervention) was randomized.

Based on our previous work (Sadler et al., 2007), we knew that the manner in which the perspectives and skepticism aspects had been operationalized required modification. For development of the SSIQ and subsequent analyses, we reconceptualized the perspectives aspect. In our initial work, the perspectives aspect captured the extent to which students adopted multiple perspectives in the justification of their own decisions. In the CATSI project, we revised the perspectives aspect such that it assessed the extent to which students could discuss the perspectives and interests of multiple parties involved in the scenarios. The new perspectives aspect incorporated themes suggested by the original perspectives category as well as the original skepticism category.

In analyzing data collected from the SSIQ, we were guided by scoring codes developed in the initial research (Sadler et al., 2007) but given the changes in data collection and the new perspectives aspect, we made significant modifications. In addition to Molly's and William's classes, we had administered the SSIQ to 37 high school students from a different school. We used these data to develop scoring rubrics for SSR. We had a priori notions of possible ranges of student practices but these ideas were shaped significantly by inductive analyses of the pilot data. We developed five-point ordinal scales for each SSR aspect (complexity, inquiry, and perspectives) and used the rubrics to score the SSIQ data. Two reviewers independently analyzed 20 sets of responses, randomly selected from among pre- and posttests. Initial inter-rater consistency ranged from 60% to 80% by SSR aspect; however, most of the discrepancies were quickly resolved and ascribed to simple misinterpretations. Following this initial negotiation phase, inter-rater consistency exceeded 90% for all aspects. Given the relatively high tendency for rater error, two reviewers independently coded all responses and rating discrepancies were mediated by a third reviewer. In order to test the validity of using the SSIQ, we conducted interviews with a subset of the sample ($n = 11$) and analyzed the transcripts using the same set of rubrics.

Results and Discussion

Findings: Content Knowledge

The first research question addressed student learning of content in the context of SSI-based instruction. Student performance on the proximal, curriculum-aligned test was assessed by means of the emergent scoring rubric described above. Table 4.3 presents the coding schemes developed for each of the five questions,

Table 4.3 Assessment rubric for scoring the curriculum-aligned test

Category	Description	Exemplars
Question 1: What is global warming?		
Misconceptions (A)	Describes global warming using a common misconception such as ozone depletion.	Global warming is the ozone layer growing thinner and thinner and the sun is shinning through more and more.
Temperature (B)	Explains global warming as an increase in temperature	Global warming is where the temperature all throughout the earth is rising.
Temperature and Effect (C)	Explains global warming as an increase in temperature and elaborates on response with a description of its effects	Global warming is when the earth is heating up at an alarming rate and polar ice caps are melting.
Greenhouse effect (D)	Explains global warming in terms of the greenhouse effect and/ or greenhouse gases	An increase in the earth's average atmospheric temperature that causes changes in climate and results from the greenhouse effect.
Question 2: What is the greenhouse effect?		
Inaccurate or Unrelated (A)	Uses unrelated concepts or underdeveloped ideas to explain GHE	The greenhouse effect is when there is a lot of green life and things have an easier time growing in the surrounding climate.
Warming (B)	Explains GHE in terms of global warming or increases in temperature	When the sun heats up the earth and causes it to warm at an increased rate.
Gases (C)	Includes direct reference to or implies a relationship between greenhouse gases the GHE	The greenhouse effect is when the greenhouse gases such as carbon dioxide, methane, etc. are burned off into the atmosphere these gases hold in the heat, therefore heating up the earth.
Question 3: How does the greenhouse effect relate to global warming?		
Inaccurate/unrelated/underdeveloped (A)	Uses unrelated concepts or underdeveloped ideas to explain the relationship between GW and GHE	It's bad for earth.
Similar (B)	The GHE and global warming are described as parallel concepts and often as both related to temperature	They are related to each other because both of them have something to do with the rising of the earth's temperatures.
Greenhouse effect (C)	Explains that GW is caused by or is a result of the GHE	The greenhouse effect speeds up the effect of global warming.

Question 4: What is the controversy associated with global warming?		
Consequences (A)	Describes the controversy of GW in terms of its possible consequences	Frozen places like Antarctica will start or have started to melt.
Uncertainty (Bi)	Describes the controversy as a decision between whether or not global warming exists and if humans are responsible	The controversy with global warming is that some feel that it is of no concern while others feel that it could very well shape the future. Many have debated the issue and feel that there is no solid proof of the fact that humans are responsible for it there for feeling no need to take action.
Inquiry (Bii)	Describes the controversy as a result of not knowing how to take action	The controversy associated with global warming is that we do not know how to solve this problem that will eventually end the world.
Complex tradeoffs (Biii)	Describes the controversy as a series of tradeoffs between personal comfort and political or economic change	Global warming is caused by things that humans do and can be stopped but the things that cause it have become a part of our daily lives and are hard to give up and stop all together
Multiple sources (C)	Expresses more than one source of the global warming controversy	The controversy associated with global warming would be that it is causing a lot of ice causing a lot of the icecaps to melt and some of the animals that live by the water are loosing their homes because their homes are melting and one big controversy is whether or not global warming is a problem and whether or not we should do something about it.
Question 5: Is global warming a challenging problem? Why or why not?		
Underdeveloped (A)	Presents an underdeveloped idea to justify whether GW is challenging	There is so much controversy over the issue.
Unchallenging (B)	States that global warming is not a challenging problem	It is not a challenging problem because it doesn't make it hard for people to live from day to day. It really doesn't affect people's daily lives.

(continued)

Table 4.3 (continued)

Category	Description	Exemplars
Uncertainty (C)	States that global warming is not a challenging problem	Most people don't know that this is a problem and if they do it's not like they care.
No Known Solution (Di)	Determines the challenge to be a result of no known or possible solution	Because no one knows if it can be stopped or how to stop it completely.
Widespread effects (Dii)	Explains that solving GW is challenging because of its widespread effects and possible consequences	Global warming is a challenging problem because we would have to get every nation to start working together to stop or slow down the process of global warming.
Complex tradeoffs (E)	Describes the challenge as a series of tradeoffs between personal comfort and political or economic change	Because if people do want to deal with it they have to find away to begin changing the ways we live on this earth which will be very hard to do because we are so settled in our ways of living now. That it would be too hard to change all of a sudden.

brief descriptions of each category, and exemplars excerpted from student tests. Although it was not our intent to create a hierarchical scoring scheme, the codes for each question could be ranked in terms of accuracy. Low-end codes captured inaccuracies, underdeveloped ideas, and misconceptions. As the codes progressed to higher levels, they captured more sophisticated and scientifically accurate responses. Despite the ordinal nature of most categories, two categories within questions four and five were conceptually distinct but equivalent in terms of accuracy. These categories were identified separately, but combined for the follow-up analyses. The number of categories per question ranged from three (question two) to six (question five). A more complete description of the coding scheme can be found in Klosterman and Sadler (2010).

In order to determine whether student performances differed on the pre- and postintervention assessments, we conducted a McNemar's test for correlated proportions (see Table 4.4). The analysis indicated that the proportion of categorical responses prior to the intervention was significantly different than the category proportions following the intervention for the first three items on the curriculum-aligned test ($p_1=0.011$, $p_2=0.008$, $p_3=0.008$). For Items 4 and 5, the number of responses within several categories was less than five. Probability rates are not reliable for variables with cell frequencies less than five (Agresti & Finlay, 1999); therefore, we chose not to apply the test in these two cases. McNemar's analysis is an omnibus test and, applied to these data, indicated changes in response patterns following the intervention. In order to determine possible directions of change, we examined visual displays of the data (see Figs. 4.1–4.5). These graphic displays,

Table 4.4 McNemar analysis of curriculum-aligned test results

Question	χ^2	df	P
Q1	16.6429	6	0.0107
Q2	14.8410	6	0.0215
Q3	14.5859	6	0.0237

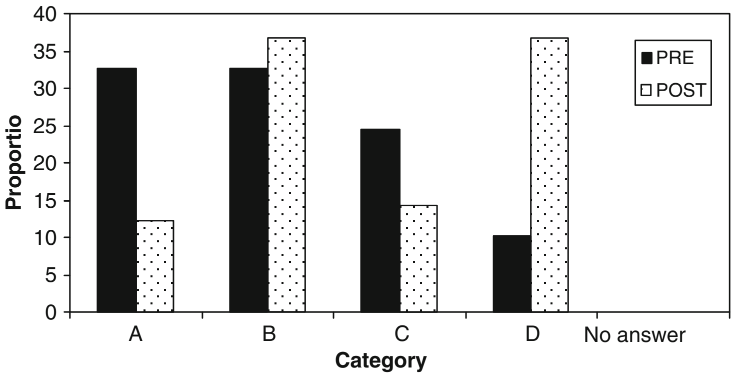

Fig. 4.1 Categorical proportions of pre- and posttest scores for Question 1

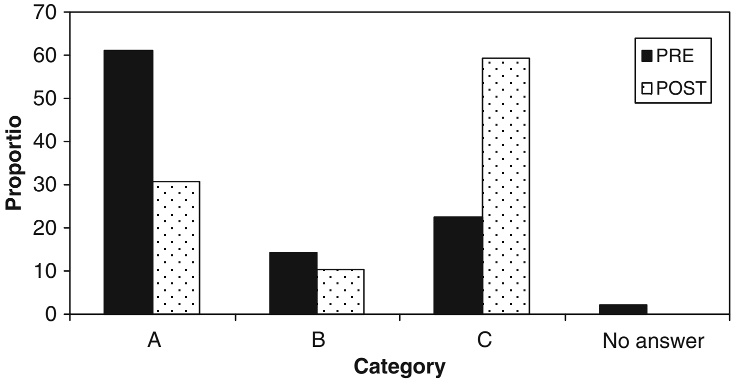

Fig. 4.2 Categorical proportions of pre- and posttest scores for Question 2

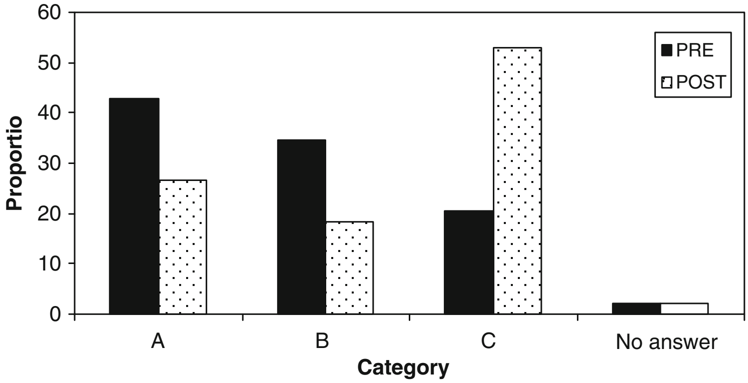

Fig. 4.3 Categorical proportions of pre- and posttest scores for Question 3

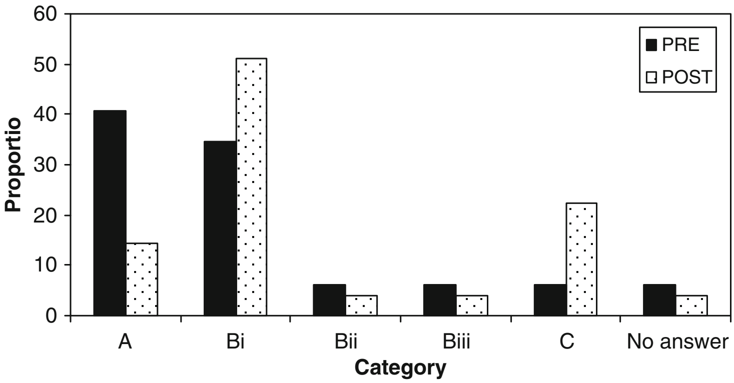

Fig. 4.4 Categorical proportions of pre- and posttest scores for Question 4

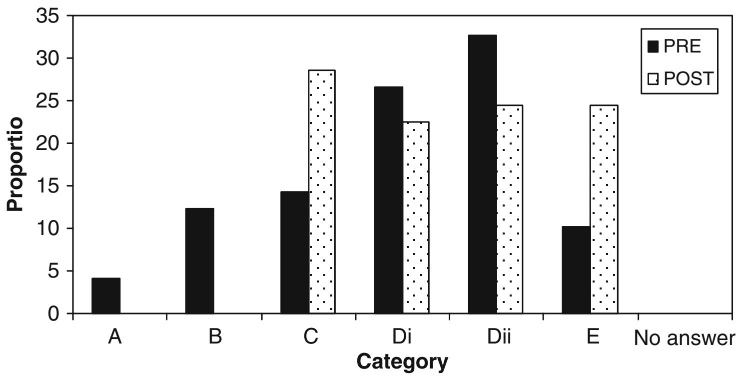

Fig. 4.5 Categorical proportions of pre- and posttest scores for Question 5

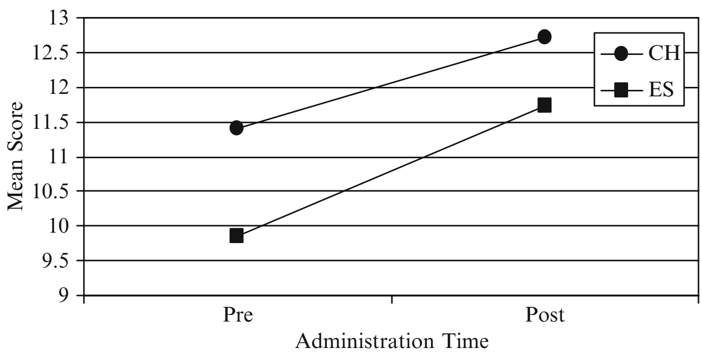

Fig. 4.6 Average scores on standards-aligned exam

which highlighted comparisons between pre- and postintervention performances, revealed shifts toward more accurate responses. The combined results indicated that student performances on the curriculum-aligned content test improved significantly following SSI-based instruction.

Student performance on more distal measures of content was assessed through the standards-aligned test. The average gain (posttest versus pretest) for Molly's environmental science classes was 1.88, and for William's chemistry classes the average gain was 1.29 (total score = 20; see Fig. 4.6). Results of a repeated measures ANOVA indicated that posttest scores were statistically significantly different than the pretest scores ($F = 15.31$, $p < 0.001$). There was no evidence of an interaction effect between the time variable (pre and post) and the course variable suggesting that the intervention produced similar effects in both classroom settings ($F = 2.88$, $p = 0.094$). Effect sizes were calculated for both sets of classes using the formula for

Cohen's *d* (Dunlop, Cortina, Vaslow, & Burke, 1996) for calculating effect sizes in dependent measures designs. The effect sizes for Molly's classes (d_{ES}=0.49) and William's classes (d_{CH}=0.41) were medium (Cohen, 1988).

Combined results of the proximal and distal tests provided evidence of student learning of science content associated with their experiences in the climate change unit. Students demonstrated learning gains for material directly aligned with the curriculum, a result that should be expected given that the unit extended over 3 weeks. They also demonstrated modest gains on the more distanced assessment indicating that SSI-based instruction can foster development of scientific ideas that transcend specific instructional contexts.

Findings: Socio-scientific Reasoning

A rubric was developed for the assessment of each of the SSR aspects. The three rubrics followed a similar format. Zero level responses indicated that students did not understand the most basic dimension of a particular aspect. Responses scored with a one indicated that students understood the basic aspect but could not provide an example. Responses scored with the three highest levels offered progressively more detailed descriptions of the aspect. Table 4.5 presents the rubric used for

Table 4.5 Scoring rubric for the Inquiry aspect of SSR

Level	Description	Exemplars
Question: If you were responsible for deciding how to resolve the Branville Bay situation, would you need additional information regarding the situation before making your decision?		
0	Suggests that additional inquiry is not necessary.	No. Just ban all boats and fishing in the preserve. That way there won't be any chance for drops in wildlife counts.
1	Suggests that additional inquiry is necessary but does not identify a specific line of inquiry.	Yes. Information like are there any other problems that is going wrong with this situation and can there be more than one solution.
2	Suggests that additional inquiry is necessary and identifies one specific line of inquiry.	Yes. What would happen if we stopped big ships from going back and forth and just allowed smaller boats do all the work?
3	Suggests that additional inquiry is necessary and identifies two specific lines of inquiry.	Yes. Exactly how much are the fish and bird counts declining [and] how much are the ships polluting the water as opposed to the fishermen.
4	Suggests that additional inquiry is necessary and identifies three or more specific lines of inquiry.	Yes. I would need to know the amount of people fishing or going through every day, the amount of fish being caught by people omitted from the fishing laws, and the amount of traffic.

assessing the inquiry aspect and exemplars taken from student products. The complexity and perspectives rubrics followed the same format but attended to the appropriate content.

Because we wanted to use the SSIQ to document pre- and postintervention changes, our goal was to develop two equivalent forms to reduce possible testing effects as a threat to validity. Results from pilot testing indicated that the two forms elicited very similar responses in terms of SSR assessment among students taking both forms. Using data from the CATSI project sample, we conducted *t*-tests between the two scenarios for each of the three SSR aspects. Data used for this analysis was restricted to the 50 students who had responded to both scenarios. Scores on all three aspects between the two scenarios were not statistically significantly different. These results provided empirical justification for our decision to use the scenarios as multiple forms thereby reducing the possibility of testing effects.

In order to check for the validity of our interpretations of student responses to the written SSIQ prompts, we conducted and analyzed interviews with a subset of the sample ($n=11$). These interviews, conducted individually with one of the researchers, took place approximately 1 week after student completion of the postintervention SSIQ. The content of student responses in both assessment contexts (written and interview) were consistent. Analysis of the interview transcripts indicated that students interpreted the SSIQ items in ways that we expected. The interviews also allowed us to check our interpretations of student responses with the students themselves. This form of member checking further supported the validity of our analysis. Finally, we scored the interview responses using the rubrics developed for each of the SSR aspects and compared these ratings with the scores obtained by the same students using the written format. In comparing scores between the written and interview data, only one aspect response (3%) varied by more than one ordinal level. Thirty-nine percent of the responses (equally distributed across the three aspects) varied by one ordinal level, but we detected no consistent patterns in terms of which assessment context tended to afford more advanced patterns. We interpreted these results as indicating a high degree of consistency in terms of the content of student responses and a moderate degree of consistency in terms of performance levels across the assessment contexts.

In the original SSR research, two aspects were highly correlated indicating likely relationships to a common latent variable. To test for these relationships in the current dataset, we conducted correlation analyses among scores on the three aspects. None of the correlation coefficients (Spearman's rho) were statistically significantly different than zero. This result offered no evidence of relationships among the three aspects; therefore, we treated them as separate variables for the subsequent analyses.

To explore the issue of change in SSR associated with the CATSI unit, we conducted paired *t*-tests (pre vs. post) for each of the SSR aspects. Average scores and standard deviations for the pre- and postintervention SSR assessments as well as the *t*-test *p* values are presented in Table 4.6. These data revealed no statistically significantly differences in pre- and posttest performances.

Table 4.6 Average scores (and standard deviations) for pre- and postintervention SSIQ responses

	Socio-scientific reasoning aspects		
	Com	Inq	Per
Pretest	1.4 (1.3)	1.9 (1.3)	2.4 (1.2)
Posttest	1.4 (1.2)	1.7 (1.5)	2.1 (1.1)
p values [a]	0.78	0.30	0.14

[a] *p* values for paired *t*-tests

Implications for…

Teaching and Learning

We begin our discussion of implications with the most obvious inference to be drawn from the research conducted as a part of the CATSI project. Students can learn important science content through SSI-based instruction. The evidence collected as a part of this study support the contentions that students can learn science content directly aligned with the context of an SSI-based unit as well as the more abstracted scientific formalisms represented in standards documents and associated standardized assessments. Given the inevitable limitations of this study, we are not claiming that all students will show similar gains in content knowledge in response to all SSI-based instruction, but we document compelling evidence of science learning for this sample in the context of this issue (global climate change). Classroom-based work like this will likely never produce the kinds of data that could legitimately be considered generalizable for all (or most) students and all (or most) SSI contexts. However, the combined analysis of these results with studies (Dori et al., 2003; Zohar & Nemet, 2002) located in other, diverse settings drawn from different populations and utilizing different issues provide growing support for the efficacy of SSI-based education in terms of promoting the learning of science content.

Most other studies that link SSI-based instruction and science content learning document gains on assessments closely aligned with the context of the SSI under consideration (similar to our proximal level data). These data are certainly important in terms of understanding how SSI-based instruction works, but the high degree of concurrence between the contexts of instruction and assessment leaves open the question of how SSI-based instruction affects learning that transfers beyond the immediate learning environment. In the current political climate, important stakeholders in science education including teachers, school administrators, and policy-makers are particularly interested in how curricular innovations can affect student performance on standardized assessments (Settlage & Meadows, 2002). This study provides some of the first evidence using a pre/post design and a multilevel assessment model documenting student gains on distal level assessments of content that serve as a proxy for standardized assessments. The raw score differences are statistically significant, but the actual change values are relatively small

(1.9 for Molly's students and 1.3 for William's students). We acknowledge the modesty of these changes, but it is important to note the modest nature of the CATSI intervention in terms of its duration. We view the fact that any statistically significant changes in performance on a standards-aligned exam occurred in association with a 3-week unit as an important finding.

In reflecting on what was (and was not) accomplished in this project particularly as related to how the unit was designed and implemented, we believe it critically important for the communities committed to promoting SSI-based instruction to advance new models for introducing SSI into classrooms. Here, we are not arguing for new teaching models (although we certainly would not argue against development of new teaching innovations for SSI-based instruction). Rather, we highlight the need to consider new approaches to support collaborations among teachers, researchers, curriculum designers, and professional development specialists to more efficiently move SSI into classrooms. We, the full CATSI team including university-based researchers and classroom teachers, spent a great deal of time working together in order to create an intervention specifically designed for our target classrooms. This obviously is not a scalable model. As a community, we need to generate better ways to develop and disseminate curriculum and teaching innovations that are responsive to the specificities of individual classrooms.

We did not systematically collect data on student interest in the SSI unit or their motivation to participate in learning activities associated with this unit. However, our classroom observations indicated that the students were not as enthused by and interested in the global climate change issue as we had expected and hoped. One of the arguments made in support of using SSI in classrooms is that SSI provide contexts that connect school science to real-life issues thereby making science more relevant and interesting (Albe, 2008; Harris & Ratcliffe, 2005). Ultimately, the students in the CATSI project were highly engaged, but this engagement seemed not to be related to issue context. The engagement we observed seemed more related to the design of learning experiences than the issue itself. The CATSI unit followed many of the recommendations promoted by the science education community in support of engaging curricular innovations. Students experienced a variety learning experiences in which they were both challenged and supported. They had opportunities to create products, interact with media and technology, and engage in inquiry. We believe that the issue in and of itself was engaging for some students, particularly those who identified themselves as environmental advocates, but many students did not seem any more motivated to learn about global climate change than science topics unrelated to contemporary social issues. We actually do not interpret these observations as suggesting that SSI-based instruction is not or cannot be motivating for secondary students. We believe that these observations highlight the fact that formal science instruction takes place within the larger context of school science. A single, issue-based unit implemented over 3 weeks is unlikely to transform the manner in which students consider and feel about their school-based science learning experiences. This interpretation suggests we exercise care in considering how and the extent to which innovations support the development of interest in and motivation to learn science.

Research

We did not address SSR in discussing implications of this project for teaching. We omitted this discussion because we are uncertain as to what the project's implications for teaching are. We did not document gains in SSR associated with the CATSI unit. This nonresult may indicate that an intervention of this limited time frame cannot affect change in SSR. Changes in SSR may require longer developmental periods. However, an equally plausible interpretation of the results is that the nature of the intervention limited changes in SSR. A 3-week SSI-based unit may have potential to affect changes in SSR, but the CATSI unit itself may not have included necessary elements for these changes to be actualized in student practices. For example, the CATSI unit encouraged students to consider the complexity, inquiry, and perspectives aspects of global climate change, but instruction did not explicitly encourage students to think about how these elements emerge across multiple issues. The unit did not present climate change as a model for other complex SSI or encourage comparisons of similarities among this specific issue and other SSI. We believe further studies designed to explore the effects of specific elements of SSI-based instruction along with possible developmental trajectories of SSR would be fruitful work.

In order for the work called for in the previous paragraph to be done well, we believe the conceptual and assessment tools associated with SSR must be improved. The work described in this chapter represents only the second iteration in the development of SSR as a measurable construct. This second iteration has offered improvements in terms of the assessment context of SSR and the internal consistency of the rubrics used to track levels of SSR; however, much work remains. Some of the issues that demand further attention include possible expansion of the SSR aspects, fuller exploration of possible relationships among SSR aspects, and continued experimentation with forms of assessment. In this iteration, we highlight three aspects of SSR resulting from a rearticulation and merging of two aspects from the original research conducted on SSR. Additional aspects may need to be added to the framework to more validly capture practices associated with the thoughtful negotiation of SSI. In fact, we suspect that the practices associated with the complexity, inquiry, and perspectives aspects vastly under-represent the full range of practices associated with negotiating SSI. The challenge is in creating frameworks that support the valid and reliable assessment of these other aspects.

In our original work on SSR, we produced data suggesting a relationship among aspects of SSR. Based on these results, we postulated an underlying latent variable to which the aspects mapped. In essence, we proposed SSR as a single construct with interrelated subconstructs (i.e., aspects). The results produced in the CATSI project did not support this interpretation. The aspects did not show significant relationships; therefore, we treated the aspects as individual variables. Additional research designed to explore these possible relationships are essential in terms of providing guidelines for how these variables should be handled in future analyses.

We believe that in the second iteration of the study of SSR, we made improvements in the process of assessing SSR. We moved from an interview protocol to an adaptive, online survey the effect of which is to make SSR assessment more feasible and likely for larger groups of learners. However, much remains to be done for the optimization of SSR assessment. Assessing SSR using a broader range of issue contexts is one possible advancement; refinement of the aspect rubrics is another. Here, we offer these two specific suggestions as initial possibilities, but much more could be done to enhance the reliability, validity, and usability of SSR assessments. We leave it to the broader community of researchers interested in SSI and assessment to further define directions for advancing this agenda.

Conclusions

At its core, the CATSI project was a collaboration among teachers and researchers committed to enhancing science learning experiences of specific groups of high school students as well developing more robust understandings of how SSI-based instruction supports progressive goals of science education. We produced evidence regarding how SSI-based instruction can support science content learning at variable distances from the curriculum. The research related to socio-scientific reasoning raised more questions than answers, but we believe that the work significantly advanced the discussion of what ought to be assessed as a part of SSI-based instruction and how it ought be assessed. As university-based researchers, we found the experience of partnering with teachers and maintaining a sustained presence in their classrooms to be productive and informative. It allowed us to better support the needs of teachers as well as better understand their concerns and constraints associated with implementing SSI-based instruction. We gained better perspectives on the politics and processes of local schools. For example, the reassignment of one of our partnering teachers a few weeks before the start of a new academic year leading to the scrapping of our initial development efforts presented a significant setback and a new appreciation for the challenges associated with working in actual classrooms situated in broader local, district, and state contexts. Despite these challenges, we think this kind of situated work is essential for building understanding of how SSI-based instruction can be used productively in classroom settings and what SSI-based instruction can afford in terms of student learning and continued development as active participants in societies increasingly shaped by science and technology.

Appendix 3.1. SSIQ Prompt and Questions

Branville Bay is located on the Gulf of Mexico. The city of Branville has built up along the northern border of the Bay and a wildlife preserve has been established along the southern border. The Branville area was the ancestral home for

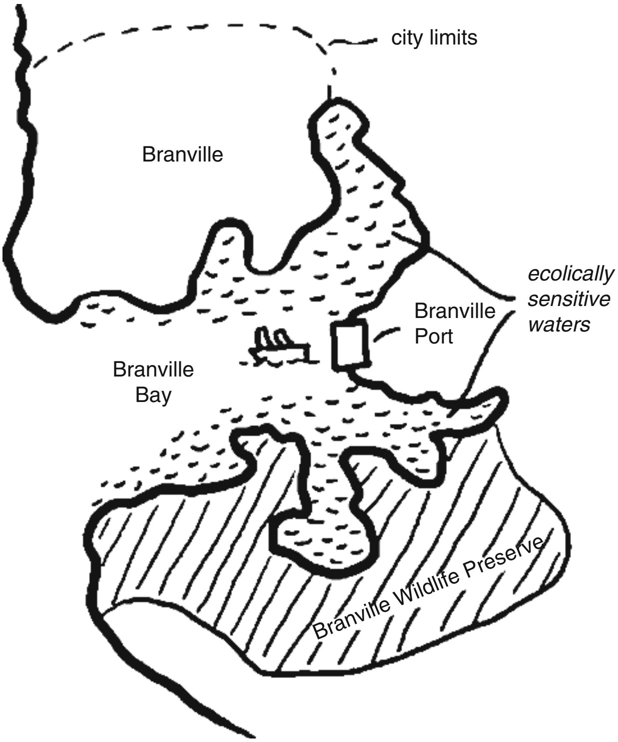

Fig. 4.7 Map of Branville Bay and the surrounding area

several tribes of Native Americans. More recently, Branville has become a major shipping port. Ships from all over the world dock at Branville Port delivering products like oil, clothing, toys, and fruit. These products are then distributed throughout the USA. Businesses in the USA also use the port to send their products around the world (see Fig. 4.7).

Branville Bay is a sensitive ecological area serving as the breeding grounds for many fish, birds, and other wildlife. There are strict laws that govern fishing in the most sensitive areas of the bay. However, these laws do not apply to the Native Americans still living in the area because they have claimed ancestral fishing rights in the area.

Managers of the Branville Wildlife Preserve have started reporting declines in fish counts, bird counts, and water quality measures. These managers have concluded that the heavy ship traffic moving in and out of Branville Port is damaging the Branville Bay ecosystem. Port Authorities claim that their ships stay in deep water channels and do not travel into the most sensitive waters of the bay. They argue that the Native American fishers are the most likely culprits because they use boats and fish in the bay's most sensitive waters.

Local leaders are trying to decide what to do.
Questions:

1. Can the Branville Bay situation be solved easily?

   A. YES
   B. NO

If A, then: Explain why you think the Branville Bay situation should be easy to solve.
If B, then: Explain why you think the Branville Bay situation cannot be solved easily.

2. If you were responsible for deciding how to resolve the Branville Bay situation, would you need additional information regarding the situation before making your decision?

   A. Yes, I would need to have additional information to make a decision.
   B. No, I have sufficient information to make a decision.

If A, then: What kinds of additional information would be necessary for you to make a decision regarding the Branville Bay situation?

If you were responsible for deciding how to resolve the Branville Bay situation, what would you recommend doing as a next step? Please explain why this would be an effective strategy.

If B, then: If you were responsible for deciding how to resolve the Branville Bay situation, what would you recommend doing? Please explain why this would be an effective strategy.

3a. In the previous prompt, you were asked to suggest a course of action for the Branville Bay situation. Describe the strengths of your proposed approach.
3b. Describe the weaknesses of your proposed approach.
4a. A group of concerned Branville citizens gathered to discuss a solution for the Branville Bay situation. The group suggested that Native American fishing permits in the most sensitive waters of the Bay be reduced by half and that ship traffic be reduced by one-third (that is, only two-third of the current number of ships traveling in the bay could continue coming into the Bay).
4b. How do you think Branville Port Authorities would respond to this suggestion? Please explain your response.
4c. How do you think Native Americans in Branville would respond to this suggestion? Please explain your response.
4d. How do you think managers of the Branville Wildlife Preserve would respond to this suggestion? Please explain your response.

5. In response to the previous questions, you commented on how three different groups (Port Authorities, Native Americans, and Wildlife Managers) would respond to a proposed solution. Which of the following statements most accurately reflects your responses?

   A. The Port Authorities, Native Americans, and Wildlife Managers would have similar responses to the proposed suggestion.

B. The Port Authorities, Native Americans, and Wildlife managers would have different responses to the proposed suggestion.

If A, then: Explain why you expect the Port Authorities, Native Americans, and Wildlife Managers to have similar responses to the proposed suggestion.

If B, then: Explain why you expect the Port Authorities, Native Americans, and Wildlife Managers to have different responses to the proposed suggestion.

References

ACS. (2006). *Chemistry in the community* (5th ed.). New York: W. H. Freeman.

Agresti, A., & Finlay, B. (1999). *Statistical methods for the social sciences*. Upper Saddle River, NJ: Prentice Hall.

Albe, V. (2008). When scientific knowledge, daily life experience, epistemological and social considerations intersect: Students' argumentation in group discussion on a socio-scientific issue. *Research in Science Education, 38*, 67–90.

Anthony, S., Brauch, T. W., & Longley, E. J. (2007). *Chem connections: What should we do about global warming?* New York: W. W. Norton.

Barab, S. A., Sadler, T. D., Heiselt, C., Hickey, D. T., & Zuiker, S. (2007). Relating narrative, inquiry, and inscriptions: Supporting consequential play. *Journal of Science Education and Technology, 16*, 59–82.

Barber, M. (2001). *A comparison of NEAB and Salters A-level Chemistry: Students views and achievements*. UK: University of York.

Berkowitz, M. W., & Simmons, P. (2003). Integrating science education and character education. In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 117–138). Dordrecht: Kluwer.

Bingle, W. H., & Gaskell, P. J. (1994). Scientific literacy for decision making and the social construction of scientific knowledge. *Science Education, 78*, 185–201.

Bryce, T., & Gray, D. (2004). Tough acts to follow: The challenges to science teachers presented by biotechnological progress. *International Journal of Science Education, 14*, 717–733.

Cajas, F. (1999). Public understanding of science: Using technology to enhance school science in everyday life. *International Journal of Science Education, 21*, 765–773.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillside: Lawrence Earlbaum Associates.

Cross, R. T., & Price, R. F. (1996). Science teachers' social conscience and the role of controversial issues in the teaching of science. *Journal of Research in Science Teaching, 33*, 319–333.

DeBoer, G. E. (1991). *A history of ideas in science education: Implications for practice*. New York: Teachers College Press.

Dori, Y. J., Tal, R., & Tsaushu, M. (2003). Teaching biotechnology through case studies – Can we improve higher order thinking skills of nonscience majors? *Science Education, 87*, 767–793.

Dunlop, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological Methods, 1*, 170–177.

Harris, R., & Ratcliffe, M. (2005). Socio-scientific issues and the quality of exploratory talk-what can be learned from schools involved in a 'collapsed day' project? *The Curriculum Journal, 16*, 439–453.

Hickey, D. T., & Pellegrino, J. W. (2005). Theory, level, and function: Three dimensions for understanding transfer and student assessment. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 251–293). Greenwich, CT: Information Age Publishers.

Hickey, D. T., Zuiker, S. J., & Taasoobshirazi, G. (2006). Balancing varied assessment functions to attain systemic validity: Three is the magic number. *Studies in Educational Evaluation, 32*(3), 180–201.

Hogan, K. (2002). Small groups' ecological reasoning while making an environmental management decision. *Journal of Research in Science Teaching, 39*, 341–368.

Klosterman, M. L., & Sadler, T. D. (2008). Information literacy for science education: Evaluating web-based materials for socioscientific issues. *Science Scope, 31*(7), 18–21.

Klosterman, M., & Sadler, T. D. (2010). Multi-level assessment of content knowledge gains in the context of socioscientific issues based instruction. *International Journal of Science Education, 32*, 1017–1043.

Kolstø, S. D. (2001). 'To trust or not to trust,…' -pupils' ways of judging information encountered in a socio-scientific issue. *International Journal of Science Education, 23*, 877–901.

Lumpe, A. T., Haney, J. J., & Czerniak, C. M. (1998). Science teacher beliefs and intentions to implement science-technology-society (STS) in the classroom. *Journal of Science Teacher Education, 9*, 1–24.

Orpwood, G. (2007). Assessing scientific literacy: Threats and opportunities. In C. Linder, L. Ostman, & P.-O. Wickman (Eds.), *Promoting scientific literacy: Science education research in transaction: Proceedings of the Linnaeus Tercentenary Symposium* (pp. 120–129). Uppsala: Uppsala University.

Pedretti, E. (1999). Decision making and STS education: Exploring scientific knowledge and social responsibility in schools and science centers through an issues-based approach. *School Science and Mathematics, 99*, 174–181.

Ruiz-Primo, M. A., Shavelson, R. J., Hamilton, L., & Klein, S. (2002). On the evaluation of systemic science education reform: Searching for instructional sensitivity. *Journal of Research in Science Teaching, 39*, 369–393.

Sadler, T. D., Amirshokoohi, A., Kazempour, M., & Allspaw, K. (2006). Socioscience and ethics in science classrooms: Teacher perspectives and strategies. *Journal of Research in Science Teaching, 43*, 353–376.

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education, 37*, 371–391.

Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific argumentation: The effects of content knowledge and morality. *International Journal of Science Education, 28*, 1463–1488.

Sadler, T. D., Eckart, T. M., Lewis, J. E., & Whitley, K. M. (2005). It's a gas! An exploration of the physical nature of gases. *Science Scope, 29*(3), 12–14.

Sadler, T. D., & Fowler, S. (2006). A threshold model of content knowledge transfer for socioscientific argumentation. *Science Education, 90*, 986–1004.

Sadler, T. D., & Klosterman, M. L. (2009). Exploring the socio-political dimensions of global warming. *Science Activities, 45*(4), 9–12.

Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education, 88*, 4–27.

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching, 42*, 112–138.

Settlage, J., & Meadows, L. (2002). Standards-based reform and its unintended consequences: Implications for science education within America's urban schools. *Journal of Research in Science Teaching, 39*, 114–127.

Sneider, C., Golden, R., & Gaylen, F. (2004). *Climate change*. Berkley: Lawrence Hall of Science.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks: Sage Publications.

Yager, S. O., Lim, G., & Yager, R. (2006). The advantages of an STS approach over a typical textbook dominated approach in middle school science. *School Science and Mathematics, 106*, 248–260.

Yang, F.-Y., & Anderson, O. R. (2003). Senior high school students' preference and reasoning modes about nuclear energy use. *International Journal of Science Education, 25*, 221–244.

Zeidler, D. L., & Sadler, T. D. (2008). The role of moral reasoning in argumentaion: Conscience, character, and care. In S. Erduran & M.-P. Jiménez-Aleixandre (Eds.), *Argumentation in science education: Recent developments and future directions* (pp. 201–216). New York: Springer.

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education, 86*, 343–367.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*, 35–62.