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Abstract

Socio-scientific teaching and learning (SSI-TL) has been suggested as an effective approach for supporting meaningful learning in school contexts; however, limited tools exist to support the work of designing and implementing this approach. In this paper, we draw from a series of four design based research projects that have produced SSI curriculum materials, research findings, and design insights. The paper describes the creation and evolution of a model for SSI-TL. The model highlights a sequence of learning experiences that should be featured in SSI-TL and the kinds of learning objectives that should result. Student learning experiences should include encountering a focal SSI; engaging in science practices, disciplinary core ideas and crosscutting concepts as well as socio-scientific reasoning practices; and synthesizing key ideas and practices through a culminating exercise. The proposed learning objectives align with Next Generation Science Standards and also reflect the important social dimensions of SSI.

Introduction

Socio-scientific issues (SSI) are complex and contentious societal issues with substantive connections to science ideas and principles (Zeidler, 2014). Prominent examples of SSI include genetically modified foods, access to water resources, and hydraulic fracturing. Science educators, social studies educators, and learning scientists have argued for the use of SSI as productive contexts for engaging students in learning opportunities that bridge school experiences with broader societal contexts (e.g., Parker & Lo, in press; Topcu & Genel, 2014; Yoon, 2011). Based on situated accounts of learning, we contend that SSI afford contextual dimensions of learning experiences that can transform the very nature of those experiences and the meaning and significance of learning (Sadler, 2009).

Socio-scientific Issues Teaching and Learning (SSI-TL) shares features with other pedagogical approaches including project based learning (Krajcik, McNeill & Reiser, 2008), case based approaches (Yadav et al., 2007), and context based learning (Bennet & Lubben, 2006). This paper does not offer a conceptual analysis of these approaches, but we think it important to situate the work with respect to other efforts. All of these approaches are based on the idea that learning should be connected to contexts that provide meaning to content. In the case of SSI-TL, the context is a societal issue with connections to science. By definition, SSI are ill-structured or wicked problems that lack simple, clear-cut solutions (Zeidler, 2014). They can be informed by ideas and commitments from various perspectives including economic, political, and ethical. They are also informed by scientific ideas and evidence; however, conclusions and courses of action are underdetermined by scientific evidence. By way of contrast, project based learning may be related to an interesting question or problem (e.g., why do droplets of water form on the outside of a soda can?), but the question or problem is not necessarily a societal issue. Case based approaches to science teaching help to contextualize learning experiences by relating content to an interesting situation or story, but the case itself does not necessarily deal with societal issues. Context based approaches, most widely used in chemistry education, draw connections between science and students' experiences (e.g., exploring chemical compounds in home products), but again, they do not necessarily engage learners in the negotiation of societally contentious issues.

For the last decade, an expanding body of research has documented ways in which SSI-TL are associated with desired educational goals including student learning of disciplinary content (Dori, Tal, & Tsaushu, 2003); engagement in argumentation practices (Venville & Dawson, 2010); development of epistemological understandings (Khishfe & Lederman, 2006); development of positive attitudes toward science (Lee & Erdogan, 2007); growth in moral sensitivity (Fowler, Zeidler & Sadler, 2009); and advancements in reasoning (Zeidler, Sadler, Applebaum & Callahan, 2009). Despite this progress, there have been fewer advances in understanding how SSI can be productively incorporated in learning environments. The lack of resources and tools to support teachers' and curriculum designers' work toward creating SSI learning experiences has been consistently highlighted as a leading constraint limiting widespread use of the approach (Ekborg, Ottander, Silver & Simon, 2013; Sadler, Amirshokoohi, Kazempour & Allspaw, 2006).

This paper addresses some of these gaps by highlighting a series of four design-based research projects. Individually, each of the projects served three purposes. First, each served to create SSI-TL design products, primarily in the form of curricular materials for secondary science classrooms. Second, each produced research findings related to student learning in the context of SSI-TL. Finally, each project focused on design processes and yielded design principles for SSI-TL. The resulting design principles were codified within a series of instructional models. Taken together, the four projects represent a research program that has iteratively refined a model for SSI-TL. Our intent is for this model to be grounded in the work of design and empirical evidence with the goal of informing practice. The purpose of this paper is presentation of the model; in doing so, we want to show where the model has come from and how it has evolved. We see this as necessary for documenting ways in which the model is grounded in design processes and systematic research.

Overview of Design Based Research Projects

Information about each of the four research projects is presented in Table 1. The first project involved a small team of SSI researchers and two high school science teachers; together, this group created an SSI unit related to climate change and the particulate nature of gases (see *Curriculum & Assessment Tools for Socio-scientific Inquiry* in Table 1). The research explored how SSI-TL supported student learning of science content. Based on findings from the project, we proposed an initial framework for SSI-TL (Sadler, 2011). This framework highlighted "design elements" and "learner experiences." The design elements highlighted the need for SSI teaching to 1) build instruction around a compelling issue, 2) present the issue first, 3) provide scaffolding for higher order practices such as argumentation, and 4) provide a culminating experience. Learner experiences called for students to 1) engage in reasoning, argumentation, decision-making, and/or position-taking; 2) confront the scientific ideas and theory related to the issue; 3) collect and/or analyze scientific ideas and theories related to the issue; and 4) negotiate the social dimensions of the issue. These central elements were encapsulated by important mediators: the classroom environment and teacher attributes. A representation of this initial framework is presented in Figure 1, image 1.

The next project was a larger scale study including four high school life science teachers implementing an SSI unit related to biotechnology, sexually transmitted disease, and genetics (see *Viral Quest* in Table 1). Design and development of the biotechnology unit and studies of teacher implementation of the unit prompted some modifications to the initial framework. The design elements and learner experiences categories remained unchanged as central elements, but given the significance of teachers' individual choices during enactment, we moved "teacher attributes" from a peripheral to central element. We also distinguished between proximal mediators such as the classroom environment and more peripheral influences such as school expectations and state standards (see Fig. 1, image 2).

The third project was a collaborative design effort with a secondary biology teacher and extended over three years and multiple iterative designs of two SSI units. One unit focused on emergence of antibiotic resistant bacteria as an illustration of natural selection; the second unit related to climate change and the cascading impacts of changes to abiotic factors on ecosystem dynamics (see *SSI and Modeling Collaborative,* Table 1). Both units were implemented, studied, and revised through two complete design based research cycles. The transition between the second and third projects was marked by significant developments including release of the *Framework for K-12 Science Education* (National Research Council, 2011) and the *Next Generation Science Standards* (NGSS Lead States, 2013). Our core design and research team also changed with the addition of new expertise particularly in the areas of teacher education and exemplary teaching practices. These developments influenced us to move away from a generalized framework for describing SSI-TL and toward a model for designing and implementing SSI-TL. In addition, we revised the model to focus much more on themes derived from NGSS, most notably on the big ideas of science in combination with scientific practices. We also highlighted dimensions of instruction that are important for SSI-TL but with which we had observed teachers struggle: 1) drawing attention to social concerns and implications of SSI; 2) engaging learners in the use of information and communications technologies to access, critique, and share information; and 3) incorporating a culminating activity that encourages students to synthesize their learning experiences (see Fig. 1, image 3). The final project moved from design for teaching high school science to design for supporting science teacher education. In this project, we have worked to create learning experiences for preservice teachers involved in professional preparation. In the first three projects, our focus was on using issues as contexts for high school student learning. The final project is a bit more complex in that we designed an SSI-TL unit for teaching nutrition-related biochemistry concepts in the context of debates over taxation of "unhealthy" foods, as well as materials for helping future teachers learn about what SSI-TL is and how to teach using this approach. The need to communicate design principles to the preservice teachers helped illuminate inconsistencies in the SSI-TL model and encouraged more explicit attention to tacit dimensions of earlier versions.

Table 1. Progression of design based research projects and their contributions to the emerging model for SSI teaching and learning

Project & Description	**Design Products**	**Research Findings**	**Contributions to the SSI-TL Model**	**Representative Publication(s)**
Curriculum & Assessment Tools for Socio-scientific Inquiry: Design and implementation of SSI-TL for high school chemistry and physical science classes.	• SSI unit on climate change as a context for learning about the particulate nature of gases. • Instrumentation for assessing socio-scientific reasoning.	• Students demonstrate learning on both proximal and distal assessments of science content knowledge. • Students can use ICT for productive exploration of SSI.	• Enactment of SSI curricula can inform a general framework for SSI-TL. Central aspects of the framework are learner experiences and design elements. Teacher attributes and classroom environment are positioned as influences. (See Fig. 1, image 1.)	Klosterman & Sadler, 2010 Sadler, 2011
Viral Quest: Design and study of SSI unit for high school biology.	• SSI unit related to biotechnology and sexually transmitted diseases as a context for genetics instruction.	• Students in classes using SSI materials make significantly greater learning gains than peers in comparison classes.	• Teacher attributes are moved to a more central position in the framework. (See Fig. 1, image 2.)	Presley et al., 2013 Sadler, Romine & Topcu, in review
SSI & Modeling Collaborative: A researcher/ practitioner (HS teacher) partnership for exploring NGSS-aligned SSI-TL.	• SSI unit on bacterial resistance to antibiotics as a context for learning about natural selection. • SSI unit on climate change as a context for learning about ecology.	• Students demonstrate NGSS-aligned learning with a focus on modeling. • Context-specific solutions are needed for balancing the content demands of SSI-TL, the incorporation of societal connections, and limited instructional.	• The general framework needs to be translated so that it can more directly inform planning and implementation. • The new model highlights 1) a focal issue, 2) NGSS perspectives on learning content and practice, 3) social connections to the issue, 4) learner engagement with ICT, and 5) a culminating activity. (See Fig. 1, image 3.)	Friedrichsen, Sadler, Graham & Brown, 2016 Sadler, Friedrichsen, Graham, Foulk, Tang & Menon, 2015
SSI in Teacher Education: An effort to help preservice science teachers develop competencies necessary for using SSI in their teaching	• Module for learning about SSI-TL. The module includes a sample unit on nutrition and taxation of unhealthy foods as a context for learning biochemistry.	• Ongoing. Anticipated findings include development of preservice teachers' ideas, beliefs, and intended practices related to SSI-TL .	• The model requires clarification and elaboration. Changes include highlighting objectives, incorporation of socio-scientific reasoning practices, repositioning of ICT, and clarifying the culminating task. (See Fig. 2.)	Foulk, 2016

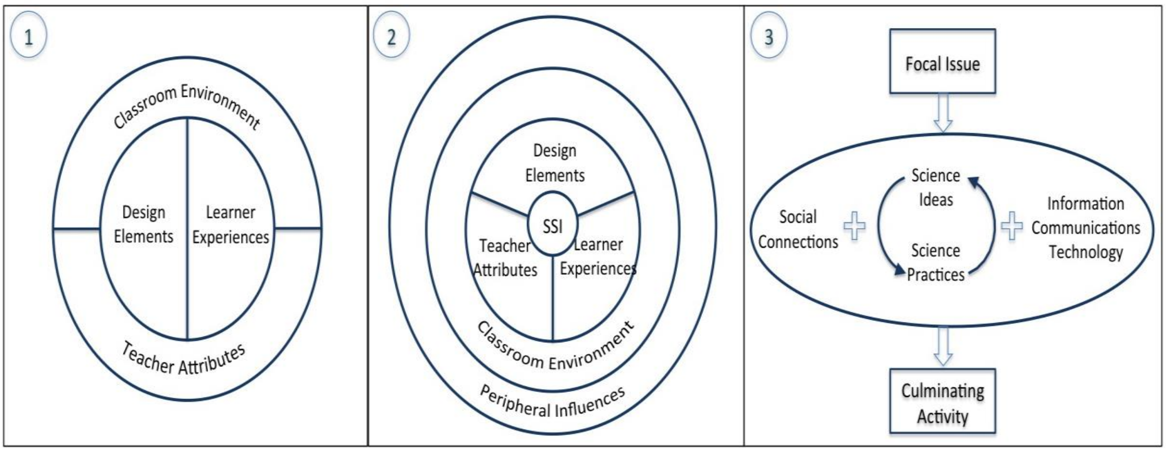

Figure 1. Initial models developed for representing SSI teaching and learning

The Emergent Model for SSI Teaching and Learning

The current model comprises two sections: 1) a sequence describing the kinds of learning experiences that students ought to have in SSI-TL and 2) a range of learning objectives that successful SSI-TL ought to support. This model is presented in Figure 2. The left side of the model presents the sequence of learning experiences. This sequence is made up by three main phases. The first phase involves students encountering the focal issue. The second phase captures the main body of teaching and learning experiences, and calls for student engagement with science ideas, science practices and socio-scientific reasoning practices. We conceptualize the learning of science consistent with NGSS and its call for three-dimensional science learning, including emphases on disciplinary core ideas, crosscutting concepts, and scientific practices. The third phase of the model corresponds with a culminating experience in which students synthesize the ideas and practices with which they have engaged throughout the unit. Each of these phases will be detailed further in the sections to follow. Throughout our presentation of the model, we highlight examples from one of the units created as a part of the *SSI and Modeling Collaborative* project. The highlighted unit, which focuses on the emergence of antibiotic resistant bacteria and natural selection, has been implemented in three iterations over the course of three years so we have had a chance to make multiple refinements. By focusing on a single SSI unit as a source of examples, our intent is to provide readers an opportunity to consider ways in which different aspects of the SSI-TL model interact. Additional details about the antibiotic resistance unit and the school context are available elsewhere (Friedrichsen et al., 2016).

Encountering the Focal Issue

The sequence begins with students encountering the focal issue. During this initial experience with the issue, our work suggests that it is important for students to develop awareness of the ways in which science ideas, principles, and/or inquiries have bearing on the issue as well as some of the social issues and problems that emerge from the issue. For instance, in the antibiotic resistance unit, referenced as a part of the third design based research project, students first encountered the focal issue through exposure to several multi-media cases that described individuals suffering from methicillin resistant *Staphylococcus aureus* (MRSA). These cases featured personal stories of people including an emotionally charged video presentation of an otherwise healthy young girl who died from MRSA-related complications. The cases also highlighted bacterial evolution as a central component of the problem and introduced societal dimensions of the issue that make the problem challenging. Some of the societal dimensions that students were encouraged to negotiate included questions about patient rights and national healthcare policies.

Three-Dimensional Science Learning

The second phase of the sequence calls for students to engage in three-dimensional science learning, as defined by NGSS, along with socio-scientific reasoning practices. Three-dimensional science learning corresponds to engaging with disciplinary core ideas (DCI), crosscutting concepts (CCC), and science practices (SP). By incorporating this orientation to science learning, we ground the model in the extensive literature base underlying NGSS (e.g., Krajcik, Codere, Dahsah, Bayer & Mun, 2014; National Research Council, 2012). Disciplinary core ideas addressed in the antibiotic resistance unit related to *natural selection* and *adaptation* (LS4.B and LS4.C from the NGSS). In terms of crosscutting concepts, our focus on evolution of antibiotic resistance led naturally to explorations of *cause and effect* as well as *stability and change*, two of the seven CCCs identified in the NGSS. Of the three dimensions of science learning spelled out by the NGSS, we have found the emphasis on student engagement in science content-dependent practices to be particularly helpful in creating productive and substantive science learning experiences connected to societally significant issues. In the antibiotic resistance unit, the scientific practice of *modeling* was a central element of student learning experiences. Learners generated models of cellular mechanisms of resistance, molecular causes of population-level changes over time (in the bacteria students were studying), and natural selection. A key design issue faced by our team related to the translation of NGSS ideas for enactment. The NGSS are presented as "performance expectations" for particular grade bands and science disciplines. Each performance expectation references a discrete DCI, CCC and SP. In the sample performance expectation presented below, we highlight the three dimensions: **DCI** (bolded), *CCC* (italicized), and <u>SP</u> (underlined). Below the performance expectation, we list each dimension as identified in the NGSS.

HS-LS4-1: <u>Communicate scientific information</u> that **common ancestry and biological evolution** are *supported by multiple lines of empirical evidence*.

DCI: Evidence of common ancestry and diversity.
CCC: Patterns.
SP: Obtaining, evaluating and communicating information

As science educators, we were familiar with organizing instruction around interconnected content ideas (DCI, as labeled in the NGSS). As such, our initial planning for the antibiotic resistance unit involved finding the performance expectations that addressed evolution and natural selection DCIs. This yielded five performance expectations that outlined important content ideas to cover in the unit, but each performance expectation also presented an SP and a CCC. In the case of CCC, each of the five performance expectations highlighted either *cause and effect* or *patterns*, but none of them drew attention to *stability and change*, which we saw as a critical aspect of teaching about natural selection and evolution. Practices featured in the selected performance expectations included 1) obtaining, evaluating, and communicating information; 2) constructing explanations (represented in two performance expectations); 3) analyzing and interpreting data; and 4) engaging in argument from evidence. The challenge, from our perspective, was that attempting to address all the CCCs and SPs highlighted in the performance expectations with the appropriate DCIs would be too ambitious in a single unit. We reasoned that targeting learning gains across all of these areas would likely result in limited learning. To address this concern, we chose to plan for NGSS-inspired three-dimensional learning by focusing on a limited number of DCIs (those that highlighted natural selection and adaptation), CCCs (cause and effect and stability and change), and a single scientific practice (modeling). In taking this approach, we positioned the NGSS performance expectations as sample arrangements of possible three-dimensional learning goals, but did not assume specific combinations within any particular performance expectation were sacred. For example, in the performance expectation listed above (HS-LS4-1) the DCI of *evidence of common ancestry and diversity* is linked with the SP of *obtaining, evaluating, and communicating information*. This particular DCI could be paired with several of the scientific practices including 1) *asking questions*, 2) *developing and using models*, 3) *planning and carrying out investigations*, and so forth. However, trying to engage students in all of the practices that could possibly fit with the DCI in ways that lead to substantive growth in student competencies in all of these areas would dilute student experiences and ultimately lead to limited learning. Therefore, we chose to identify one practice and two CCCs on which to focus throughout the unit. In reality, students engaged in some of the other practices as they engaged in modeling (e.g., *collecting and analyzing data* to inform their models and *constructing explanations* related to their models), but the instructional and assessment foci remained on the practice of modeling. We have devoted time and space to explicating our position on the use of (and suggestion to essentially deconstruct) NGSS performance expectations because we have found this to be a critical design decision in the creation of SSI curricula. The teachers with whom we have worked and who have attempted to design SSI learning experiences for their students aligned with NGSS but who are unable (or unwilling) to decouple specific dimensions highlighted in a particular performance expectation have struggled to create successful materials. Our own position on the NGSS is that they provide a helpful frame for moving science education forward, but that the standards ought to be interpreted with a degree of flexibility and reasoned professional judgment.

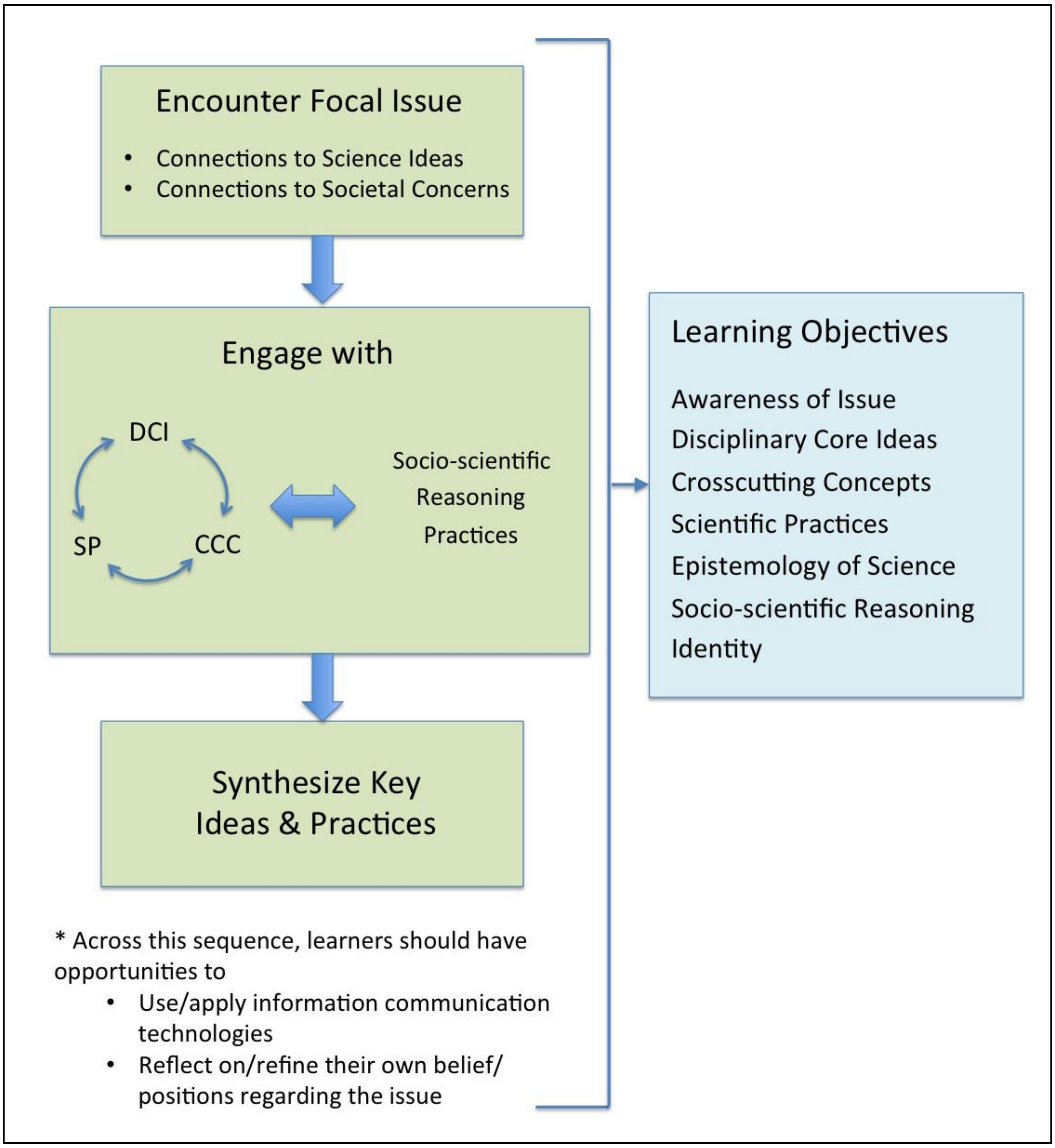

Figure 2. Graphic representation of the SSI Teaching and Learning model

Socio-scientific Reasoning

In addition to learning the science embedded in complex issues, the second phase of the SSI-TL learning model calls for learners to engage in practices that reflect the social and scientific intersections that make the focal issue complex, interesting, and difficult to resolve. These practices have been identified as socio-scientific reasoning (SSR; Sadler, Barab & Scott, 2007). A set of inter-related competencies make up SSR including 1) accounting for the inherent *complexity* of SSI, 2) analyzing issues from *multiple perspectives*, 3) identifying aspects of issues that are subject to ongoing *inquiry*, 4) employing *skepticism* in analysis of potentially biased information, and 5) exploring how science can *contribute* to the issues and the *limitations of science*. Earlier versions of the model called for opportunities for students to consider the "social connections" of issues as they engage in SSI learning (see Figure 1), but this is one of the more challenging aspects of the approach for many science teachers (Hughes, 2000; Sadler et al., 2006). By referencing "socio-scientific reasoning" which has been unpacked by researchers and practitioners (Herman, 2015; Sadler, Klosterman & Topcu, 2011; Sadler & Zeidler, 2009; Simonneaux & Simonneaux, 2009), we intended to add detail and depth to the suggestion for incorporating social dimensions of issues.

Throughout the antibiotic resistance unit, students had multiple opportunities to engage in socio-scientific reasoning practices. Early in the unit students explored multiple websites authored by stakeholders with different perspectives and interests on the issue. Some of these materials included a personal blog from an individual suffering from MRSA; posts from an online MRSA support group; a mainstream media site cataloging the spread of MRSA; a MRSA information site maintained by a US government agency; and medical summaries of MRSA infections and possible treatments prepared by a physicians group. Exploration of these materials challenged students to consider the issue from diverse perspectives and to employ critical analysis and skepticism. Later in the unit, the instructor led students in a classroom discussion relating a controlled laboratory experience they had completed (students plated bacteria on media with varying concentrations of antibiotic over several days and observed microevolutionary changes) and the resultant models with the challenges of studying and controlling bacterial evolution *in natura* particularly in light of lateral gene transfer. This discussion pushed students to consider dimensions of the problem that scientists were still trying to work through (the *inquiry* aspect of socio-scientific reasoning) as well as some dimensions for which science simply does not and cannot have answers (the *contributions and limitation of science* aspect of socio-scientific reasoning).

After students had developed familiarity with the problem of antibiotic resistance and understandings of natural selection as a basic driver of the issue, they were challenged to explore some of the societal dimensions of the problem that make the issue so difficult to address. In our treatment of the issue, we highlighted social, political, and economic challenges. A social challenge associated with antibiotic resistance is the potential tension between patients, who often want antibiotics for conditions that may be viral, and physicians, who may not be able to rule out a bacterial infection but suspect a viral cause and do not want to overprescribe antibiotics. Political issues associated with antibiotic resistance include 1) the perception that guidelines or controls on antibiotic prescriptions amounts to governmental interference in healthcare and 2) vastly different policies for the use and regulation of antibiotics in different regions of the world. In terms of the economics of antibiotic resistance, research and development of new antibiotics to combat emerging strains of resistant bacteria are costly and lengthy. Despite the clear societal need for new antibiotics, pharmaceutical companies face significant financial disincentives, which stymy potential work in this area. We did not expect students to develop expertise in all of these social, political, and economic challenges, but we wanted them to be exposed to the range of societal concerns that contribute to the intractable nature of the issue of antibiotic resistance. Students worked through a jigsaw-style activity in which individuals read about, answered questions, and prepared summaries of one of the societal challenges. They then shared summary information in small groups with students who had explored the other societal challenges. This exercise highlighted the *complexity* and *multiple-perspectives* aspects of socio-scientific reasoning.

Synthesis of Ideas and Practices

The final phase of the sequence calls for students to synthesize ideas and practices they have encountered and engaged with throughout the unit. Consistent with the status of SSI as open-ended problems without clear-cut solutions, it is critical that students have opportunities to reflect on their own perspectives on the issue and the ways in which those perspectives may interact with the science ideas (including DCI and CCC), science practices, and socio-scientific reasoning practices which they have been developing. In the antibiotic resistance unit, students developed policy recommendations as a culminating exercise and summative assessment for the unit. More specifically, students were challenged to craft a policy that could limit the development and spread of antibiotic resistant bacteria with human health risks. Students had flexibility to choose policies that could be enacted at state, national, or international levels and could pursue their own ideas and suggestions. Requirements of the final product included analyses of epidemiological data, explanations of natural selection as a mechanism for ongoing change in bacterial populations, and discussion of likely responses of stakeholders to their policy recommendations. Students were strongly encouraged to consider their previous explorations of cases of individuals suffering from bacterial diseases such as MRSA and specific social, political and economic challenges associated with finding solutions to the issue. Each student was responsible for crafting her/his own policy statement and justification, but small groups worked together to brainstorm initial ideas, and later in the process, provided peer reviews of one another's products.

In response to this assignment, students prepared essays that presented and justified the policies for which they advocated. Student products ranged in length from one to four pages. For our research team, the students' work served as artifacts of their reasoning and argumentation in the context of an SSI. As such we looked for argument structures such as claims, evidence, and warrants. We also looked for the ways in which students used scientific models, ideas and evidence to frame their policies, as well as how social, political, economic and/or ethical concerns were addressed. For the teacher with whom we partnered, the students' policy statements served as a summative assessment and a portion of the students' unit grade. To facilitate her grading and feedback process, the teacher developed a rubric with four levels for six dimensions. The rubric dimensions included statement and description of the policy, use of evidence to support the recommendation, analysis of the problem and impacts of the policy, written communication, research processes (including credibility of sources and citation formatting), and evaluation of multiple perspectives.

Additional Elements

The SSI-TL model contains two additional elements, but they are not presented in sequence. This positioning outside of the sequence highlights the fact that these elements should be integrated across the three major phases. The first recommendation is that learners should have opportunities to use information and communications technologies (ICT) in the exploration of the focal issue. An earlier version of the SSI-TL model presented student use of ICT as a core component of the model alongside student explorations of science ideas and practices and negotiation of social dimensions (see Figure 1). However, multiple design iterations revealed that ICT opportunities could occur within any of the sequence phases. By definition, SSIs are contemporary issues; as such, information about the issues is emerging and evolving. In some cases, the underlying science has not reached a point of consensus or may be considered science-in-the-making (Kolstø, 2001). In other cases, there may be new or changing perspectives associated with the social dilemmas created by the issue. In either of these situations (or combined situations) static media such as science textbooks are not likely ideal options for student information-finding and analysis. More dynamic and timely media, most of which are accessed through the web, such as news reports and stories, new scientific reports (or secondary presentations of original scientific literature prepared for broader audiences), social media, websites maintained by various stakeholders, etc. will likely provide a more useful range of information for students exploring SSI (Klosterman, Sadler & Brown, 2012).

We include ICT as an explicit component of the SSI-TL model because while student negotiation of media and information tools are critical to learning about SSI, traditional science teaching has not always emphasized deliberate use of popular media or the skills necessary for students to navigate these information sources in informed and productive ways (Reid & Norris, 2015). In the antibiotic resistance unit, students had multiple opportunities to use ICT as they made sense of the issue, the underlying science, and societal questions and implications. For example, they collected epidemiological data through websites maintained by health agencies; reviewed personal accounts of patients suffering from bacterial diseases through blog posts; explored multiple perspectives of different stakeholders; and analyzed media reports on MRSA. Whenever students were using popular media, they were encouraged to think critically about the information they were consuming. The instructor consistently encouraged students to consider the source and author of the information, the purpose of the publication, potential biases of the author or publisher, evidentiary support for the information, and possible missing information. As a physical reminder for students to thoughtfully consider these aspects of media, we created a *Know Your Sources of Information* form (see Figure 3). The form contains several media literacy questions, but students were not asked to complete each question as if it were a typical worksheet. Instead, the form was positioned as a resource to guide student thinking about the kinds of issues they should be considering when interrogating media. Students received the resource, and we also distributed ample copies around the classroom (e.g., at laboratory benches, on the teacher's desk in front of the room, posted on the fume hood) as a means of providing constant reminders that accessing information about issues should be an active process of asking questions and exhibiting reasoned skepticism.

The second recommendation is that students have opportunities to reflect on and/or refine their own beliefs and perspectives. In earlier versions, this suggestion was embedded exclusively in the the culminating activity stage of the model. However, as in the case of ICT, the design work and implementation studies highlighted a need to create multiple opportunities for students to do this reflective work. In the antibiotic resistance unit, students were consistently encouraged to apply their own ideas and perspectives to the question of how the problem of antibiotic resistance should be addressed. All participating students were expected to develop understandings of natural selection generally, the evolution of bacterial populations more specifically, and evidence related to the spread of drug resistant bacteria, but students were encouraged to take agency in terms of how to use this scientific knowledge in conjunction with their own personal perspectives on the social, political, and economic aspects of the issue. While the instructor offered informal reminders for students to engage in this multi-dimensional reasoning throughout the unit, the policy recommendation assignment, which served as the culminating experience, mandated creation of a product that reflected students' own thinking about the problem and potential solutions.

Learning Objectives

The right side of the SSI-TL model presented in Figure 2 identifies categories of learning objectives that SSI-TL should target. Table 2 lists these categories of objectives along with specific learning objectives from the antibiotic resistance unit. Also provided in this list are sample assessment strategies, aligned with each specific objective, used in the context of the antibiotic resistance unit. The very nature of creating lists forces independent enumeration of constructs; in this case, our work has yielded seven learning objective categories. However, despite this listing, it is not our intent to imply that the categories are independent. For example, we highlight disciplinary core ideas, crosscutting concepts, and scientific practices as important learning constructs, but in line with NGSS assumptions, we view these strands of learning as necessarily connected. Nevertheless, we find it helpful for research, design, and teaching purposes to draw attention to the individual, yet, interconnected categories of learning objectives. These interconnections are evidenced by the assessment strategies which overlap multiple objective categories. For example, the culminating activity from the antibiotic resistance unit, which challenged students to create and justify policy recommendations, provided a platform for students to demonstrate their awareness of the issue, disciplinary core ideas, crosscutting concepts, epistemology of science, and SSR practices.

Know Your Sources of Information

Consider your sources as you collect information regarding any difficult issues, especially issues that involve science.

With modern technologies, it is possible to find information on virtually any topic, but the quality and usefulness of the information to which you have access will vary. It is critical that you pay attention to where information is coming from, who is behind the information (their credibility, expertise, biases, etc.), and what you can and/or should do with that information. There is no single method for documenting the credibility and reliability of information and information sources, but here are some suggested questions to explore in your analysis of any information source. Keep in mind that not all of these questions will be pertinent for all information sources.

1. Who (or what organization or company) is presenting the information?
2. What is the purpose of the publication?
3. What expertise and/or relevant experience does the author (or organization or company) have?
4. What biases does the author (or organization or company) have and how might those biases affect the presentation of information?
5. Does the information presented seem to be accurately reported? Are the claims made in the presentation supported? Do any facts or analyses seem to be distorted?
6. Does the presentation leave important information out? Does the presentation offer information that is unnecessary (particularly if the extra information distorts the message)?

Figure 3. Resource provided to students for supporting critical analysis of media used for exploring the issue of antibiotic resistance

Disciplinary core ideas, crosscutting concepts, and scientific practices represent the key competencies outlined in NGSS, the development of which was significantly influenced by both the learning sciences and science education communities. The other learning objectives are a bit more removed from mainstream consensus, and therefore, we offer brief justifications for their inclusion in the SSI-TL model. Most frameworks and standards documents for science education make some allusions to an ultimate goal of helping students be better prepared for considering, making decisions, and engaging in discourses about societal issues. Roberts (2007) refers to this goal as “Vision II Scientific Literacy.” Based on a situated learning perspective (Lave & Wenger, 1991), it seems highly unlikely that students will, in fact, apply their school learning in Vision II contexts unless they gain experiences which support these ambitious practices (Sadler, 2009). We contend that SSI-TL provides these kinds of experiences and that highlighting learning objectives associated with the negotiation of issues (i.e., awareness of the issue and SSR) helps ensure that issues become substantive aspects of the learning experience and not just an initial "hook" to generate student interest.

The learning objective category list also includes epistemology of science. Vigorous debate regarding the place of epistemology of science, often referred to as nature of science (NOS), within science teaching and learning has emerged. The purpose of this paper is not to recount the varying perspectives on the teaching and learning of NOS, but we situate the SSI-TL model in a middle ground area between the perspective of some science educators who call for explicit reflective NOS teaching (see Abd-El-Khalick, 2012) and some learning scientists who contest the value of traditional NOS teaching and instead focus on epistemic practices (see Duschl & Grandy, 2013). Based on our design work and implementation studies, we advocate an approach that intentionally features issue-relevant epistemological ideas within SSI-TL. This does not amount to identifying consensus lists of NOS features; nor does is assume that understandings of epistemological ideas will naturally emerge through engagement in practice. Rather, the model calls for deliberate instructional attention to epistemological issues in the context of science and SSR practices.

As a part of the antibiotic resistance unit, students worked on a laboratory experiment in which they monitored the frequency of antibiotic resistance in a bacterial population over time. As a part of this work, small groups of students plated bacteria from different subcultures on agar petri dishes at different time points. The groups observed different results due to sampling differences. Therefore, in order to make sense of the experimental results, it was essential for the groups to share data, and this data sharing created opportunities for the discussion of how the class as a community needed to report data in interpretable ways. Given this concern, the class adopted specific conventions for how to record and report their data. This episode created an opportunity to discuss the importance of collaboration in the scientific community as well as the need for and sources of common protocols and reporting conventions. By focusing on epistemological themes important for the science and the issue that students are exploring, support for NOS learning becomes contextualized and can transcend simple statements of abstract facts (such as "science is collaborative").

The final learning objective category is identity development. This aspect of the model is consistent with other research that suggests a primary dimension of education should be supporting learners as they explore and develop new identities (e.g., Calabrese Barton, Kang, Tan, O'Neill, Bautista-Guerra, & Brecklin, 2012). During this identity work, students position themselves with new competencies, interests, and ideas about self that enable new patterns of participation and discourse. The SSI-TL directs a focus toward learner identities that make it possible for learners to engage with complex SSI both in and out of school. The goal is for students to not only develop interest in contributing to discourses regarding complex issues in society but also for them to see themselves as valuable contributors to those discourses. We see identity development as a learning goal that transcends single teaching and learning experiences or units. Rather, identity develops over long periods of time (Gee, 2001), but it is reasonable to expect that identities can and do evolve in response to extended efforts to engage students in meaningful negotiation of important issues (Sadler, 2009). So while it may not be feasible to assess changes of identity through the course of a single SSI unit, it is possible to consider ways in which students' identities change in response to multiple SSI learning experiences facilitated throughout a school year.

Conclusion

In approaching this paper, our intent was to synthesize insights derived from a coordinated series of projects that have focused on the design of learning experiences using SSI as a focal element. Each of these projects has yielded discrete research findings related to student learning of science content (Klosterman & Sadler, 2010; Sadler et al., in review), student modeling practices (Sadler et al., 2015), socio-scientific reasoning (Sadler, 2011) or classroom implementation of SSI (Friedrichsen et al., 2016). Design work and reflections upon the research findings from the individual projects generated ideas regarding how SSI could be productively situated in science classrooms. We were able to apply and refine these ideas in each successive iteration of the design based research. This process of learning about how to design better SSI-TL materials by developing, implementing, and researching instructional materials has resulted in a series of models. The earliest models were general and descriptive. As the work progressed, the model incorporated NGSS perspectives and became more responsive to needs and concerns of teachers and curriculum designers. The final version (figure 2) directs explicit attention to student learning experiences and potential learning outcomes.

Thus far, the primary users of the SSI-TL model have been researchers and designers with experience working with SSI. An important question that remains unanswered is how teachers, researchers, and designers who have not worked with SSI interpret and apply the model. As a part of the *SSI in Teacher Education* project highlighted in Table 1, we are exploring issues associated with how preservice teachers make sense of the model. Our team has also initiated work with a group of experienced science teachers interested in implementing SSI-TL in their classrooms but with limited experience doing so. We anticipate generating new insights regarding how the model is used at broader scales and suspect that these findings will lead to new refinements to the model itself.

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