Chapter 6
Supporting Teachers in the Design and Enactment of Socio-Scientific Issue-Based Teaching in the USA

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6.1 Introduction

The authors lead an on-going, five-year project working with teachers to co-design socio-scientific issues-based (SSI) curricula. In this chapter, we begin by describing our motivation for the project, followed by our perspective on collaborative professional development (PD). Next we describe our theoretical framework and our commitment to specific aspects of SSI teaching. The rest of the chapter consists of three design cases, presented in chronological order, representing how our thinking evolved over time. We close the chapter by reviewing what we have learned and then describe next steps.

Initially, the desire to collaborate with teachers and with each other was the motivation for our project. Collaboration is often defined as individuals working together to achieve a common goal (Katz and Martin 1997). Our research team's common goal is to support teachers and students in learning science through the use of scientific practices embedded within SSIs. In this project we collaborated with teachers to co-design SSI curricula, focusing on the development of tools and strategies to support SSI teaching and learning. In a collaboration, the members have complementary domains of expertise (John-Steiner et al. 1998). In our research team, Troy brings SSI expertise, Pat has expertise in teacher learning, and Laura has scientific modeling expertise. Our collaboration began in the autumn of 2013, shortly after the release of the *Next Generation Science Standards* (*NGSS*) (*NGSS* Lead States 2013) in the United States. Although the state of Missouri did not adopt the standards until

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4 years later, the local school district adopted *NGSS* as soon as they were released. The release of the new standards provided us with a window of opportunity to collaborate with teachers as they revised their curricula and challenged us to deepen our own understanding of how to implement the new standards using an SSI approach.

As we initially negotiated this collaborative research space, our individual research backgrounds and experiences sparked additional motivations for our collaboration. In Troy's previous work, his research team designed SSI curricula and researched student learning as classroom teachers implemented the units. Troy was further motivated to collaborate on this project because of the opportunity to co-design SSI curricula with an innovative high school biology teacher with curriculum design expertise. In Pat's previous research, using an etic approach, she studied science teachers' pedagogical content knowledge development which was often idiosyncratic depending on teachers' goals. She was further motivated to be part of this team because of her interest in collaborating with teachers who shared a common research-based vision for teaching (i.e., SSI). Laura's prior research focused on student learning and teacher thinking within modeling contexts in elementary classrooms. She found that teachers and students faced many challenges with modeling. She was looking for ways to help teachers see the need to overcome these challenges and incorporate modeling into their instruction. Laura's additional motivation to work on the project was that an SSI approach brought a level of complexity that necessitated scientific modeling as a sense-making tool. Our common goal of supporting teachers in using scientific practices embedded within an SSI context provided a context that allowed us to collaborate with each other and with teachers, while supporting our individual research interests.

6.2 Collaborative Professional Development Model

From the beginning of this project, we used a collaborative professional development (PD) model that emphasizes 'nurturing learning communities within which teachers try new ideas, reflect on outcomes, and co-construct knowledge about teaching and learning in the context of authentic activity' (Butler et al. 2004, p. 436). In our collaborative PD model, teachers collaborate with each other and with researchers, resulting in the sharing of both formalized and practical knowledge (Butler et al. 2004). In considering authentic teacher activity, we prioritize a) the importance of curriculum coherence (Schmidt et al. 2005) and b) teachers as curriculum designers. As researchers, our goal is to empower teachers to design, implement, and reflect upon an SSI-based approach to teaching science. To accomplish this goal, we co-design curricular materials with teachers, and develop tools and strategies to support the design and implementation of this approach. As we design PD, we draw upon the National Academies of Science, Engineering, and Medicine's (2015) recommendations for effective science PD: (1) active participation of teachers engaging in examples of effective instruction and analysis of student work, (2) content focused,

(3) alignment with district policies and practices, and (4) sufficient duration for implementation and reflection. As teachers implement their newly designed SSI curriculum, we support their reflection-on-practice (Schön 1983; Valli 1997) through follow-up interviews. In this project, we drew upon the aspects of collaborative PD described in this section. Over time, our ideas about collaborative PD evolved and these ideas are represented in the Design Cases section of this chapter.

6.2.1 Theoretical Framework

SSIs are contentious, societal issues with conceptual or procedural connections to science (Zeidler 2014). Working to understand and resolve these issues can (and, we argue, should) be informed by scientific evidence, but science alone cannot render solutions (Sadler and Zeidler 2005a, b). Take, for instance, climate change, arguably the most important SSI of our time. Scientists identified the problem, can monitor the problem, and can make predictions about what will happen given different responses to the problem. However, working toward climate change solutions requires political and economic actions, and social change in addition to scientific inquiry.

We take the view that being a responsible citizen requires that one engage in the problem-solving/solution-seeking associated with SSIs. Dealing with SSIs, like all wicked problems, is notoriously complex and requires a wide range of knowledge and competencies. We posit that these knowledge bases and competencies can be learned, but in order to be useful, knowledge and competencies require applications in context. Further, employing knowledge and competencies in complex contexts requires practice (Sadler 2009). SSI teaching represents a pedagogical approach to supporting learner development of knowledge, competencies, and abilities to apply these to understanding and problem-solving in the context of science-related societal issues. In our approach, we engage learners (or support teachers as they engage learners) directly in the exploration of SSIs (Friedrichsen et al. 2016). As a part of this exploration, students learn about the science content and practices necessary for understanding the issue. They also have opportunities to explore some of the social dimensions of the issue, which may include political, economic, or ethical factors, depending on this issue.

In this chapter, we report on a set of three design cases conducted iteratively within a broader design-based research project (Brown 1992; McKenney and Reeves 2013). An important dimension of the broader agenda is to generate an empirically supported framework for SSI teaching. This framework evolved through the course of the studies presented. When the work began (i.e., Design Case 1 described in the next section), our framework highlighted several commitments: (1) Instruction should begin with the SSI and subsequent learning experiences should continually connect back to the issue; (2) Students should have opportunities to engage with scientific practices, content, and evidence as they make sense of the issue; (3) Students should use current media to access information about issues, and they likely need support for building media literacy skills; (4) Students should have opportunities to explore the social dimensions of SSI; and, (5) Issue-based learning experiences should conclude with a culminating exercise so that learners can synthesize their understandings, competencies, and personal positions on the issue. Based on our student-centered approach to teaching, our framework purposefully focuses on the nature of student engagement. As the work has progressed, details regarding these aspects of SSI teaching have evolved and become better substantiated, but these basic commitments remain. The following Design Cases section of the chapter presents highlights from the studies we conducted based on these initial commitments and explicates some of the ways in which our ideas have changed.

6.3 Design Cases

6.3.1 Design Case 1: Collaborating with an Exemplary Biology Teacher

Research Focus Our initial focus was on developing a collaboration among the research team members and a local high school biology teacher. We sought to develop our understandings of the newly released *NGSS* by co-designing *NGSS*-aligned curriculum units situated within an SSI context. As we co-designed two curriculum units, our research focus was on student learning of science content and practices within the SSI context. For example, in the Climate Change unit, our research questions were: (1) In what ways did students' model-based explanations of carbon cycling, climate change, and the interrelationships between them change over time in response to a model-oriented SSI unit? and (2) What are the ways that students come to understand carbon cycling, climate change, and the interrelationships? (Zangori et al. 2017).

PD Design In the fall of 2014, we invited a local teacher, Kerri Graham, to collaborate with us. Pat had previously supervised student teachers in Kerri's classroom. Kerri was in the process of re-designing the Honors Biology curriculum to align with *NGSS* and welcomed our help with the re-design process. (Honors Biology is a course offered to 16-year-old students in the 10th grade and has a focus on college preparation with more challenging content). We met approximately every 2 weeks for 6 months during Kerri's planning period at her school. For our first unit, we chose a second-semester topic, evolution, giving us time to develop our collaboration and design the new unit. After considering the affordances and limitations of different SSIs, we selected antibiotic resistance (ABR) as the issue, since many of Kerri's students were interested in healthcare-related careers. We chose to focus on one *NGSS* practice, modeling, because we sought to better understand how to support students with this particular practice. After making these decisions, we invited a microbiologist to join our team. Collaborating with a scientist became a curriculum design feature that we often incorporated as we designed additional curriculum units.

We discussed the components of our SSI framework and developed a general outline for the unit. Next, different team members took the lead in developing components of the ABR unit. We used a video case to introduce ABR and designed a media-based lesson to engage students in exploring the issue in more depth. We developed an ABR lab, several modeling activities, and additional instructional resources to help students make sense of the ABR phenomenon (Williams et al. 2018). We also designed an activity for students to explore various stakeholders' perspectives (e.g., doctors, parents, pharmaceutical companies). For the culminating activity, each student developed a policy recommendation (at a local, state, federal or international level) to reduce the spread of antibiotic resistant bacteria. (For more detail of the design process, see Friedrichsen et al. 2016). During the implementation of the ABR unit, we continued to support Kerri as we collected student data.

In subsequent years, we continued our collaboration with Kerri to design a second SSI unit using the issue of climate change to teach ecology (Kinslow et al. 2017). For this unit, we invited an ecologist to join our design team. The students were introduced to the issue by taking a field trip to a local prairie to observe the effects of climate change. Due to a change in precipitation patterns, woody plants were beginning to replace the prairie grasses. Throughout the rest of the unit, students applied ecological concepts to the local prairie context. We continued to develop modeling tools and strategies to support students in making sense of climate change on both local and global scales. For example, we developed a modeling packet format which included the following features: an initial model and written explanation in response to a scenario, multiple revised models and written explanations, critique of previous models, and a final model and written explanation in response to the original scenario. For the culminating activity, students were asked to apply their knowledge by exploring the effects of climate change on a species indigenous to a different ecosystem.

Research To understand student learning related to science content and modeling practices, we collected student artifacts, including pre- and post-assessments, and their modeling packets. We also interviewed a sub-set of the students about their models. In the climate change unit, modeling supported students' understandings of causal mechanisms for transfer and transformation of carbon which were needed to make connections between carbon cycling and climate change (Zangori et al. 2017). In the ABR unit, we found students gained greater understanding of generalized natural selection, but had difficulty in understanding how natural selection occurred in bacteria (Peel et al. 2019).

Implications We learned that SSI teaching with an emphasis on NGSS-aligned practices, such as modeling, could produce desired student learning outcomes. We also learned how to better support students' modeling practices through the development of a modeling packet format. However, Design Case 1 had several limitations: results were based on a single teacher's enactment, our team provided extensive planning support to the teacher, and her honors classes were populated with high achieving students.

6.3.2 Design Case 2: Secondary Teachers Co-Designing Curriculum

Research Focus Based on the limitations of Design Case 1, we sought to explore processes for helping a broader range of teachers use SSI teaching. We wanted to find out how teachers, working in varied settings with more diverse students, might take up SSI teaching. Given the goal to work with a larger number of teachers, the kinds of individualized collaboration we employed in Design Case I would be impossible. We needed to adopt a PD model that could reach more participants, and we felt that it would be helpful to formalize some of the design rationales and principles used in (and for some, modified after) the first design case. We chose to concretize dimensions necessary for SSI planning and teaching through the development of several tools. These tools and how teachers used them became another focal point for our research.

PD Design In order to recruit participants, we sent invitations to teachers in a broad geographic area across our state. We purposefully invited teachers from schools of different sizes and community types (rural, suburban, and urban). We also targeted teachers with different levels of experience, from second year novices to 25-year veterans. In our communications with potential participants, we called attention to the fact that the opportunity would focus on using issues as contexts for teaching science and prioritize connections to the NGSS, particularly in terms of scientific practices. Ultimately, we worked with 19 high school biology, chemistry, and environmental science teachers. Many of these teachers participated as the sole representative from their school—for some, they were the only teacher for a particular course, but others worked as a part of a professional learning community (PLC) within their home institutions. Two teachers taught together in the same school, and five participants taught together and worked collaboratively in the same district.

We designed the PD as a series of workshops and working sessions with the goal of small teams of teachers co-designing SSI units that they could enact in their classes. The sessions began with an orientation meeting at a science teacher conference in the autumn. The group met for two full days the following March, and then again for 3 days in June when the teachers were on summer break. We used an online teacher networking platform to encourage continued communications and resource sharing between the face-to-face sessions. The sessions were designed such that the teachers could: (1) experience dimensions of SSI teaching as learners; (2) reflect on the pedagogy of those experiences; (3) access examples (e.g., SSI curricula and learning activities), samples (e.g., student work and rubrics), and relevant tools; and, (4) work with colleagues to design an SSI unit to meet the needs of their own classrooms. For more detail about this PD, see Peel et al. 2018.

The tools shared included a framework for SSI teaching, a heuristic for planning SSI units, and a guide for assisting in the selection of educationally productive issues. We fully describe the *SSI Teaching Framework* elsewhere (Sadler et al. 2017). In short, this Framework offers a pathway for sequencing SSI instruction with attention to student learning objectives. The pathway begins with student exploration of the issue followed by student engagement in scientific practices as they make sense of the underlying science content. Student development of science ideas and practices is complemented by opportunities to build socio-scientific reasoning skills (Romine et al. 2017). The sequence concludes with an issue-focused culminating activity that allows students to synthesize their ideas, practices, and reasoning. The *Planning Heuristic* provided a list of nine recommended steps for the successful design and development of SSI units. The *Issue Selection Guide* presented a list of ordered questions designed to encourage critical analysis of possible SSIs in terms of how effective they might serve as contexts for science teaching and learning. The three tools can be accessed on the project website (http://ri2.missouri.edu/content/Planning-Tools).

Research In order to explore how a diverse group of teachers engage in SSI design and teaching, as well as use tools that formalize SSI design principles, we collected data from multiple sources. These data included field notes taken during the workshops, interviews with teacher design teams during the workshops, individual teacher interviews following unit enactment, and the teachers' design products (i.e., their SSI curricular materials). Qualitative analyses have yielded numerous insights regarding the research foci.

As the teachers participated in the PD, they moved through two emergent, sequential phases (Hancock et al. 2019). In the first phase, each design team created a safe and shared space by identifying common topics taught, discussing tensions and discontentment related to their existing curricula, and exploring how the PD could be used to generate opportunities to address their tensions and discontentment. Once the design team established a safe and shared space, they explored potential SSIs for their curriculum unit. The design team's selected issue was based upon three considerations: an individual's passion for a particular issue, the ability to leverage existing resources, and their perceptions of the relevance of a given issue for their particular students.

All of the teachers were able to successfully participate in the development of SSI units, although many initially lacked curriculum design skills. The resulting design products varied extensively, and many did not incorporate all of the teaching elements called for in the *SSI Teaching Framework* although several did. Most of the participants implemented at least some dimensions of their planned units and when doing so, featured opportunities for students to explore the focal issue at the outset of instruction. However, several teachers reported that they struggled to keep the issue connected to the science content and practices throughout the unit. In addition, only half of the teachers who implemented were able to complete a culminating activity with their students. They cited time constraints and concerns about how to assess the culminating projects, many of which took the form of essays, organized debates, or student-generated artifacts such as posters.

In the PD, we encouraged teachers to focus on any of the NGSS practices they perceived fitted best with their units and the needs of their students. We provided explicit support for teacher use of the practices of modeling, argumentation, and computational thinking as evidence suggests that these are some of the more challenging practices for teachers to enact with learners. The extent to which scientific practices were meaningfully incorporated in the teachers' unit designs and enactments varied, and teachers' prior experiences with NGSS was a strong predictor of how well practices were incorporated. The ways in which participants experienced the PD relative to connections with colleagues from their schools served as another mediator for successful enactment. In general, participants with school colleagues at the PD were most successful. Participants who were the sole instructors for a course at their home institutions were also reasonably successful. However, participants who worked as a part of a PLC in their schools but were lone representatives at the PD tended to struggle with enactment, because they had the added challenge of bringing their units back to colleagues who had not been involved in the PD.

Results regarding teacher use of the planning tools varied. The *SSI Teaching Framework* was perceived by teachers as a useful tool particularly as they considered issues of lesson sequencing. However, the design products suggest that they struggled to make sense of how to situate socio-scientific reasoning, a key dimension of the *Framework*, with science content and practices. In contrast, the teachers indicated that the *Planning Heuristic* was not very useful to them, and there is little evidence to suggest that this tool was even used by many of them. Some of the teachers lacked experience in designing curricula which may have contributed to their perceptions of the usefulness of the *Planning Heuristic*. Finally, most teachers used the *Issue Selection Guide*, but they found it helpful for assessing issue choices they had already made and potential adjustments to the framing of an issue, instead of a tool for generating potential issues, as we had originally intended.

Implications These results offer several implications for further research and development. First, we intend to pay much closer attention to the natural groups that teachers work in. Rather than recruiting individual teachers, it seems prudent to consider teachers nested within PLCs. Working with PLCs wherein individual teachers have access to natural, school-based support mechanisms may help overcome some of the challenges associated with SSI teaching. Second, the results forced us to question our decision to leave open the selection of scientific practices. The findings suggest that a more focused approach may have ultimately been more supportive for teachers, particularly those less familiar with the NGSS. Third, tools such as the *SSI Teaching Framework* and the *Issue Selection Guide* can be helpful for teachers engaged in SSI planning and enactment. We need to adjust aspects of the *Framework* to account for aspects with which teachers struggled (viz., socio-scientific reasoning), but we will continue using these resources. We also intend to use the *Planning Heuristic* again; however, how the heuristic is featured in the PD and supports for using this tool need to be considered. Finally, an important implication of this phase is that while a culminating activity can be an effective exercise for student synthesis of ideas and practices (see Design Case I), it represents one of the more challenging dimensions of our model of SSI teaching. Our team needs to develop more effective ways to support teacher incorporation of this dimension of SSI pedagogy.

6.3.3 Design Case 3: Implementing SSI Teaching in an Elementary School

Research Focus The impetus to try SSI-based instruction within the elementary classroom was two-fold. First, we sought to explore how elementary teachers implement and grapple with the multiple dimensions inherent in issues-based learning as this is missing from the literature base. We also wanted to examine how elementary students learn within an SSI context, as this is emerging area of study (e.g., Evagorou 2011). However, since SSI-based instruction is naturally interdisciplinary, elementary classrooms seemed an ideal setting, as elementary teachers are generalists, teaching across disciplines within their daily work. Second, we wanted to explore how an SSI context could support teachers in understanding the purpose and utility of model-based teaching and learning. The few studies about elementary teacher knowledge and implementation of model-based instruction highlight the challenges they have in understanding the purpose and utility of modeling (Vo et al. 2015; Justi and Gilbert 2002). We theorized that situating modeling within an SSI would provide a utility and purpose to scientific modeling, since teachers could see their students develop and use scientific models to understand phenomenon, and they could apply their new scientific understanding when negotiating complex societal problems.

PD Design Based on results from our previous work (Design Case 2), we wanted to engage with an intact PLC as opposed to teachers whom we might recruit from across multiple schools. Therefore, we approached a third-grade PLC of four teachers from a local school to co-design and implement an SSI-based ecosystem curriculum. Because of what we had learned from Design Case 2 about the difficulties of supporting teacher curricular design for multiple scientific practices, we intentionally focused on the practice of modeling. The project team worked with the teachers to choose the focal issue of decreasing Monarch butterfly (*Danaus plexippus*) migration (an issue that was playing out within our state context), and whether or not we should conserve and/or restore prairies to return Monarch numbers to previous levels. The biological content focus of the unit was ecosystem interdependence.

Because we wanted the SSI curriculum to focus on the practice of modeling, the project team wrote the SSI and modeling-focused lessons prior to the workshop, and then co-designed the ecosystem lessons with the PLC during the workshop. Working with the PLC, we integrated modeling throughout the unit, wherein students used the practice to answer the question, ‘How do organisms interact within an ecosystem?’ The students were also asked to use their scientific models to provide evidence to answer the issue-based restoration question, ‘Should our school turn one soccer field into a garden to attract butterflies?’ In their final lesson, students responded to the following scenario:

> An elementary school has a prairie habitat in their backyard next to a soccer field. But more students want to be able to play soccer and have asked for another soccer field. The principal is thinking about turning the prairie habitat into a soccer field. Write a letter to the school principal about whether or not the prairie should be turned into a soccer field.

The PLC attended a four-day workshop, spending the first 2 days immersed in a SSI unit for high school students to provide the teachers with experiences in both modeling and SSI. The last 2 days of the workshop were spent introducing the teachers to the ecosystem curriculum, during which we worked with the PLC to design, modify, and adapt the lessons for their classrooms (full curriculum available at: http://ri2.missouri.edu/ri2modules/MONARCH/intro). We followed all four teachers through their implementation of the curriculum.

Research Our research focused on how the teachers perceived the individual SSI and modeling aspects of the curriculum, and how they valued this pedagogical approach. Our results indicated that the elementary teachers perceived SSI as a way to promote social responsibility and make real world issues relevant to their students. In addition, the teachers wrapped their understanding of modeling within the context of the SSI. The two seemed inseparable to the teachers as they focused their modeling reflections on how the students used their models to make sense of ecosystem interdependence and articulate their position on prairie restoration or conversation. As one of the teachers stated about her students using her model to articulate her position on the issue:

> I was so blown away with [student] who is a [below grade level] in reading and what she could share with me about her model was so above that level of reading. That was incredible to see that the kids that do have trouble with reading or expressing themselves can still have the same level of thinking with the model.

Implications Implications from this work suggest that elementary teachers are able to successfully navigate the challenges of discussing grade-level appropriate complex issues with social dimensions in their classrooms, and they also find SSI-based instruction as a productive way to contextualize science for their students. The teachers expressed how the cross-curricular nature of SSI felt familiar, because teaching across subject-domains occurs daily in the elementary classroom. This study also provided two important strategy implications for our team. First, the curriculum helped the teachers see how their third-grade students (8–9 years old) used models of their own design to make sense of ecosystem interactions and apply their understanding to the Monarch issue. Second, this work highlighted the importance of working with PLCs from idea conception through unit implementation. All four PLC members attended the workshop, worked with us to co-design the unit, focused weekly PLC meetings on lesson planning for the SSI unit, and taught the unit during the same time frame. These actions served as important support mechanisms for their individual enactments. Since the teachers were integral in co-designing the unit, the PLC had full buy-in enacting the curriculum. As they planned together and enacted the curriculum, the teachers reminded each other why they made certain choices during the unit design, and they checked with each other on whether modifications and adaptations were successful or not during the enactments.

6.3.4 Conclusions and Next Steps

Reflecting on the questions that drove each design case, we come to the following conclusions. In Design Case 1, we sought to understand the following questions: (1) Could this be a productive collaboration? (2) What do we learn in co-designing *NGSS*-aligned curriculum using an SSI-based approach? (3) How do we support teachers and students in the practice of modeling? We found that it was, indeed, a productive (and enjoyable) collaboration that we plan to continue. We greatly valued our collaboration with the microbiologist and plan to continue collaborating with scientists whose expertise aligns with a particular SSI. We learned students do learn *NGSS*-aligned science content using an SSI-based approach to curriculum design. We also learned how to support modeling through tools embedded in a modeling packet that included student prompts for initial and final models explaining a scenario, written explanations of their models, and critique and revisions of models.

Design Case 2 was driven primarily by the question: How do we support a larger, more diverse group of teachers in co-designing SSI curricula? To explore this question we designed a PD for 19 teachers from across our state; the teachers varied in experience and teaching context, ranging from rural to urban schools. For this PD, we designed a set of tools to support teachers in their curriculum design work, including the *SSI Teaching Framework*, the *SSI Planning Heuristic*, and the *Issue Selection Guide*. We learned that the teachers perceived the *SSI Teaching Framework* as useful, giving them an overview of our teaching approach. In general, most of the teachers struggled with curriculum design and they did not use the *Planning Heuristic*. Finally, rather than starting with the *Issue Selection* Guide, teachers chose issues based upon their own passion for a particular issue, existing resources, and their perceptions of student relevance. After selecting an issue based on a combination of these three considerations, teachers tended to use the *Issue Selection Guide* tool to confirm the appropriateness of their selected SSI. We also learned that it was more productive for us to support teachers in using a single *NGSS* practice, modeling, rather than having teachers choose from among the eight practices. From their implementation of the SSI units, we learned that teachers were challenged in keeping the content and issue connected throughout the unit, and teachers often omitted the final culminating project due to time constraints and assessment concerns. We also learned that teachers were more likely to implement their SSI unit and feel successful when they had the support of their teaching colleagues.

For Design Case 3, based on the lessons learned in the previous design case, we worked with one elementary PLC of four elementary teachers. Our questions were: (1) How will elementary students respond to an SSI curriculum unit? and (2) How will elementary teachers integrate modeling and SSI? We learned that elementary students were able to grapple with age-appropriate, ill-structured societal problems and use their scientific knowledge to take and justify a position on the issue. We learned that elementary teachers saw SSI-based instruction as a way to integrate social studies and science, and they saw it as a productive way to contextualize science for their students. We also learned that the teachers came to understand the purpose of modeling as they saw students using their models to make sense of the SSI.

We plan to continue our project with an ongoing focus on tools and strategies to support teachers and students as they engage in learning science within SSI contexts. We are currently developing new tools to address the challenges identified in the design cases described in this chapter. In particular, we are developing tools to aid teachers in keeping the science content and issue connected throughout their SSI unit, and we are developing shorter alternatives to the culminating activity used in Design Case 1 – ones that requires less time and are less writing intensive. In the summer of 2018, we began working on a new design case, collaborating with a secondary biology PLC comprised of six teachers who teach in a high-needs school. We collaborated to revise an existing SSI curriculum unit (from Design Case 2) and co-design a second SSI unit. This new design case is driven by a new set of questions: (1) Is our SSI approach viable with students from a wider range of backgrounds, interests, and skills? (2) As teachers implement their SSI units, what teacher-designed tools and strategies are developed?

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References

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141–178.

Butler, D. L., Lauscher, H. N., Jarvis-Selinger, S., & Beckingham, B. (2004). Collaboration and self-regulation in teachers' professional development. *Teaching and Teacher Education, 20*(5), 435–455.

Evagorou, M. (2011). Discussing a socioscientific issue in a primary school classroom: The case of using a technology-supported environment in formal and nonformal settings. In *Socio- scientific issues in the classroom* (pp. 133–159). Dordrecht: Springer.

Friedrichsen, P., Sadler, T., Graham, K., & Brown, P. (2016). Design of a socio-scientific issue curriculum unit: Antibiotic resistance, natural selection and modeling. *International Journal of Designs for Learning, 7*(1). Available at: https://scholarworks.iu.edu/journals/index.php/ijdl.

Hancock, T., Friedrichsen, P., Kinslow, A., & Sadler, T. (2019). Forming design teams and selecting socio-scientific issues: A grounded theory study of how science teachers collaboratively design SSI-based curricula. *Science & Education, 28*(6–7), 639–667.

John-Steiner, V., Weber, R., & Minnis, M. (1998). The challenge of studying collaboration. *American Educational Research Journal, 35*(4), 773–783. Retrieved from http://www.jstor.org/stable/1163466.

Justi, R., & Gilbert, J. (2002). Science teachers' knowledge about and attitudes towards the use of models and modelling in learning science. *International Journal of Science Education, 24*(12), 1273–1292. https://doi.org/10.1080/09500690210163198.

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy, 26*(1), 1–18.

Kinslow, A., Sadler, T., Friedrichsen, P., Zangori, L., Peel, A., & Graham, K. (2017). Connecting global climate change to a local ecosystem: A socio-scientific issue approach. *Science Teacher, 84*(7), 39–46.

McKenney, S., & Reeves, T. C. (2013). Systematic review of design-based research progress: Is a little knowledge a dangerous thing? *Educational Researcher, 42*(2), 97–100. https://doi.org/10.3102/0013189X12463781.

National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. Committee on Strengthening Science Education through a Teacher Learning Continuum. Board on Science Education and Teacher Advisory Council, Division of Behaviorial and Social Science and Education. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Peel, A., Sadler, T., Friedrichsen, P., Kinslow, A., & Foulk, J. (2018). Rigorous investigations of relevant issues: A professional development program for supporting teacher design of socio-scientific issue modules. *Innovations in Science Teacher Education, 3*(3). http://innovations.theaste.org/rigorous-investigations-of-relevant-issues-a-professional-development-program-for-supporting-teacher-design-of-socio-scientific-issue-units/.

Peel, A., Zangori, L., Friedrichsen, P., Hayes, E., & Sadler, T. D. (2019). Students' model-based explanations about natural selection and antibiotic resistance through socio-scientific issues based learning. *International Journal of Science Education, 41*(4), 510-532.

Romine, W. L., Sadler, T. D., & Kinslow, A. T. (2017). Assessment of scientific literacy: Development and validation of the quantitative assessment of socio-scientific reasoning (QuASSR). *Journal of Research in Science Teaching, 54*, 274–295.

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education, 45*, 1–42.

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

Sadler, T. D., & Zeidler, D. L. (2005b). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education, 89*, 71–93.

Sadler, T. D., Foulk, J. A., & Friedrichsen, P. (2017). Evolution of a model for socio-scientific issues teaching and learning. *International Journal of Education in Mathematics, Science, and Technology, 5*(2). http://www.ijemst.net/issue/view/5000017771.

Schmidt, W. H., Wang, H. C., & McKnight, C. C. (2005). Curriculum coherence: An examination of US mathematics and science content standards from an international perspective. *Journal of Curriculum Studies, 37*(5), 525–559.

Schön, D. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Valli, L. (1997). Listening to other voices: A description of teacher reflection in the United States. *Peabody Journal of Education, 72*, 67–88.

Vo, T., Forbes, C. T., Zangori, L., & Schwarz, C. V. (2015). Fostering third-grade students' use of scientific models with the water cycle: Elementary teachers' conceptions and practices. *International Journal of Science Education, 37*(15), 2411–2432.

Williams, M. A., Friedrichsen, P., Sadler, T., & Brown, P. J. B. (2018). Modeling the emergence of antibiotic resistance in bacterial populations. *American Biology Teacher, 80*(3), 210–216.

Zangori, L., Peel, A., Kinslow, A., Friedrichsen, P., & Sadler, T. (2017). Student development of model-based reasoning about carbon cycling and climate change in a socio-scientific issues unit. *Journal of Research in Science Teaching, 54*(10), 1249–1273. https://doi.org/10.1002/tea.21367.

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research and practice. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 697–726). New York: Routledge/Taylor and Francis.

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