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A FRAMEWORK FOR TEACHING FOR SOCIO-SCIENTIFIC ISSUE AND MODEL BASED LEARNING (SIMBL)

Uma abordagem para o ensino através de Questões Sociocientíficas e aprendizagem baseada em modelos (SIMBL)

Una perspectiva para la enseñanza de cuestiones socio-científicas y aprendizaje basada en modelos (SIMBL)

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Resumo

Ensinar com questões sociocientíficas (QSC) representa uma abordagem específica para a educação CTSA. Demonstrou-se que o ensino baseado em QSC apoia a aprendizagem dos alunos e apresenta noções progressivas de letramento científico. No entanto, a abordagem pode ser desafiadora e nossa equipe tem trabalhado para desenvolver uma estrutura para apoiar o ensino baseado em QSC. Nossos primeiros esforços levaram à criação de uma sequência de ensino que descreve fases sequenciais para a implementação de uma unidade baseada em QSC. O trabalho subsequente com os professores que aprovaram a QSC levou ao desenvolvimento de um conjunto de seis características essenciais da aprendizagem baseada em Questões Sociocientíficas e em Modelos (SIMBL). Esses recursos se concentram nas oportunidades de aprendizado que os alunos devem ter ao se envolverem com a QSC. As seis características são: 1) explorar fenômenos científicos subjacentes; 2) engajar-se em modelagem científica; 3) considerar a dinâmica de questões sobre o sistema; 4) empregar estratégias de letramento em informação e mídias; 5) comparar e contrastar múltiplas perspectivas; e 6) elucidar a própria posição/solução. Apresentamos exemplos retirados de dois módulos, um projetado para a exploração climática por estudantes do ensino médio e outro projetado para a exploração de perda de habitat de borboleta por alunos do ensino fundamental, para ilustrar maneiras pelas quais cada um dos recursos essenciais pode ser abordado nas salas de aula de ciências.

PALAVRAS-CHAVE: Questões sociocientíficas. Modelagem. Modelo de ensino.

Abstract

Teaching with Socio-Scientific issues (SSI) represents a specific approach to STSE education. SSI teaching has been shown to support student learning and to advance progressive notions of scientific literacy. However, the approach can be challenging to enact, and our team has been working to develop a framework to support SSI teaching. Our early efforts led to creation of a teaching sequence which describes sequential phases for implementing an SSI unit. Subsequent

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work with teachers enacting SSI led to development of a set of six essential features of Socio-scientific Issue and Model Based Learning (SIMBL) learning. These features focus on learning opportunities that students should have as they engage with SSI. The six features are 1) explore underlying scientific phenomena, 2) engage in scientific modeling, 3) consider issue system dynamics, 4) employ information and media literacy strategies, 5) compare and contrast multiple perspectives, and 6) elucidate own position/solution. We present examples taken from two modules, one designed for high school student exploration of climate change and the other designed for elementary school student exploration of butterfly habitat loss, to illustrate ways in which each of the essential features can be addressed in science classrooms.

KEYWORDS: Socio-scientific issues. Modeling. Teaching framework.

Resumen

La enseñanza con problemas socio-científicos (CSC) representa un enfoque específico para la educación CTSA. Se ha demostrado que la enseñanza de CSC apoya el aprendizaje de los estudiantes y promueve nociones progresivas de alfabetización científica. Sin embargo, el enfoque puede ser difícil de implementar, y nuestro equipo ha estado trabajando para desarrollar un marco para apoyar la enseñanza basada en CSC. Nuestros primeros esfuerzos llevaron a la creación de una secuencia de enseñanza que describe fases secuenciales para implementar una unidad basada en CSC. El trabajo posterior con los maestros que promulgaron la CSC condujo al desarrollo de un conjunto de seis características esenciales del aprendizaje basado en problemas sociocientíficos y en modelos (SIMBL). Estas características se centran en las oportunidades de aprendizaje que los estudiantes deberían tener al tener contacto con la CSC. Las seis características son 1) explorar los fenómenos científicos subyacentes, 2) participar en la construción del modelo científico, 3) considerar la dinámica de los problemas del sistema, 4) emplear estrategias de alfabetización informacional y mediática, 5) comparar y contrastar múltiples perspectivas, y 6) clarificar su propia posición/solución. Presentamos ejemplos tomados de dos módulos, uno diseñado para la exploración del cambio climático por parte de los estudiantes de secundaria y el otro diseñado para la exploración de la pérdida de hábitat de mariposas por parte de los estudiantes de primaria, para ilustrar las formas en que cada una de las características esenciales puede abordarse en las aulas de ciencias.

PALABRAS CLAVE: Cuestiones socio-científicas. Modelado. Modelo de enseñanza.

INTRODUCTION

When engaging teachers in professional development, we often begin sessions by asking them to consider what motivated them to become science teachers. Despite having asked this question with diverse groups of teachers, we tend to hear similar responses. Most science teachers with whom we have worked cite the desire to help learners become more effective problem-solvers, more thoughtful critical thinkers, and better citizens as a primary driver for their career choice. Our science teacher colleagues tell us that they want to make the world a better place by helping their students to be better prepared for living and prospering in it. They often see science as a powerful tool (or set of tools, both conceptual and process-oriented) for informing key issues in society, and they want their students to be able to use this tool responsibly and productively. These responses to our question of why they went into teaching as a profession resonate strongly with our own motives for becoming science teachers.

This sentiment from the world of practice connects with theoretical and conceptual arguments that have been made regarding the purposes of science education. For decades, scholars have debated scientific literacy as an aim for science education with many researchers advocating for a version of scientific literacy that foregrounds the ability to use science for everyday purposes—that is, use science for problem solving, critical thinking, and ultimately as a tool for being responsible citizens (DEBOER, 2000). Roberts (2007) and later Roberts and Bybee (2014) synthesized the extant literature on scientific literacy and offered a heuristic comprising two visions to categorize various stances on the construct. Vision I scientific literacy represents ideas and practices derived and prioritized from within science disciplines. That is, in order to be classified as scientifically literate, students ought to learn a version of the content and practices used by scientists. In contrast, vision II scientific literacy considers the contexts in which science ideas and practices will likely be applied by learners. Vision II scientific literacy represents a related set of perspectives that emphasize the use of science for addressing issues, questions, and problems that emerge beyond the boundaries of scientific disciplines. Vision II scientific literacy offers a scholarly account of rationales for science education that we hear from our teacher colleagues, namely, that science teaching ought to help students use science in their lives.

If we take this notion as a basis for science education, we must next ask what forms of teaching and what kinds of learning experiences can be used to achieve these ends. Answers to these questions have varied widely throughout the history of science education. For us, any attempt to answer these questions ought to start with consideration of what it means to know and learn, and we find great utility in situated accounts of learning to inform these considerations (LAVE; WENGER, 1991). Situated learning highlights the significance of the contexts in which we learn and suggests that what we come to know is inextricably connected to how and under what circumstances we engage in learning (COBB; BOWERS, 1999). Our goal here is not to recapitulate situated learning theory, which is elsewhere well described in general (PATEL, 2018) as well as for science education (SADLER, 2009); however, this theoretical commitment is an important part of the argument we will make throughout this article about the value of situating science learning in the context of issues.

If we are serious about pursuing vision II scientific literacy and subscribe to situated perspectives on learning, then traditional approaches to teaching science must be challenged. If the contexts we learn within shape what we come to know, how can learners possibly be expected to use science as they grapple with societal challenges when their science education has been mediated through acquisition of science vocabulary or participation in scripted laboratory exercises? Some could legitimately argue that science vocabulary and cookbook labs (what we have used to describe traditional science teaching) are not the only activities that most students engage in as a part of their science learning experiences. This may, in fact, be an oversimplification, but it is not far from the truth for a lot of science classrooms that we have observed in the US. However, our point is not to argue for how prevalent traditional science teaching is or what exactly it entails, but rather, to make the case that we ought to be engaging students in very different kinds of learning experiences if we expect to realize the goals of many teachers in promoting vision II scientific literacy among our students.

The Science-Technology-Society-Environment (STSE) movement, the focus of this special issue, represents an important step in the directions for which we advocate; that is, the serious contextualization of science learning in societal issues that matter for students. One of the challenges associated with STSE, and the STS movement which preceded it, is its breadth (ZEIDLER; SADLER; SIMMONS, 2005). A lot of different approaches can be categorized as a form of STSE making it difficult to know precisely what a curriculum, teaching approach, or study labeled as STSE actually entails. In our work, we have attempted to keep our research and teaching innovation efforts linked to a specific thread that can be located within the broader STSE movement. This thread has been identified as Socio-Scientific Issues (SSI) teaching and learning (ZEIDLER, 2014). SSI is a teaching approach that locates a specific societal issue as the central theme for instruction. This central issue must have meaningful connections to both science ideas and social implications. Consider, for example the issue of hydraulic fracturing, or fracking—this is a process being used and debated as a means of extracting oil and natural gas from shale deposits. The science of fracking connects to ideas from geology, energy, and ecology. From a social perspective, numerous questions exist regarding environmental safety and human health impacts, the economics of fracking, and the ethics of natural resource use (POWERS; SABERI; PEPINO; STRUPP; BUGOS; CANNUSCIO, 2015). We have made the case that SSIs like fracking can be used as productive contexts for science learning particularly when the learning goals are aligned with vision II scientific literacy (SADLER; MURAKAMI, 2014).

A Brief History of Framework Development

Research around teaching with SSIs has grown steadily for over 15 years (see ZEIDLER; WALKER; ACKETT; SIMMON, 2002, which is the scholarly article that arguably represents the beginning of the SSI movement). As the movement expanded, ideas about what should be included in SSI teaching evolved. Members of our team have been interested in articulating a framework, built on the underlying theoretical commitments for SSI teaching and reflecting ongoing research, in order to inform teaching. The first iteration of our SSI teaching framework resulted from the analysis of 11 classroom based studies of SSI teaching and learning conducted across the globe (SADLER, 2011b). These studies, reported as chapters in an edited volume (SADLER, 2011a), offered empirical evidence of the potential of SSI teaching across instructional contexts ranging from elementary school classrooms to college courses. Presley and colleagues (2013) expanded the initial framework to incorporate feedback from teachers and teacher educators. This second iteration of the framework called attention to design elements that should be included in SSI teaching, a set of experiences in which students should engage as a part of SSI learning, and attributes helpful for teachers working to enact SSI.

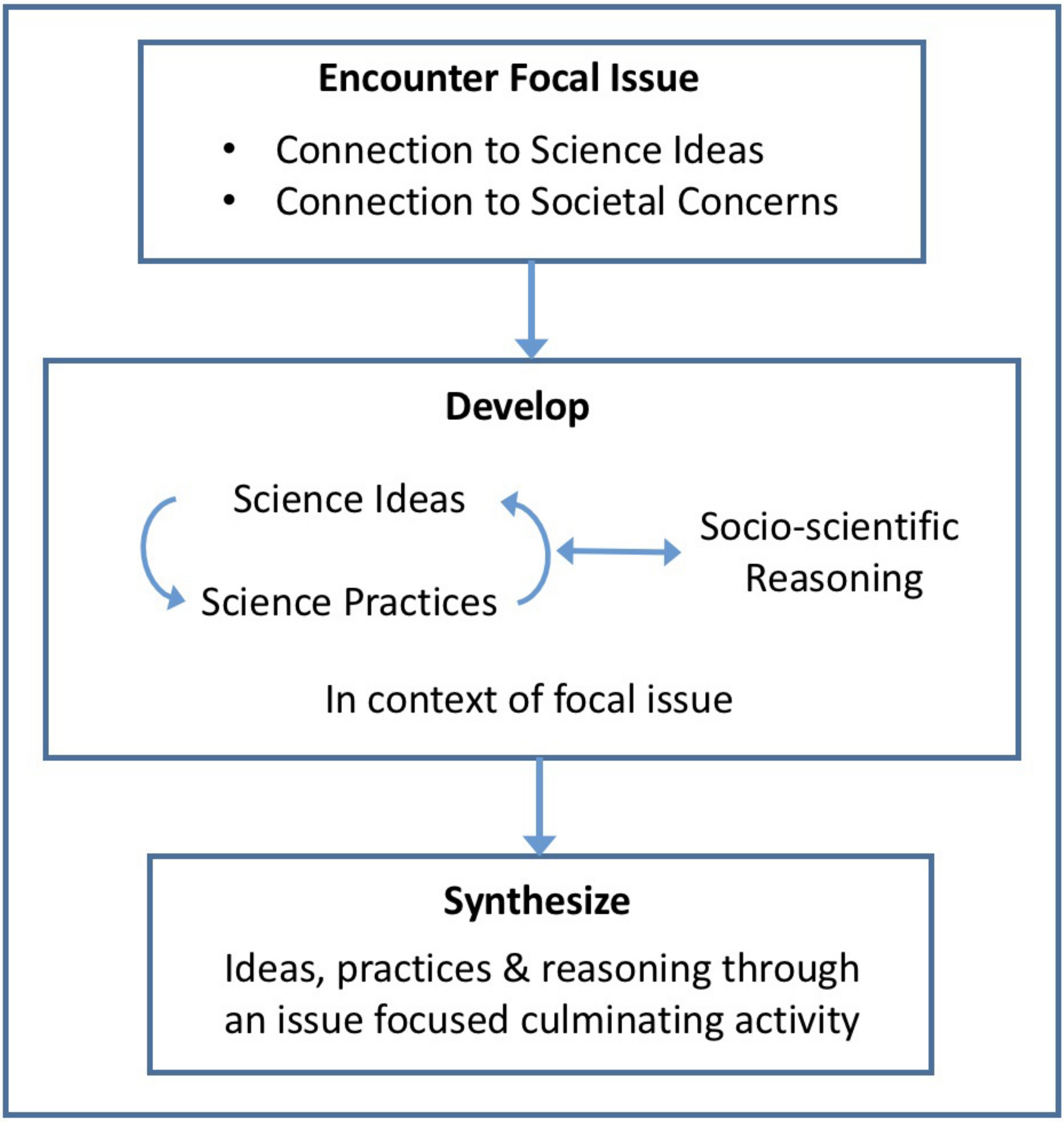
As our team worked to use the framework more extensively for shaping teacher professional development and curriculum design, we saw a need to provide a more specific tool for teacher use. The original framework (SADLER; 2011B; PRESLEY; SICKEL; MUSLU; MERLE-JOHNSON; WITZIG; IZCI; SADLER, 2013) was received by some practitioners as being too abstract to provide the level of support that we had originally envisioned. Based on work with an experienced teacher to design, implement, and test new SSI modules for high school biology, we articulated a teaching sequence for SSI-based education (FRIEDRICHSEN; SADLER; GRAHAM; BROWN, 2016). This sequence describes a series of sequential phases that teachers and students should move through as they implement an SSI focused unit of instruction. We have found that units which span at least two weeks of instructional time represent a reasonable amount of time in order for students to engage substantively in reasoning through societal issues while still fitting within the confines of many school systems. Upon testing the teaching sequence with a broader group of educators, we iteratively revised the tool and offered a formal explanation and justification of the sequence (SADLER; FOULK; FRIEDRICHSEN, 2017). The next section will present an overview of the SSI teaching sequence.

The SSI Teaching Sequence

Since the 2017 publication (SADLER et al., 2017), we have made a few revisions to the teaching sequence informed by our use of it with teachers working to design their own SSI units, but the basic organization and focus remains unchanged. Figure 1 presents a visual depiction of the sequence. The SSI teaching sequence begins with opportunities for students to encounter the SSI that will serve as the focus for the unit. As a part of this experience, we recommend that students are encouraged to recognize scientific dimensions of the issue as well as some of the associated societal concerns and implications.

The next phase of the sequence calls for opportunities to develop science ideas, science practices, and socio-scientific reasoning in the context of the focal issue. Our thinking about science ideas and practices has been informed significantly by the *Next Generation Science Standards* (NGSS; National Research Council, 2013). NGSS conceptualizes science learning as three dimensional and necessarily involving disciplinary core ideas, crosscutting concepts, and science and engineering practices. Disciplinary core ideas (DCI) represent the key ideas from the various disciplines of science; for example, heredity, ecosystem dynamics, and natural selection are DCIs for biology. Crosscutting concepts (CCC) are ideas that have broad application across the sciences. For example, cause and effect, energy and matter, and structure and function, are concepts that cut across the life, physical, and Earth sciences. While the NGSS advocates delineating between DCIs and CCCs, some scholars have questioned the utility of CCCs as an explicit dimension of science learning (OSBORNE; RAFANELLI; KIND, 2018). We agree with elements of this critique, and from a pragmatic perspective, the challenge of discriminating between DCIs and CCCs when working with teachers and students seem to outweigh the potential benefits in making these distinctions. Therefore, in the SSI teaching sequence we focus on “science ideas” which subsumes DCIs and CCCs.

Figure 1 – SSI Teaching Sequence



Source: Elaborated by the authors.

Science and engineering practices, such as modeling, argumentation, analyzing data, and asking questions, represent the kinds of things that scientists and engineers (and by extension students of science) do to investigate and make sense of the world. Science and engineering practices incorporate both skill and knowledge. This means that practices cannot be taught in isolation from meaningful science content as was the case in earlier approaches to science teaching which attempted to isolate inquiry skills as discrete actions that could be taught independent of ideas. This perspective suggests that a practice like scientific argumentation should not be presented as an exercise divorced from science ideas (such as identification of argument structures without considering what the claims and evidence are actually about). Instead, students should have opportunities to engage in advancing and critiquing claims about scientific phenomena as they consider evidence and think deeply about those phenomena. We find this stance on the necessary interconnections between science ideas and practices as a very helpful way of conceptualizing what it means to learn science, and this interconnectivity is reflected in the SSI teaching sequence.

Developing socio-scientific reasoning (SSR) is positioned as the other half of the teaching sequence's second phase. SSR is a set of interrelated reasoning practices necessary for the negotiation of complex socio-scientific issues (SADLER; BARAB; SCOTT, 2007). The SSR sub-dimensions include 1) appreciating the *complexity* of issues, 2) recognizing that all relevant information necessary for a solution may not be known, and therefore the issues remain subject to *inquiry*, 3) considering the issue from varied *perspectives* reflective of the competing interests of stakeholders, 4) exhibiting *skepticism* when considering potentially biased information, and 5) understanding the *affordances and limitations of science* for issue resolution (ROMINE; SADLER; KINSLOW, 2017). The SSI teaching sequence suggests that as a part of the main learning experiences of an SSI unit, students ought to have opportunities to develop their SSR competencies alongside efforts to develop science ideas and practices.

The final phase of the teaching sequence calls for opportunities for students to synthesize the science ideas, science practices, and SSR reasoning competencies that they have been developing throughout the unit. Like other instructional approaches such as learning cycles (Lavoie, 1999), the focus of this final phase is on students pulling together what they have learned in a way that supports reflection and application with the ultimate intent of strengthening the learning experience. For many of the teachers with whom we have worked to implement the SSI teaching sequence, this final synthesis phase has been accomplished by creation of a culminating activity that challenges students to take a stand on the focal issue. This has been accomplished by engaging students in debate activities, crafting policy recommendations, and developing presentations around potential issue solutions. For all of these examples, the key to a productive culminating activity is pushing students to link the recommendations, positions, or solutions that students offer to the science ideas, practices and SSR competencies they have been learning throughout the unit.

Insights based on Using the SSI Teaching Sequence

We have used the SSI teaching sequence primarily as a tool within teacher professional development (PD) programming aimed at helping teachers develop understandings of the SSI approach and design of SSI units for implementing in their own classrooms. Our team has worked through three iterations of this PD with three different groups of teachers, two sets of secondary teachers and a group of elementary teachers (for a description of these efforts, see FRIEDRICHSEN; SADLER; ZANGORI, *in press*). Analyses of the PD programs and their results have pushed our thinking on several dimensions of the teaching sequence and our broader goal of supporting SSI-based teaching and learning. The first insight gained relates to how we positioned scientific practices within the sequence. For many of the teachers, our PD efforts were one of the first times they seriously considered science practices as articulated in the NGSS. After the PD programs, when we examined the ways in which teachers were incorporating science practices in their units, we realized that we had not done enough to help the teachers understand science practices to an extent that afforded effective incorporation of practice-oriented learning experiences for their students. This trend was particularly apparent with the more epistemically demanding practices such as argumentation and modeling.

Teachers incorporated practices such as planning investigations and interpreting data reasonably well, but for the practices which are more central to sense-making, the teachers' designed learning experiences were underdeveloped. For us, the epistemic practices with which teachers struggled, such as modeling, are the most potentially productive for science learning in general and SSI-based learning more specifically. Therefore, we made a design decision to shift from covering all science practices to focusing specifically on the practice of modeling. Modeling is one of the more sophisticated practices which simultaneously supports student sense-making around complex phenomena and connects to other science practices such as analyzing data and constructing explanations (DUSCHL; BISMACK; GREENO; GITOMER, 2016). Our focus on modeling does not deny the importance of other practices; rather, we are choosing to focus on modeling as an anchor practice which can encourage student engagement in other practices while supporting meaningful learning.

Another insight we gained related to SSR. The teaching sequence directs attention to SSR, but the construct itself is not widely recognized, and we found that teachers struggled to make sense of how to incorporate SSR in their SSI units. We reasoned that unpacking the SSR construct more explicitly would likely be helpful in terms of supporting the incorporation of more meaningful opportunities for students to develop SSR competencies. During this time, we also realized that much of what SSR represents is captured by systems thinking (RICHMOND, 2013), and most science educators would be more familiar with systems thinking than SSR. So, as we started introducing teachers to SSR dimensions of complexity, inquiry, and the affordances and limitations of science, we couched the discussion in considering the complex systems in which issues are embedded.

These two decisions (first to foreground modeling as a focal scientific practice and second to highlight systems thinking) forced us to consider the ways in which these ideas relate to one another. In some scholarship, modeling is a form of systems thinking (VERHOEFF; WAARLO; BOERMA, 2008), but in order for us to use these constructs side-by-side in our work to promote SSI teaching, it is important to differentiate their use. When we discuss modeling, we refer to scientific modeling specifically. From this perspective, it makes sense to create models of scientific phenomena using evidence and theory determined by the epistemic criteria of the scientific community (FORD, 2008). Scientific modeling can help build understanding of the scientific phenomena underlying an SSI, but scientific modeling will not help learners make sense of social aspects of the issue which are not subject to the epistemic criteria of science. In contrast, we use systems thinking more broadly. Systems thinking can be applied to a wide range of contexts and is not necessarily tied to scientific evidence and associated epistemic criteria (WARING, 1996). Systems thinking can be a helpful tool for making sense of the complex interactions of an SSI, including both scientific and social dimensions. How these two practices can build on each other is evident in the case of climate change: scientific modeling may be quite helpful in constructing a scientific explanation of the greenhouse effect, the cycling of greenhouse gases, and the implications of anthropogenic releases of greenhouse gases on temperature. Scientific modeling cannot be used to understand the politics and ethics of climate change. However, systems thinking strategies, such as the creation of causal maps (WARING, 1996), can incorporate ideas from science as well as social concerns like politics and ethics. Therefore, we have incorporated a focus on both scientific modeling (of science phenomena) and systems thinking (of the broader issue) in our approach to SSI teaching.

Our final insight, informed by use of the SSI teaching sequence, relates to teacher needs and implementation practices. Our teacher partners have demonstrated remarkable diversity in the ways in which they implemented SSI teaching and learning materials—including curricula that our team developed and curricula that the teachers created. The teaching sequence offers a good starting place for teachers first considering SSI as a part of their teaching, but it, like all tools, has limitations. Teachers deal with a wide range of challenges and they frequently engage in adaptations of curricula and techniques as they attempt to negotiate student needs and classroom constraints (FORBES; DAVIS, 2010). It seemed to us that a more flexible tool that anticipates teacher adaptation practices would be helpful. This led us to consider articulating a set of essential features of SSI teaching without the temporal format offered by the teaching sequence. Given our decision to focus explicitly on modeling within SSI teaching, we call our approach *Socio-scientific Issue and Model Based Learning* (SIMBL). We apply this unique label in order to advocate for a particular way of teaching with SSI in recognition that there may be other productive approaches to SSI education. In the following section, we present the essential features of SIMBL.

Essential Features of Socio-scientific Issue and Model Based Learning

We propose a collection of six interrelated features to define the essence of SIMBL (see Figure 2). This representation highlights the centrality of the SSI in our approach and that ongoing connections should be made to the SSI throughout the curriculum unit. The six features are 1) explore underlying scientific phenomena, 2) engage in scientific modeling, 3) consider issue system dynamics, 4) employ information and media literacy strategies, 5) compare and contrast multiple perspectives, and 6) elucidate own position/solution. The ordering of the features themselves can be fluid depending on the particular needs of a classroom community or issue specificities. We use this tool to encourage teachers to include all of the essential elements in their SSI teaching but do not prescribe a set order for these features. Using this tool, teachers have flexibility in when they introduce an essential feature, the sequencing of the essential features in the unit, and the amount of time devoted to each of the features.

Figure 2 – Essential Features of Socio-scientific Issues & Model Based Learning (SIMBL)

Source: Elaborated by the authors.

In the sections that follow, we provide a definition and rationale for each essential feature, as well as examples from two SSI units that our team co-developed with teachers and that have been implemented in classrooms. Both of the units have ecological and environmental themes. The *Vanishing Prairie* unit focuses on climate change and ideas about carbon cycling and ecological interactions. This unit was designed for and implemented in high school biology courses, and students considered how climate change was impacting tallgrass prairies, the historically dominant ecosystem where the school was located (within the Midwestern US). The *MONARCH* (Modeling Natural systems, Restoration & Conservation of Habitat) unit was designed for elementary school learners and focused on declining populations of monarch butterflies as a consequence of habitat loss. Participating students, who lived in an important migration pathway for monarchs, explored ecological interactions and organismal life cycles as they considered possible actions to address the monarch population declines. More details on both of these units can be accessed on our project website (www.ri2.missouri.edu).

Explore Underlying Scientific Phenomena

This essential feature highlights the science content embedded in the selected SSI and is the feature most familiar to science teachers. Our stance is that in teaching science content, teachers must give students opportunities to explore the scientific phenomenon associated with the focal issue. This stance is grounded in reform-oriented science teaching as linking science concepts to phenomena and engaging students in investigations are core science teaching practices (KLOSER, 2014). Following NGSS recommendations, we often use an anchor phenomenon in the SSI units we design. Anchor phenomena are relevant to students' everyday experiences; observable; complex; have associated data, text and images; and have a stakeholder community or audience interested in the findings (PENUEL; BELL, 2016). In the *Vanishing Prairie* unit, students explore the effects of climate change during a field trip to a local native prairie. At the prairie, students move through a series of stations in which they collect data related to soil moisture levels, examine soil profiles, learn to identify native plants, estimate biodiversity, and observe burn plots demonstrating the effects of varying burn regimes on the survival of woody versus herbaceous plants. The field trip serves as an anchor phenomenon that the teacher makes connections to throughout the unit. In the *MONARCH* unit, elementary students observe the phenomenon of the monarch life cycle and habitat requirements. An important part of the monarch life cycle is migration; therefore, students look at monarch migration pathways across North and South America and explore monarch population data in their state. They also take a field trip, which serves as an anchor phenomenon, to explore a recently restored conservation area and explore monarch habitat.

Engage in Scientific Modeling

Model-based reasoning occurs through the development and use of models that serve as cognitive tools for scientific reasoning (DUSCHL et al., 2016). The models are evaluated and revised as scientific knowledge grows. As such, the practices of modeling— development, use, evaluation, and revision of models— is fundamental to scientific progress and prior models serve as artifacts of the development of scientific knowledge (NERSESSIAN, 2002). Within science education, engaging students in the practices of modeling shifts science instruction from a focus on learning *from* models, textbooks, teachers, and lab exercises, to providing students the opportunity to learn with – using their ideas to construct and evaluate scientific knowledge (GOUVEA; PASSMORE, 2017). When students develop models, they have a platform with which to connect observation with underlying theory (i.e., engage in sense-making) to build conceptual understanding of how and why the world works (BECHTEL; ABRAHAMSON, 2005; SENSEVY; TIBERGHIEN; SANTINI; LAUBE; GRIGGs, 2008).

In our work, while we have included modeling in many forms both through online platforms and mathematical modeling, we are intentional in always including a modeling packet in which students develop their own models in response to a question or problem that targets the scientific phenomena. In the *Vanishing Prairie* unit, we include a modeling packet in which secondary students draw their ideas in response to the question "Where does carbon come from and where does it go?" In the *MONARCH* unit, we ask elementary students to draw a model in response to the question "How do plants and animals interact in an ecosystem?" In both instances, after students draw their initial model, they write about what their model shows, including how and why the process works. Half-way through the unit, we ask students to return to their initial models and evaluate them for how well they explain the scientific phenomenon. In the *Vanishing Prairie* unit, we ask students to give their model a rating of 1 (the lowest) to a 5 (the highest) and explain why they gave their model that rating. In the elementary classroom, we ask students to use a different colored pencil and draw on their first model to show what should be changed and answer a question as to why they removed, changed, or added to their model. Students then draw and write about a second model. We do this again at the end of the unit, in which students evaluate and rate their second models. Returning to the prior models, evaluating, and revising is a crucial step to using models to learn *with*. Students come to realize that their ideas, as expressed in their models, are not static entities, but dynamic learning tools. As students' understandings change and grow, so must their models if they are to continue to productively use them for sense-making.

Consider Issue System Dynamics

Learning about complex systems can appear deceptively simple in the science classroom as they are broken apart by the discipline in which they are associated (e.g., biology, chemistry, physics, earth science), then the system is further broken down into parts and pieces within the discipline (HMELO-SILVER; AZEVEDO, 2006). As a result, something as complex as ecosystem dynamics may appear to students as a simplified food chain. However, natural systems are large complex, dynamic systems that operate over spatial and temporal boundaries (CAPRA, 1996). Furthermore, scientific systems interact with equally complex human engineered systems (Advisory Committee for Environmental Research and Education [AC-ERE] 2015). As change occurs within a scientific system, it can in turn have powerful effects on human engineered systems, and vice-versa. Learning about these interactions is system dynamics.

System dynamics within the sciences has been brought to the forefront as a lacking, but necessary, skill that students need to build throughout their education (AAAS, 2011; DUSCHL et al., 2016). Therefore, when we ask students to consider a system associated with an SSI, we encourage them to consider the scientific elements as well as human and social elements such as political, economic, ethical, and religious considerations. It is only through this consideration of the interrelated science and social dimensions of complex societal problems that we can hope to move toward productive solutions. Our classroom approach to supporting students to consider system dynamics was informed by the design principles for complex thinking proposed by Jacobson and Wilensky (2006). The complex systems we are discussing should be made explicit so that students can consider the parts of each system that are interacting, impacting, and/or affecting other systems. Within the *Vanishing Prairie* unit, students are prompted to consider how strategies for minimizing climate change (i.e., reducing the release of atmospheric carbon) interact with economic and political influences. In the *MONARCH* unit, the elementary students are not necessarily positioned to tackle the global politics of intercontinental habitat destruction; however, the students are encouraged to think about the biological needs of butterflies in conjunction with their own desire for play spaces. By encouraging students to balance environmental considerations with personal desires or shared commitments for recreation, students begin the work of systems thinking.

Employ Information and Media Literacy Strategies

SSIs, by definition, are contemporary problems and therefore are subject to ongoing inquiry, new ideas, and novel perspectives. The knowledge landscapes surrounding these issues are dynamic, unlike the situation for many ideas that are typically presented in science classrooms which tend to be settled science (KOLSTØ et al., 2006). Well established science ideas can be presented relatively unproblematically in science textbooks, but the same cannot be said for issues for which relevant information changes or grows. Whereas learners may find sufficient information on settled science in their textbooks or other static educational resources, more frequently updated sources are required for the consideration of SSI. Much of what we as a society come to understand about contemporary societal issues including SSI is mediated through modern media (KLOSTERMAN; SADLER; BROWN, 2012). If we want students to make sense of SSI, then accessing information about those issues through media is an inevitable dimension of their learning. This reality raises new challenges: interpreting media and making decisions about information quality require skills not often taught within science education contexts. However, these skills have been explored, and helpful teaching frameworks have been advanced by the field of media literacy.

For SSI teaching, we draw upon recommendations from media literacy and encourage learners to consider 1) the meanings and messages of an information report, 2) the authors and their intent in preparing an information report, 3) the intended audiences, and 4) potential biases that may influence the generation of the information or the ways in which it is reported. In the *Vanishing Prairie* unit, there are multiple opportunities throughout the unit for students to access information from media reports and online sources. Early in the unit we provide students with a resource, “Know Your Sources,” which is a list of questions students are encouraged to ask of each report or Internet site with which they interact (for more on this resource, see KINSLOW; SADLER, 2018). Some of the questions students are encouraged to consider include:

- Who is the author or organization disseminating this information?
- What is the purpose of the publication?
- What expertise and/or relevant experiences does the author have?
- What biases could affect the presentation of the information?

As the unit unfolds, students become familiar with the questions and accustomed to exercising criticality in their consumption of media. In the *MONARCH* unit, most of the information choices are made by the teachers, and teachers play a more active role in helping to mediate learner experiences with particular media. However, even in this work with elementary school students, teachers encourage learners to think about where their information is coming from and why different information sources (e.g., a picture book and an article in the local newspaper) may communicate different messages even when they address the same topic.

Compare and Contrast Multiple Perspectives

The ability to think beyond one’s own immediate vantage point is an essential critical thinking skill (as well as an aspect of SSR) and an important step in the development of empathy (KAHN; ZEIDLER, 2017). SSI are wicked, complex problems that lack straightforward solutions that all stakeholders would find agreeable (OWENS; SADLER; ZEIDLER, 2017). Therefore, SSIs provide ideal contexts for exercising multiple perspective taking. In the case of some SSIs, science provides guidance on what might happen with respect to a complex issue in response to various courses of action. For example, we know that drastic reductions in human-caused carbon dioxide emissions may reduce the rate of global temperature increases (Intergovernmental Panel on Climate Change, 2018); however, various stakeholders in the climate change debate have very different perspectives on what should be done (or not done) in response to the issue. It is valuable for learners to understand why different groups have different ideas about courses of action in response to controversy. The ability to incorporate anticipated responses from different stakeholders into one's own reasoning and decision-making leads to more robust understandings of the problem and more realistic solutions.

To introduce multiple perspectives in the *Vanishing Prairie* unit, we introduce learners to a scientific consensus report on climate change (National Academy of Sciences and the Royal Society, 2014) with the purpose of reviewing evidence the scientific community has amassed regarding climate change. This resource offers a clear imperative to stem anthropogenic carbon dioxide emissions. Next, students explore a set of internet resources that feature a range of stakeholders (including environmental activists, conservative politicians, and gas and energy executives) offering insights into their stances on climate change. Students then discuss how each of these stakeholders would make sense of the recommendations offered in the scientific consensus report and their proclivity for enacting these recommendations. In the *MONARCH* unit, elementary students are challenged to consider transforming their school soccer field into a butterfly garden. In order to support development of perspective taking competencies, students are asked to consider how soccer players and conservationists might respond to different outcomes.

Elucidate Own Position/Solution

For this essential feature, depending on the nature of the SSI, students are asked to either defend their position and/or propose a solution to the SSI. This essential feature is often introduced at the beginning of the unit when teachers elicit students' initial positions and then is re-visited in a culminating activity. Consistent with Robert's (2007) vision II scientific literacy, discussed in the introduction, students require opportunities to learn science in the context of issues similar to those they will face as citizens (SADLER, 2011), and they need experience proposing and defending solutions to complex issues.

In the beginning of the Vanishing Prairie Unit, the teacher elicits students' positions on climate change by asking them to stand on a continuum line in which one end represents climate change denial and the other end represents human-induced climate change. Toward the completion of the unit, we ask students to reflect on their initial positions and consider how their positions may have changed during the unit. In many of our units, we design culminating activities that prompt students to develop a written product in which they defend their current position, synthesize the science embedded in the SSI, and propose a solution to address the issue. We recommend having students explore multiple perspectives before the culminating activity as this helps to problematize simplistic solutions that students might initially propose. In the *Vanishing Prairie* Unit, we narrow the focus of the culminating activity by encouraging students to consider the impacts of climate change on a single species. Students select a threatened or endangered species to research and develop a model to show the effects of climate change on that species. Next, students propose a conservation plan for the species. We ask them to identify stakeholders who would be opposed to their plan and those who would support it. In the *MONARCH* unit, students spend much of the unit considering whether a soccer field within their schoolyard should be restored to a prairie for monarch butterfly habitat. For the culminating project, they are challenged to provide advice to a school principal in a neighboring community who is considering construction of a soccer field using a natural area that includes an ideal monarch habitat. This provides a venue for the students to apply the ideas and practices they have learned in the unit to a new, but related situation in which they are called upon to articulate their own position.

CONCLUSIONS

Teaching with SSI offers a means through which progressive goals of science education (e.g., helping students become better prepared for their lives in modern society) can be achieved. Many science teachers espouse these kinds of goals (SADLER; AMIRSHOKOOHI; KAZEMPOUR; ALLSPAW, 2006), and at least portions of the field have embraced these goals through pursuit of vision II scientific literacy (ROBERTS; BYBEE, 2014). However, teaching with SSI can be challenging work. For the last several years, our team has focused on understanding the challenges teachers face when using SSI as central features of their teaching and on developing tools to help teachers negotiate these challenges. One of the key tools for doing this work is a framework for guiding SSI based teaching and learning. Our first attempts at creating such a framework were driven primarily by research (Sadler, 2011b). Subsequent efforts were informed by both research and teacher reactions to and use of the framework tools (PRESLEY et al., 2013).

These early iterations led us to advance a framework in the form of a teaching sequence (SADLER et al., 2017). The teaching sequence prescribes a series of three phases of instruction: 1) encountering the focal issue; 2) developing science ideas, practices, and socio-scientific reasoning; and 3) synthesizing what students have learned through a culminating activity. Our work with this sequence pushed us to make three important design decisions. First, applying primary focus to one scientific practice, in our case scientific modeling, may be more supportive of teacher learning and classroom practices than highlighting all eight NGSS practices simultaneously. Second, socio-scientific reasoning needs to be further unpacked in order to be useful for most teachers. Finally, for many teachers who are naturally inclined to modify and adapt teaching and learning materials, a prescriptive sequence may not afford enough flexibility.

Considering these design decisions led us to explore essential features of SSI teaching and to posit six such features. Given the specific focus on modeling, we labeled this revised approach *Socio-scientific Issue and Model Basel Learning* (SIMBL). Each of the SIMBL essential features describes activities in which students should engage as they experience SIMBL opportunities. These features include 1) exploring the underlying scientific phenomena, 2) engaging in scientific modeling, 3) considering issue system dynamics, 4) employing media and information literacy strategies, 5) comparing and contrasting multiple perspectives, and 6) elucidating one’s own position or solution. When introducing these essential features, we encourage teachers to think flexibly about the timing of their enactment within SIMBL modules. There is not a prescribed order or pathway for enacting the features, nor is there a predetermined amount of time that should be devoted to each feature. Instead, teachers should use professional judgment and consider both contextual dimensions of the focal issue as well as the specific needs of their students in determining the timing of essential feature enactment.

In our previous efforts to articulate a framework for SSI teaching and learning, we considered each iteration as a replacement of its predecessor. However, with the current work, we see the essential features as adding to the existing tool set for a framework for SIMBL. The teaching sequence, with its prescribed suggestions for structuring an SSI unit, provides teachers with some concrete guidance on how to approach SSI teaching and learning. We have found it to be a useful tool particularly when working with teachers new to the SSI approach. As teachers gain experience and see a need for more flexibility in their SSI teaching practices, we shift to the essential features tool which is more geared toward supporting teachers' enactment of professional decision-making. Together, the teaching sequence and the essential features provide complimentary tools to support teachers as they engage in teaching for SIMBL.

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