Eco-Solutioning: The Design and Evaluation of a Curricular Unit to Foster Students' Creation of Solutions to Address Local Socio-Scientific Issues

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The global pandemic and climate change have led to unprecedented environmental, social, and economic challenges with interdisciplinary STEM foundations. Even as STEM learning has never been more important, very few pre-college programs prepare students to address these challenges by emphasizing socio-scientific issue (SSI) problem solving and the engineering design of solutions to address local phenomena. The paper discusses the design and evaluation of a pre-college, SSI curricular unit where students expand their learning by creating solutions to increase biodiversity within local urban neighborhoods. The learning approach, which we call eco-solutioning, builds from current vision and policy documents in STEM education emphasizing phenomenon-centric instructional materials, science investigations, and engineering design. The paper outlines design principles for creating an eco-solutioning instructional unit that guides young students to: collect and analyze data on local organisms, use an engineering design approach to craft solutions to increase local biodiversity, and present their solutions to local city planners and community members. Two cycles of research studies evaluated student learning using paired t-tests. Results demonstrated significant pre-post learning outcomes in both research cycles. A third research cycle in the form of a summer extension program supported students as they implemented their local solutions. Conclusions highlight design principles for the successful creation of SSI curricular units centered on local environmental issues of interest to students, teachers, and stakeholders.

Keywords: socio-scientific issues, science education, STEM education, curriculum development, problem solving

INTRODUCTION

The global pandemic and climate change have led to unprecedented environmental, social, and economic challenges grounded in the interdisciplinary fields of Science, Technology, Engineering, and Mathematics (STEM). These ecological, socio-scientific challenges need the intelligence and resources of all of us to tackle them successfully. Therefore, it seems increasingly evident that today's pre-college students need to develop problem-solving and solutioning skills to practice and become adept at addressing these complex, interdisciplinary challenges.

Some use the term Socio-Scientific Issues (SSI) to describe science education instructional programs that center on phenomena and problem solving and provide opportunities for student ownership of learning. The design of educational programs that emphasize SSI and environmental problem solving is an idea recently championed in policy documents from several countries and multi-country organizations. As stated in the report, "The Future of Education and Skills: Education 2030" (Organization for Economic Co-operation and Development (OECD), 2018), certain kinds of science education programs are valuable, including programs that emphasize solving problems, working with others, and identifying multiple solutions. The report states, "In the face of an increasingly volatile, uncertain, complex and ambiguous world, education can make the difference as to whether people embrace the challenges they are confronted with or whether they are defeated by them. And in an era characterized by a new explosion of scientific knowledge and a growing array of complex societal problems, it is appropriate that curricula should continue to evolve, perhaps in radical ways" (Organization for Economic Co-operation and Development (OECD), 2018, p. 4).

The paper discusses the design and evaluation of a pre-college, SSI curricular unit where elementary-age student learning is drawn upon to create solutions to increase biodiversity within local urban neighborhoods. The learning approach, which we call eco-solutioning, builds from current vision and policy documents in STEM education emphasizing phenomenon and SSI-centered instructional materials. In eco-solutioning, student learning also leads to tangible products, such as the engineered design of solutions to local environmental challenges. The paper also presents research on student learning associated with two research cycles. Our work contributes to knowledge of design principles for creating SSI programs and empirical studies to extend the research literature relative to practical, and theoretical understanding of socio-scientific issues. The research is timely and necessary. Even as learning about SSIs has never been more important, very few pre-college instructional programs currently prepare students to address these challenges by emphasizing SSI problem solving and the engineering design of solutions.

CONCEPTUAL FOUNDATIONS FOR SOCIO-SCIENTIFIC ISSUE PROGRAMS

A review of research literature provides several essential characteristics of SSI. Educational programs emphasizing SSI center on phenomena and problem-solving in STEM fields and provide opportunities for student ownership of learning, improved scientific literacy through argumentation, and the opportunity for shifting the student focus to active participants in the decision-making process by moving the learning outside the classroom and making it personally relevant, as their learning is closely linked to improving their own communities (Zeidler et al., 2002; Zohar and Nemet, 2002; Hodson, 2003; Tal and Kedmi, 2006; Lenz and Willcox, 2012; McNeil and Vaugh, 2012; Zeidler, 2014; Karahan and Roehrig, 2015; Lee, 2015; Yoon et al.,

2019; Kim et al., 2020). SSI programs have been implemented both in the United States and internationally as a way to shift into sociocultural forms of learning by contextualizing socially relevant real-world problems informed by science (Sadler et al., 2007). In particular, Zeidler (2014) offers specific features of an ideal SSI educational program:

- Utilizing personally relevant, controversial, and ill-structured problems that require scientific, evidence-based reasoning to inform decisions about such topics.
- Selecting scientific issues with social ramifications that require students to engage in dialogue, discussion, debate, and argumentation.
- Integrating implicit or explicit ethical components that require some degree of moral reasoning, and
- Emphasizing the formation of virtue and character as long-range pedagogical goals. (Ziedler, 2014, p. 699).

Similarly, recent United States policy documents discuss essential components of science education curricular programs that emphasize personally relevant problem solving and argumentation, leading to deep conceptual understandings of science concepts. For example, a recent National Academy of Sciences report indicates that all science education instructional materials should situate learning in culturally and locally relevant contexts and phenomena. In these curricular units, the suggested classroom activities are also different. Instead of students receiving knowledge from the teacher or a textbook, students learn to make sense of phenomena through exploration, reflection, discussion, and argumentation (National Research Council, 2019). This approach builds from other recent National Academy of Science documents (e.g., National Research Council, 2012) that outline a vision that also includes a shift in learning goals. For example, by the end of science instruction at each age, students should demonstrate evidence of three-dimensional (3D[1]) science and engineering performances (National Research Council, 2012), e.g., knowledge that integrates science and engineering practices, disciplinary core ideas, and crosscutting concepts.

Policy documents and empirical studies also document the value of local investigation and engineering design-focused science activities. For example, Karahan and Roehrig (2015) describe how SSI learning has the potential to make the learning personally relevant. Similarly, the National Academy of Sciences' 2019 report states, "Science investigation and engineering design can allow students to participate in science as a social enterprise and help them to connect science and engineering concepts and principles to their own experience and ideas" (National Research Council, 2019; p. 11).

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[1]The three dimensions are science and engineering practices, disciplinary core ideas, and crosscutting concepts. The Framework (National Research Council, 2012) was the foundational document that outlined the importance of 3D performance expectations as the backbone for standards, curricular materials, assessment, and instruction in the United States.

Realizing student learning of 3D science and engineering performances and emphasizing SSI also requires changes in classroom activities and pedagogical approaches (McNeil and Vaughn, 2012; National Research Council, 2019). The National Academy of Science 2019 report articulates the shifts in classroom activities that are needed. Instructional materials must provide opportunities for students to ask and address questions, participate in discussion, propose and critique multiple explanations for phenomena, and design and recognize various solutions to an engineering problem (National Research Council, 2019). In a related article, Penuel and Reiser (2018) call for materials that emphasize 3D science and engineering performances, anchor student learning within phenomena and design challenges, and promote incremental sensemaking, among other characteristics (Penuel and Reiser, 2018). Empirical studies comparing 3D science and engineering performance-fostering classroom practices to more traditional pedagogy demonstrate that 3D curricular programs lead to deeper conceptual understandings of scientific phenomena than learning demonstrated through more conventional approaches, such as textbook-driven or "cookbook-style" laboratories (Songer et al., 2009; National Research Council, 2019).

In this paper, we identify eco-solutioning as a learning approach that draws from empirical studies in SSI and programs fostering 3D science and engineering performances. Eco-solutioning has features in common with SSI and some classroom-based citizen science projects, including the study of ill-structured problems and the use of dialogue, discussion, and argumentation in problem-solving (Zeidler et al., 2002; Zohar and Nemet, 2002; Tal and Kedmi, 2006). Eco-solutioning is different from many citizen science and SSI programs in several ways. In particular, eco-solutioning programs:

1. Always ground learning activities in local data collection, analysis, reflection, argumentation, and solution generation associated with a local ecological or environmental problem,
2. Focus learning activities on a small number of 3D science and engineering performances, and
3. Culminate in the design of a solution to address a local environmental issue, followed by sharing or implementing the solution with local stakeholders.

RESEARCH DESIGN AND RESULTS

The research work associated with the design and evaluation of an eco-solutioning curricular unit has two components: 1) qualitative research to identify and characterize the design principles realized in the creation of the SSI curricular unit, and 2) quantitative research studies to evaluate student learning associated with two iterative cycles of research.

Qualitative Research to Articulate Curricular Unit Design Principles

We utilized a basic qualitative study approach (Merriam, 2009) to structure our data collection and analysis associated with

characterizing the design principles involved in our curriculum development. We selected a basic qualitative study approach as there were several features of our analysis that fit with this approach (Merriam, 2009). First, our focus was on understanding and codifying a process, that of the design principles associated with eco-solutioning curriculum design. Second, our data collection occurred over twelve months and consisted of generative documents associated with the design process, including field notes chronicling curriculum design-team activities, participants in each activity, and artifacts of the design work such as multiple versions of a template for the sequence and goals of each lesson which we called the curriculum story. Third, data analysis emphasized the inductive process of coding observations and steps articulated in the generative documents leading to a sequential list of design principles.

While the process of the productive design of curricular programs sometimes combines bottom-up and top-down processes (Songer and Kali, 2014), our work followed an iterative, bottom-up approach. In such an approach, curricular templates and curricular activities are developed and refined in often multiple, repetitive cycles. Sometimes products of design are implemented with small numbers of students in classroom contexts so that the lessons can be evaluated relative to their validity and match to the learning goals and the target audience. In our case, our iterative, bottom-up process involved cycles of design work followed by cycles of implementation in classroom settings following the methodological approach of Design Based Research (DBR; Barab and Squire, 2004).

Qualitative Research Results

Over twelve months, the curriculum development team chronicled a series of steps to develop the curricular unit using an iterative process and two DBR cycles of design and implementation work. The iteration design of the project allowed the opportunity for curriculum and student workbooks to change from cycle 1 to cycle 2 to take into account aspects as logistics—school timelines, inclement weather, available areas for outdoor exploring, as well as the final iteration of the workbook that took into account and allowed for a much more engaging student experience (workbooks were designed for that particular age group).

The following sections outline the significant steps and design principles. These steps and design principles chronicle what we learned in the development of a six-week eco-solutioning curricular unit that guided late-elementary-age students to gather and analyze data on local organisms and use an engineering design approach to craft and share their solutions with local stakeholders.

Step 1: Select a Small Number of Three-Dimensional Science and Engineering Performances

Our first step was to select a small number of 3D performance expectations from the Next Generation Science Standards that would be the focal learning goals for our unit (NGSS Lead States, 2013). **Table 1** presents the two 3D performance expectations we selected and the associated lesson numbers. As these 3D performance expectations are more ambitious than many

3D Performance Expectations for the Elementary Unit	Lesson Addressed
3–5 LS4-3 Biological Evolution Unity and Diversity: Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all	Lesson 1, 2, 3, 4, 5
3–5 ETS1-2 Engineering Design: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem	Lesson 6, 7, 8

learning goals often used for our elementary-age audience, we selected only two 3D performance expectations for the six-week unit. Our selections dictated that one 3D performance expectation emphasizes age-appropriate life science content that would anchor students' design of their local solutions. The second 3D performance expectation emphasized an age-appropriate version of students' engineering design and critique of created solutions. The design principle that summarizes this step is DP 1: Anchor the curricular unit by focusing on a small number of 3D performance expectations.

Step 2: Select a Local Phenomenon to Serve as the Eco-Solutioning SSI

Either concurrent with Step 1 or shortly afterward, our qualitative research analysis documented the identification of a local phenomenon to serve as the focal SSI for students' solutions. Building from scientists' work to introduce simple solutions to increase urban biodiversity (e.g., Conniff, 2014), we selected one focal phenomenon as a fruitful SSI for student solutions: the introduction of indigenous plants to increase the number of pollinators in city parks and open spaces. The design principle that summarizes this step is DP2: Select a local phenomenon to serve as the eco-solutioning SSI.

Step 3: Create and Revise a Curriculum Story that Outlines a Sequence of Learning Goals to Build Toward the 3D Performance Expectations

After the team identified the 3D performance expectations for the larger unit, our design team needed to map out a sequence of precursor learning goals that would guide students to the learning outlined in the two 3D performance expectations. To begin this sequencing and mapping of goals, we first created a template document called a "Curriculum Story." The development of this document started with the creation of eight learning goals, one for each lesson. After identifying and sequencing these learning goals to ensure they would lead to students' understanding of the 3D performance expectations, we began to draft short activity descriptions for each lesson. The Curriculum Story drafting process consisted of approximately four different iterative versions before the team adopted a final version. As a part of our DBR work, we implemented version 2 and 4 with students in research cycles 1 and 2 (see below). As mentioned, alternating design cycles with implementation cycles allowed us to draw from student and teacher feedback and learning results toward an improved curricular unit. Also noteworthy was the design of student badges. The team developed badges to acknowledge

students' development of scientific and engineering expertize. By the end of Step 3, we created a version of the Curriculum Story that identified a title, a learning goal, the national standards addressed in that lesson, and a short activity description for each lesson. **Table 2** presents the final Curriculum Story and the five locations where students would earn a badge that indicated their socio-scientific problem solving and learning. The design principle that summarizes this step is DP3: Create and revise a curriculum story that outlines a sequence of learning goals that build toward the 3D performance expectations.

Step 4: Design Classroom Activities That Emphasize Student Dialogue, Argumentation, and Sensemaking Discussions

The Curriculum Story outlined a general plan, but provided very little information on the kind of classroom activities that might support student' learning associated with these lesson goals and 3D performance expectations. Step 4 was an iterative process in conversation with others, including classroom teachers, to brainstorm activities where, for example, students could draw on their evidence to support argument construction or engage in sensemaking conversations (National Research Council, 2019) to support or refute conjectures. Besides, we wanted to ensure that students had good practice with learning science content through the science and engineering practices, such as engaging in argument (National Research Council, 2012). Therefore, step 4 included a series of generating, discussing, and revising classroom activities that helped students practice, with various support and scaffolding, classroom activities demonstrating learning that included engaging in argument and productive sensemaking conversations. By the end of this step, our Curriculum Story outlined a plan where students constructed arguments four times, collected data and carried out investigations two times, and communicated about science and engineering two times. The design principle that summarizes this design principle is DP 4: Design classroom activities that emphasize student dialogue, argumentation, and sensemaking discussions.

Step 5: Draft Individual Lessons, Then Look for Ways to Build Continuity Across the Unit

Once we had an outline of classroom activities, the next step was each lesson's iterative design. Eco-solutioning lesson design involves more detail than is commonly seen in a traditional textbook-driven lesson. For example, eco-solutioning design includes creating lesson versions for individual and group student engagement and teacher guidance. Teacher guidance

Lesson	Learning Goal	Short Activity Description and Students Badges
1: Is my animal an insect?	Students use their observations to ask questions and create a claim + evidence as to whether or not their animal is an insect	Students are given a letter of invitation from a Professional Animal Tracker that contains a picture to identify. Students engage in a sensemaking discussion about the features of insects. They construct scaffolded claim + evidence about their animal as an insect. Mini-Beast Badge
2: What is a good observation?	Students make observations of plants and animals to compare the diversity of life in different habitats	Students learn about the fieldwork of Professional Animal Trackers. Students are guided in field observations in their neighborhood. Urban Tracker Badge
3: What lives in my neighborhood?	Students collect animal and plant data within an area of their schoolyard	Student teams are assigned to a specific area of the schoolyard. Over multiple days, students systematically collect and organize data identifying a variety of plants and animals in their assigned area. Field Researcher Badge
4: Which local area has the lowest biodiversity?	Students construct claim + evidence to indicate which habitat has the lowest biodiversity	Students engage in a sensemaking discussion to discuss animal abundance (total count), richness (total number of different species), and biodiversity (variety based on richness and abundance). Students use their neighborhood data to construct a claim + evidence for which area has the lowest biodiversity
5: How does energy flow in a food web?	Students develop a model to describe the movement of matter among plants, animals, decomposers, and the environment	Using their data, students engage in sensemaking discussion about a local food web, producers, consumers, decomposers, and energy flow. Students complete food chains on local organisms and construct a claim + evidence to complete a simple food web
6: What solution might increase local biodiversity?	Students generate and compare multiple possible solutions based on how well each is likely to meet the criteria and constraints of the problem	Using information from the model of their simple food web, students engage in a sensemaking discussion about a modeled solution for a student named Rasheda. Students are guided through a scaffolded solution creation template to create a solution backed with evidence to increase local biodiversity. Solution Generator Badge
7: Communicating our solution	Students create a display of their solution including tables/charts showing patterns in observed data	Student teams create a poster that includes their solution, the evidence that backs the solution, their field data, and the food chain for their animal
8: Sharing our solutions	Students communicate data and solutions with local stakeholders, families, and peers	Student teams present their solution posters to local community leaders, families, scientists and engineers in the Student Summit Urban Scientist Badge

often provides information on how to guide students' argument construction, and anticipation of prompts teachers will need to guide sense making discussions. The Design principle associated with this step is DP5. Draft each lesson, including tips for teacher guidance of challenging activities, including engaging in argument and sense making discussions.

Step 6: Create Formative Feedback, Badges and Summative Assessments to Provide Opportunities for Multiple Feedback and Evidence of 3D Performance Expectations

Assessment design recognized the importance of formative assessment and badges for feedback and summative assessment to provide evidence of learning of 3D performance expectations. Assessment design drew upon previous research designing formative and summative 3D performance expectations assessments (Gotwals and Songer, 2013; National Research Council, 2014) to create a pre-post assessment instrument designed to provide evidence of learning. In particular, our assessments had these features:

1. Both formative and summative assessments consisted of multiple and varied assessment opportunities.

2. Assessments emphasized short answer and constructed response items organized in clusters.
3. Assessments needed to provide evidence of progress in developing 3D performance expectations rather than only right or wrong answers.

Multiple opportunities are meaningful because even as specific questions can focus on a particular disciplinary core idea, it is challenging to gather strong evidence of 3D performance expectations with only a single multiple-choice or constructed response task (National Research Council, 2014). Evidence of progress is vital as students often develop integrated 3D performance expectations in fits and starts. For example, when students create an argument based on evidence, many students struggle to select appropriate evidence to back their claims. If the assessment item only rewards a complete 3D performance expectation product, this area of struggle might not be well documented or understood. As a result of these assessment design rules, we created an identical pre-post test consisting of eight, multi-part item clusters. The design principle for this step is: DP 6: Create formative feedback, badges and summative assessments to provide opportunities for multiple feedback and evidence of 3D performance expectations.

In summary, the Design Principles for the design of eco-solutioning SSS units are:

1. Anchor the curricular unit by focusing on a small number of 3D performance expectations.
2. Select a local phenomenon to serve as the eco-solutioning SSI.
3. Create and revise a curriculum story that outlines a sequence of learning goals that build toward the 3D performance expectations.
4. Design classroom activities that emphasize student dialogue, argumentation, and sensemaking discussions.
5. Draft each lesson, including tips for teacher guidance of challenging activities, including engaging in argument and sensemaking discussions.
6. Create formative feedback, badges and summative assessments to provide opportunities for multiple feedback and evidence of 3D performance expectations.

Research Studies on Student Learning

After the team completed the development of a full set of lessons for the six-week curricular unit, we implemented the program with cohorts of 3–6th grade students in two research cycles. Research studies address the question, what kinds of evidence of three-dimensional performance expectations learning do students in diverse, under-resourced in and out-of-school locations demonstrate in association with an SSI curricular unit designed to foster students' eco-solutioning about local biodiversity? Research studies utilized qualitative and quantitative research methods to gather and analyze empirical data within design-based research (DBR) cycles (Anderson and Shattuck, 2012). The team organized the studies into two formal research cycles conducted during the fall and spring of an academic year and a third extension cycle during the following summer. Cycle 1 and Cycle 2 data collection instruments consisted of pre and post-tests to evaluate student learning outcomes associated with implementing the eco-solutioning curricula focused on 3D performance expectations outlined in the Framework for K-12 Science Education (National Research Council, 2012). Cycle 3 data collection instruments included student interviews and student surveys to provide evidence of student attitudes and beliefs associated with student implementation of solutions related to a local urban farm.

Participants

Project participants were students and teachers within an urban neighborhood designated as a United States Promise Zone. In 2014, the Obama administration created the Promise Zone designation for urban communities challenged by deep and persistent poverty and a lack of resources. The Promise Zone designation allowed local and national government and non-profit organizations to coordinate initiatives and attract resources (The While House, 2014). In this and several Promise Zone neighborhoods, students consistently demonstrate patterns of underperformance on state and national standardized tests.

Student participants were a total of 94 students in grades 3, 4, 5, and 6 and their teachers from three culturally, racially, and linguistically diverse, under-resourced schools and out-of-school

programs (**Table 3**). The team used a purposeful sampling method for this research. The population was selected for several reasons, including the absence of 3D performance expectation-focused curricular units provided to these students in the past and the productive, ongoing relationships between school personnel and the project staff.

Pre-Post Assessment Design and Analysis

Guided by documents on how to assess 3D performance expectations (e.g., National Research Council, 2014), the project team created a pre and post-assessment instrument. The team designed the assessment to provide evidence of students' abilities to demonstrate learning associated with the selected 3D performance expectations (**Table 1**) and learning goals (**Table 2**). In other words, the team designed items to provide evidence of students' life science content knowledge (disciplinary core ideas and crosscutting concepts) through science and engineering practices (e.g., data analysis, generation of claims, evidence, and solutions). The assessment instrument consisted of eight item clusters containing eight Content Only short answers and four clusters of Content and Science Practices constructed-response items (see examples in **Figure 1**). As illustrated in the **Figure 1** example, Content Only items helped the research team to gather information on whether or not the students were able to demonstrate understanding of fundamental science concepts associated with the curricular unit. Content and Science Practices Tasks helped the research team to gather evidence on students' abilities to demonstrate learning of 3D performance expectations. In previous studies (Gotwals and Sanger, 2013), results demonstrated that Content and Science Practices Tasks such as in **Figure 1** were challenging for students even as they provided more information on what students had learned relative to the 3D performance expectations. The team implemented the tests to the students in all locations both before and after the curricular program.

Two project members coded students' pre and post-tests using a pre-established coding rubric (e.g., **Figure 1**) to measure a change in students' learning. The two coders graded the student pre and post-tests independently using a binomial code, 0-wrong and 1-correct. The independently graded pre and post-tests results were then compared to calculate the overall agreement. The inter-rater reliability among the two test coders was greater than 90% for both tests. Paired-samples t-tests were performed on overall and individual pre and post-tests questions to compare means between the pre and post-tests to account for change, with a 0.05 level of significance, using SPSS version 25 for statistical analysis. A secondary data source was 30 min exit interviews conducted with each teacher after implementation. These interviews were conducted, recorded, and transcribed for further analysis.

QUANTITATIVE RESEARCH RESULTS

Cycle 1 and Cycle 2

Analysis of student pre-posts in Cycles 1 and 2 resulted in the following results. In Cycle 1, thirty-six 4th-6th graders from three

TABLE 3 | Demographics of student populations in each research site and research cycle

Research cycle & Location	N Students, In School/After School	Demographics
Fall site A	16 fourth grade, in school	100% ED; 98% REM
Fall site A	8 fourth, fifth, sixth grade, afterschool	100% ED; 98% REM
Fall site B	12 fourth, fifth, sixth grade, afterschool	100% ED; 97% REM
Spring site A	8 fourth, fifth, sixth grade, afterschool	100% ED; 98% REM
Spring site B	20 third grade, in school	96% ED; 86% REM
Spring site C	8 fourth, fifth, sixth grade, afterschool	100% ED; 97% REM
Summer Extension	22 third, fourth, fifth, sixth grade, afterschool	100% ED; 97% REM, 20% SwD
	Total students N = 94	

ED, Economically Disadvantaged; REM, Race/Ethnic Minorities; SwD, Students with Disabilities.

different sites took the pre and post-tests before and after Cycle 1 implementation. The results of the paired-samples t-tests were statistically significant [t (35) = −3.138, p = 0.003, two-tailed] for the overall pre and posttest and [t (35) = −3.823, p = 0.000, two-tailed]. When items were separated by Content Only and Content and Practices items, there was a significant learning outcome from pre-post tests for the Content and Practices constructed response items but no significant difference for Content Only items (**Table 4**).

In Cycle 2, thirty-six 3rd-6th graders from three different sites took the pre and post-tests before and after the Cycle 2 implementation. The Cycle 2 pre/post-test contained eight assessment item clusters that included five Content Only items and eight Content and Practices constructed response items. Two team members coded the students' pre and post-tests, and the IRR was over 90%. The answers were compared using paired-samples t-tests. The results showed to be statistically significant for all items and all item types, including multiple-choice and constructed-response items [t (35) = −11.409, p = 0.000, two-tailed] (**Table 5**).

Results from Cycle 1 and 2 unit implementation with 3-6th grade students indicate that students realized significant learning gains associated with the eco-solutioning instructional materials. In particular, cohorts of late elementary students from three different low-resource urban school locations demonstrated significant learning gains on Content and Practices tasks in two consecutive research cycles.

Cycle 3: Summer Extension

While Cycles 1 and 2 allowed students to build toward 3D performance expectations, construct possible solutions to increase neighborhood biodiversity, and present their solutions to local stakeholders, the Cycle 1 and 2 programs did not allow the students to test their solutions' feasibility through implementation in local settings. Cycle 3 was a summer extension of the curricula that was open to students who had participated in Cycle 1 or Cycle 2. This summer extension extended the initial program and provided students with the opportunity to enact a subset of their local socio-scientific solutions. Also, Cycle 3 activities emphasized awareness of socio-scientific issues and STEM career opportunities.

Students' activities included interactions with local scientists and solution-implementation and activities focused on a local

urban farm during this week-long summer extension program. Students met various scientists and learned about the importance of biodiversity, habitats, and the roles, abundance, and richness of local populations of insects, pollinators, and other species. Students also visited an urban farm located in their neighborhood and learned about sustainably growing and harvesting various fruits and vegetables from urban farmers and volunteers. While the students visited the local urban farm, they discovered that their urban neighborhood is designated a food desert. Building from this information, students drew on the science and engineering learning gained during Cycles 1 and 2 to revise and implement their solutions to create a safe home for pollinators to thrive within the local urban farm. Additionally, they helped local farm volunteers harvest, clean, and transport fruits and vegetables to an outdoor farmers market as one means to address the scarcity of fresh fruits and vegetables readily available in their urban neighborhood.

The research team conducted informal student and teacher interviews after the summer extension. In these interviews, students and teachers discussed the importance of students' learning that realizes impacts beyond the classroom. Students and teachers expressed an appreciation of the opportunity to communicate their solutions to community leaders and realize them on the local urban farm. Open-ended responses surveys administered at the end of the program demonstrated that students enjoyed the program and saw themselves as scientists engaged in asking questions and implementing solutions while learning ways to increase their neighborhood's biodiversity. An example taken from **Figure 2** shows how one of the students responded to the questions "Did you like the program? Would you want to do it again? Why?" with "Yes because I can help the community." Student responses after the summer program also reflected their interest in STEM for their learning and careers. For example, when students were asked, Have you been working as a scientist during the eco-solutioning project? all students said yes. Also, students added, "We observed animals and then made solutions to figure out how to make our neighborhood more biodiverse," and "we researched bugs, animals, plants, and birds." It is essential to mention that for most of these students, the eco-solutioning and summer extension programs were the first time they were exposed to the idea of a scientist and the first time they met a scientist.
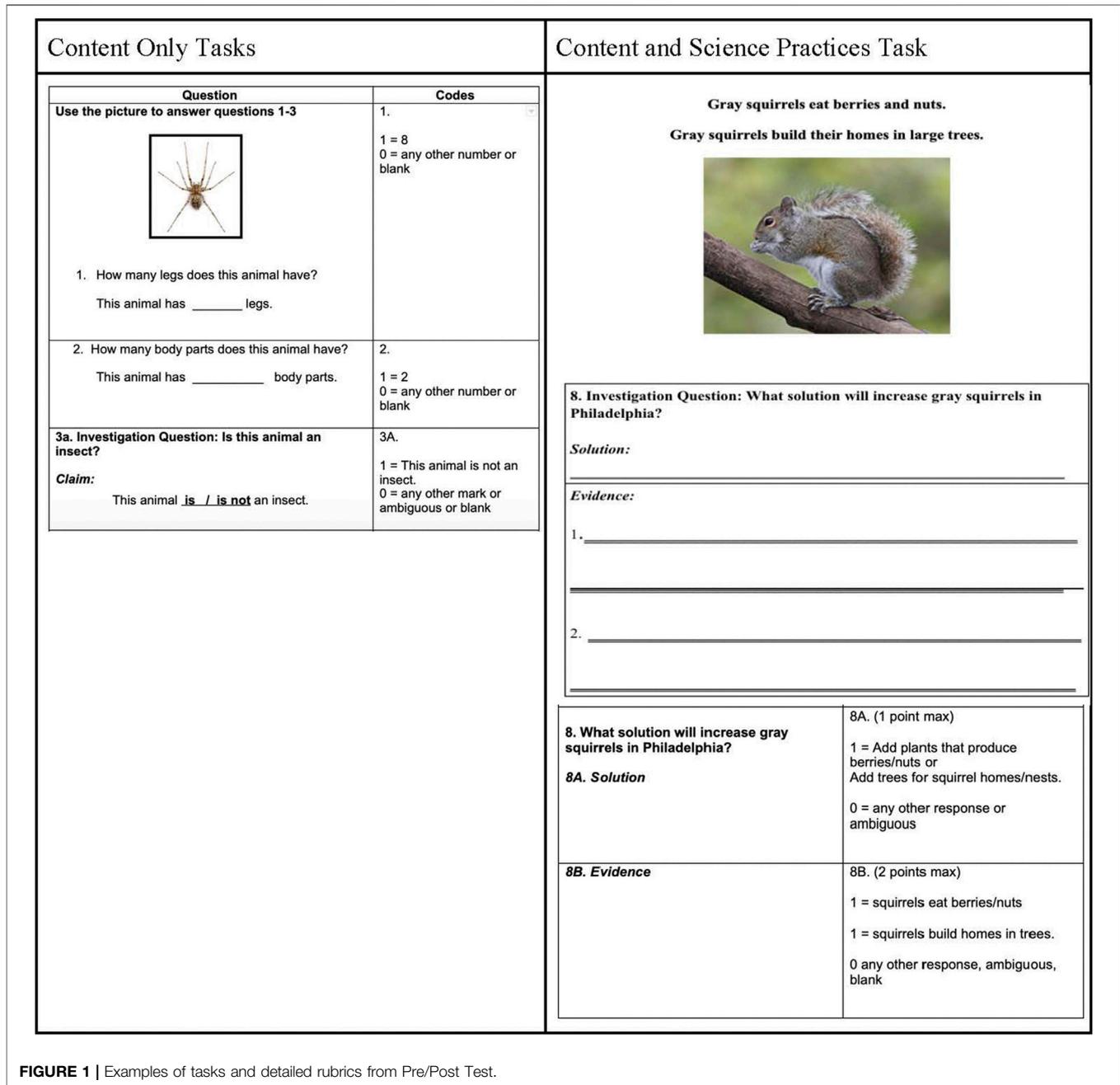
FIGURE 1 | Examples of tasks and detailed rubrics from Pre/Post Test.

DISCUSSION AND CONCLUSION

Even as we might share a desire to shift instructional materials to emphasize the application and extension of science and engineering learning to address local eco-solutions and students' contribution to socio-scientific issues, few researchers have implemented multiple DBR research cycles to study, articulate design principles, and evaluate learning associated with SSI instructional materials. This research work not only articulates the development process for the design of SSI-rich instructional materials but also provides two cycles to evaluate student learning. The work

builds from and extends essential components of the research literature that discuss the value of classroom-based learning that has application to local problems, how to promote scientific literacy and awareness, and how to direct classroom-based learning toward students' engagement in local environmental decision making (e.g., Tal and Kedmi, 2006; Lee, 2015; Yoon et al., 2019; Kim et al., 2020). Our work is different from others in that we are situating our research cycles within classrooms of young students within under-resourced, urban communities. In addition, we have introduced and provided empirical information on an approach to learning, eco-solutioning, that is designed to

TABLE 4 | Descriptive Statistics and *t*-test Results for Pre and Post Tests (Cycle 1)

Outcome	n	Pre-Test		Post-Test		df	t
		M	*SD*	*M*	*SD*		
All Test Items	36	8.75	3.102	11.42	3.660	35	−3.138**
Content Only Items	36	0.81	0.53	0.9	0.473	35	−1.884
Q 1	36	0.94	0.232	1.00	0.000	35	−1.435
Q 2	36	0.39	0.494	0.69	0.467	35	−2.743*
Q 4	36	0.22	0.422	0.08	0.280	35	1.536
Q 5A	36	0.92	0.770	1.17	0.845	35	−1.271
Q 5B	36	1.58	0.732	1.56	0.773	35	0.183
Content and Practices constructed response items	36	0.46	0.47	0.53	0.49	35	−3.823***
Q 3A	36	0.39	0.494	0.53	0.506	35	−1.221
Q 3B	36	0.97	0.167	0.07	0.167	35	0.000
Q 3C	36	0.47	0.560	0.67	0.478	35	−1.745
Q 6A	36	0.28	0.454	0.36	0.487	35	−0.770
Q 6B	36	0.42	0.500	0.44	0.504	35	−0.215
Q 6C	36	0.33	0.478	0.42	0.500	35	−0.723
Q 7A	36	0.58	0.500	0.67	0.478	35	−0.723
Q 7B	36	0.31	0.577	0.81	0.889	35	−2.646*
Q 8A	36	0.42	0.500	0.78	0.422	35	−2.996**
Q 8B	36	0.53	0.845	1.28	0.779	35	−4.170***

*p < 0.05, **p ≤ 0.01, ***p < 0.001.

TABLE 5 | Descriptive Statistics and T-Test Results for Pre and Post Tests (Cycle 2)

Outcome	n	Pre-Test		Post-Test		df	t
		M	*SD*	*M*	*SD*		
All Test Items	36	6.92	3.160	13.97	2.646	35	−11.409***
Content Only items	36	0.74	0.561	1.22	0.356	35	−6.786***
Q 1	36	0.97	0.167	1.00	0.000	35	−1.000
Q 2	36	0.33	0.478	0.64	0.487	35	−3.494**
Q 4A	36	0.83	0.811	1.78	0.485	35	−5.060***
Q 4B	36	1.22	0.929	1.92	0.368	35	−3.915***
Q 5	36	0.22	0.422	0.75	0.439	35	−4.842***
Content and Science Practices constructed response items	36	0.42	0.508	0.99	0.504	35	−10.861***
Q 3A	36	0.14	0.351	0.81	0.401	35	−7.483***
Q 3B	36	1.17	0.609	1.47	0.609	35	−2.231*
Q 6A	36	0.56	0.558	0.97	0.167	35	−4.511***
Q 6B	36	0.28	0.454	0.83	0.378	35	−6.614***
Q 7A	36	0.47	0.506	0.92	0.280	35	−5.292***
Q 7B	36	0.36	0.723	1.00	0.862	35	−3.764**
Q 8A	36	0.22	0.422	0.75	0.439	35	−6.254***
Q 8B	36	0.17	0.447	1.14	0.899	35	−6.010***

*p< 0.05, **p< 0.01, ***p< 0.001.

provide specific means of SSI-rich alternatives to traditional educational approaches so that students can see themselves as contributors to community problems as one way to challenge patterns of under-performance common in these schools. In particular, our program emphasized:

1 The design of engaging, higher-order pedagogical experiences centered on local phenomena,
2 The implementation and evaluation of an educational model for students' science learning where student learning has a direct connection to local environmental problems, and
3 The development and dissemination of an eco-solutioning unit and design principles for use by other curriculum designers, researchers, and classroom teachers.
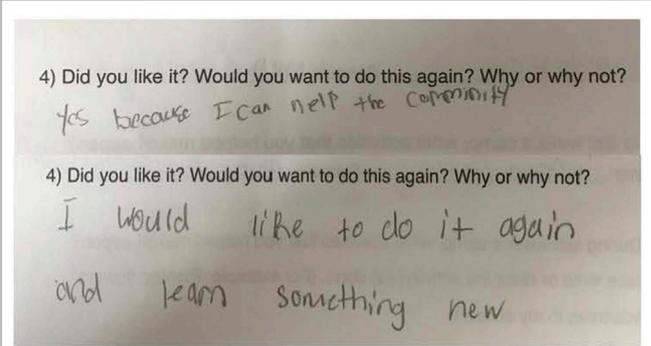

FIGURE 2 | Third-grade student comments after science eco-solutioning unit on local biodiversity.

By chronicling the steps in the construction process and documenting the kinds and quality of student learning demonstrated, the work contributes to a greater understanding of how teachers, curriculum developers, and other key stakeholders can work productively together toward essential SSI educational outcomes.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Drexel University Human Subjects

Committee and The Philadelphia Public Schools Research Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NS conducted the conceptual framework, designed the research studies, led the design of curriculum and assessment materials, and was the primary author. GIR conducted data analysis and was the secondary author.

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