sustainability

MDPI

Article

Addressing Sustainability in the High School Biology Classroom through Socioscientific Issues

Wendy M. Jackson , Maia K. Binding *, Kelly Grindstaff, Manisha Hariani and Bon W. Koo

Lawrence Hall of Science, University of California, Berkeley, CA 94720, USA
* Correspondence: mbinding@berkeley.edu

Abstract: The Science Education Program for Public Understanding System (SEPUP) at the Lawrence Hall of Science at the University of California, Berkeley, recently redesigned its high school biology program, Science and Global Issues, which is centered around sustainability-related socioscientific issues. The goal of this work was to fill a gap in standards-based, sustainability-themed high school biology curricula. Curriculum developers began the redesign process by asking the question: What does it look like for students to think about sustainability/sustainable development in the context of operationalized goals for sustainability (such as the UN Sustainable Development Goals) while also allowing them to be successful in meeting rigorous science standards (in this case, the US Next Generation Science Standards)? The process used by the developers is described, from conceptualizing the program and units to enacting the program in student-facing materials. The framework for presenting sustainability to students is described, as are the specific contexts that allow students to develop a deep understanding of scientific concepts while addressing current and important socioscientific issues. A selection of feedback from teachers and students gathered during the field test of the curriculum is shared, as is feedback from teachers who used the published program. The developers concluded that sustainability provides a powerful framework for allowing students to learn biological concepts and apply them to real-world issues.

Keywords: socioscientific; issues; sustainability; curriculum; biology; secondary education

Citation: Jackson, W.M.; Binding, M.K.; Grindstaff, K.; Hariani, M.; Koo, B.W. Addressing Sustainability in the High School Biology Classroom through Socioscientific Issues. *Sustainability* **2023**, *15*, 5766. https://doi.org/10.3390/su15075766

Academic Editors: Yael Shwartz, Dürdane Bayram-Jacobs and Maria Evagorou

Received: 16 February 2023
Revised: 16 March 2023
Accepted: 24 March 2023
Published: 26 March 2023

1. Introduction

The role of science in addressing significant, real-world problems related to sustainability has never been more important than it is today. Finding solutions to disease outbreaks, climate change, and growing world hunger, among other challenges, requires a firm understanding of the science underlying and driving these problems. While solutions must be multidimensional (incorporating economics, social science, ethics, etc.), the field of science has an important role to play in developing them. In an individual's education, early exposure to sustainability problems and potential solutions based on science provides an opportunity to develop a progressively sophisticated understanding and appreciation of both. The Framework for K–12 Science Education [1] served as the basis for the Next Generation Science Standards (NGSS) published in the United States in 2013. The authors of The Framework made it clear that students' education, from kindergarten to 12th grade science, should prepare them with "sufficient knowledge of science and engineering to engage in public discussions on related issues" and to become "careful consumers of scientific and technological information related to their everyday lives" (p. 1).

Since 1987, the Science Education for Public Understanding Program (SEPUP) at the Lawrence Hall of Science at the University of California, Berkeley, has produced science curricula and associated instructional materials for grades 6–12 that are centered around real-world socioscientific issues. With the publication of the NGSS, SEPUP redesigned its curricula to address the new science standards while maintaining a focus on its mission:

"to foster student agency and engagement in science by developing and supporting issue-oriented, evidence-driven, and hands-on curriculum that is relevant and accessible, and positions teachers for classroom implementation that is equitable and inclusive."

SEPUP's high school biology program, Science and Global Issues: Biology (SGI), is a year-long program that uses sustainability as the unifying theme, exploring it at multiple scales from global to local. Herein, we describe how SEPUP's goals for the program, the development and redesign process, and the components of the final program provide students with the knowledge and skills to better consider the role of science in addressing problems in sustainability.

2. Why Sustainability

Studies suggest that students are better able to learn the concepts within a discipline when they are presented in a context that provides meaning for those concepts, such as a social or cultural context [2–7]. When meaningfully integrated into science curriculum, socioscientific issues can provide this context and enhance students' abilities to make sense of complex scientific concepts and ideas [8–12]. One important aspect of any issue-oriented pedagogy is that scientific evidence is used to draw a conclusion or make a decision about an issue. The issue is examined from the perspective of multiple stakeholders, and the trade-offs associated with a decision or perspective are identified. Throughout an issue-oriented science course, students learn what it means to evaluate scientific evidence, how to base an argument on scientific evidence, and how science and society are intertwined and interact. Many of the issues that lend themselves to teaching students methods for evaluating evidence and making evidence-based decisions have no obvious "correct" answer. Instead, the use of complex issues allows students to examine the pros and cons of the issue and identify the trade-offs involved. Socioscientific issues fit this pedagogical role particularly well.

The use of sustainability as a framework in higher education has received growing attention in recent years [13–15]. Substantial progress has been made through incorporating sustainability into the curriculum [16,17]. Far less attention has been paid to using sustainability as a lens for high school or secondary education, even though this level has a much broader reach for this vital content in preparing an educated citizenry. Recent work has shown the value of providing professional learning experiences for teachers to incorporate suitable teaching approaches for implementing environmental citizenship in the classroom [18]. However, there has been little focus on using sustainability as a theme for a high school biology curriculum. Such an approach can bring together the pedagogical benefits described above while simultaneously helping students understand the interconnectedness of the complex systems that support life on Earth and the impact of human activity on these systems and the environment. A focus on sustainability can help students develop critical thinking, problem-solving, and decision-making skills that are essential for making informed decisions about how to live more sustainably and improve the health and well-being of people and communities around the world. It can help students develop a sense of civic responsibility and inspire them to take action to protect the environment and promote sustainability in their communities.

3. Original Curriculum Design

SGI was first published in 2011. This course was designed to be used in general high school biology courses. It was centered around a theme of sustainability, with specific sustainability-related socioscientific issues for each of the four main units. Since the initial publication, there have been two important developments that led to a significant redesign of the curriculum: the development of new science standards in the United States and growth in the field of sustainability. This provided SEPUP with the opportunity to reconsider how curricula can guide teachers to engage high school students to think deeply about issues of sustainability and sustainable development in concert with meeting the new science standards.

First, the Next Generation Science Standards (NGSS), a set of guidelines for science education in K–12 schools in the United States, were published in 2013 [19]. Developed in collaboration by a group of scientists, educators, and experts in science education, the NGSS aim to provide clear, consistent, and evidence-based standards for what students should know and be capable of in science at each grade level. The NGSS are designed to challenge students and to encourage them to think critically and apply their scientific knowledge in real-world contexts. They also emphasize the integration of science, technology, engineering, and mathematics (STEM). STEM education requires students to use a variety of skills and knowledge from different subjects to solve problems and understand complex systems. The NGSS focus on three dimensions of science learning: science and engineering practices, crosscutting concepts, and disciplinary core ideas.

In order to better incorporate the science and engineering practices in the Framework for K–12 Science Education and the NGSS, aspects of SEPUP's original instructional model for issue-oriented science (Figure 1) [20] were updated and expanded to incorporate these practices. The flexibility of the components in the instructional model allows for each practice to be incorporated at various points within the pedagogical cycle while maintaining the core principle of collecting and analyzing evidence to address a problem related to a socioscientific issue. For example, after being presented with a challenge, students may collect scientific evidence specifically to develop a system model to help them frame the problem. When analyzing the evidence, students may analyze and interpret data and engage in scientific argumentation around those interpretations. Additional examples are provided in later sections of this paper.

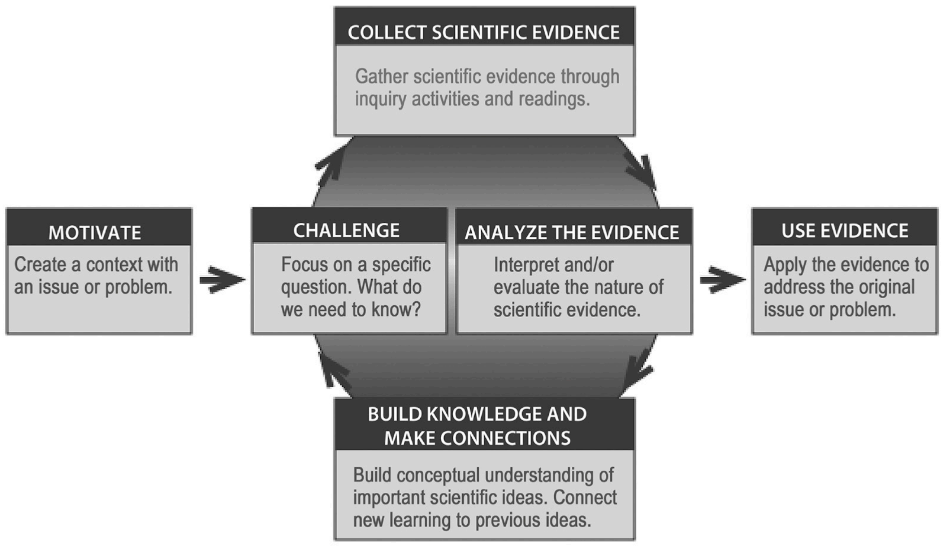
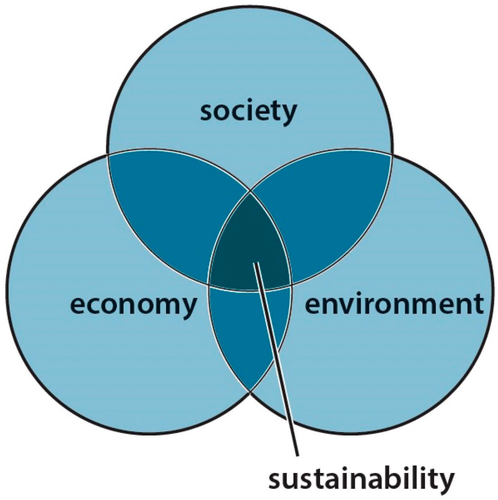


Figure 1. Issue-oriented instructional model.

Figure 1 presents a model for issue-oriented curriculum and instructions, starting with motivating students to investigate an issue and concluding with the use of evidence to address the problem. Students engage in an iterative process, gathering and analyzing evidence before they apply that evidence to an issue.

The second significant development since SGI was first published is the work that has been done to further define and understand problems in sustainability. The United Nations Sustainable Development Goals (SDGs) from 2015 [21] provided specific goals, targets, strategies, and indicators for promoting and achieving sustainability. Recently, the US National Academy of Sciences published a report on operationalizing sustainability, including in educational institutions, stating specifically: "Cities and school districts could initiate and support locally relevant K–12 learning on the SDGs, and . . . education leaders could engage the public to raise awareness of the SDGs." [22] (p. 2).

When SGI was first published, SEPUP defined sustainability using a broad-stroke approach: meeting the needs of the current generation without compromising the needs of future generations. The framework used in the curriculum as a tool for students to consider issues in sustainability is based on three pillars, shown in Figure 2 [23] as they are presented in the student book. This framework and definition are accessible for high school students, and while they do not necessarily encompass all of the nuances of sustainability, they provide a useful framework for students to begin to appreciate the main aspects of sustainability. Thus, since this framework is still valid and a useful entry-level framework for students, the decision was made to continue to use it in the revised curriculum and to expand upon it in specific units in context.



The Three Pillars of Sustainability: Economic, Social, and Environmental

- The **economic pillar** includes information on how the action affects the economy. Does the action create or take away jobs? What is the financial cost or benefit of implementing the action?
- The **social pillar** considers information about how the action affects social aspects of the community. Does it protect or improve human health? How does it affect the local community in terms of food availability or human interactions?
- The **environmental pillar** considers the effects on the environment. Does it protect or endanger critical ecosystems? Does it create or reduce pollution?

Figure 2. The original framework for sustainability presented to students in *Science and Global Issues*.

Figure 2 presents the three-pillar framework for sustainability from the student book of *Science and Global Issues*, in addition to student-friendly definitions of the three pillars: the economy, society, and the environment.

The UN's concomitant work in defining and operationalizing sustainability and the development of new science educational standards in the US provided SEPUP with an opportunity to combine the more sophisticated approach to sustainability with the rigorous goals of the NGSS. SEPUP's revision team challenged themselves to investigate and eventually address the question: What does it look like for students to think about sustainability/sustainable development in the context of operationalized goals for sustainability (such as the SDGs) while also allowing them to be successful in meeting the new science standards? It is important to note that while the particular standards addressed by SEPUP are in the NGSS, the process described below could be utilized for any learning standards in the life sciences.

4. The Redesign Process

4.1. Program Redesign

The initial version of SGI received very positive feedback and was used widely in classrooms across the United States. The redesign needed to build upon this prior work while embracing the new developments in the field of sustainability and addressing the new standards. The general steps involved in the redesign process are shown in Figure 3. The SEPUP curriculum developers reaffirmed the use of sustainability as the overarching course theme, based on the demonstrated value of using the three pillars of sustainability framework for enabling students to see the relevance of science to their lives and those of their family, friends, and community members.

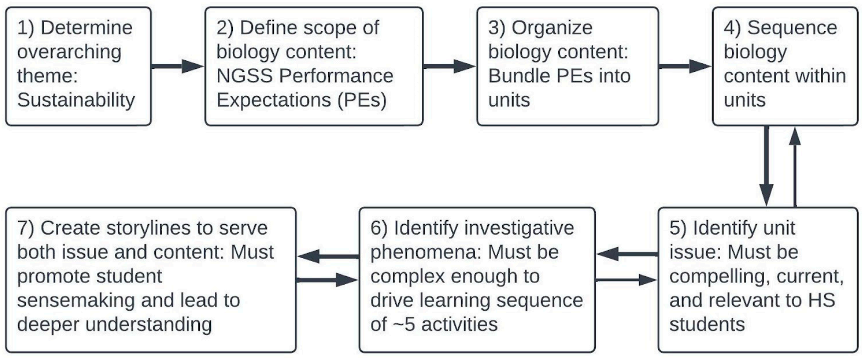


Figure 3. The *Science and Global Issues* Redesign Process.

The next step was to define the scope and configuration of the biology content that would be incorporated into the curriculum. Since the goal was to align with the NGSS, the course would include all 24 Performance Expectations (what students should know and be able to do at the end of instruction) in Life Science and an additional two Performance Expectations (PEs) in Engineering, Technology, and Applications of Science explicitly linked in the standards to Life Science. The curriculum developers organized the PEs into bundles to determine the course units. The units of Ecology, Cells, Genetics, and Evolution are organized around core ideas which "have a long history and solid foundation based on the research evidence established by many scientists working across multiple fields" [1] (p. 141). Most significantly, the development team decided to reconfigure the first unit as a short introductory sequence on sustainability to provide an overarching thematic framework for the entire program. This introductory sequence provided students with an engaging, low-stakes opportunity to become familiar with the SGI approach to sustainability and set them up for success in the four larger units.

Figure 3 presents the process used by SEPUP curriculum developers in redesigning *Science and Global Issues* to align with the Next Generation Science Standards. The process is linear in the first few steps but becomes iterative in the later steps.

The fourth step of sequencing the content within units is essential for determining an issue that will connect well through the unit. Many of the PEs had been written in such a way as to suggest a possible logical sequence for student learning. For example, the first PE in ecology required students to understand that all populations of organisms have the potential to grow exponentially. This understanding was essential for most of the remaining PEs in the ecology bundle. Thus, it made sense to address this PE first in the Ecology unit. In some cases, the ordering of the PEs was less obvious, and in a small number of cases, modifications were made to the order after the unit issue had been chosen; this is indicated by the narrow arrow pointing backwards to this step in Figure 3.

The fifth step in the process involved identifying the socioscientific issue to drive the learning for an entire unit of 15 to 17 activities. General criteria for selecting an issue included: (1) the issue requires students to develop an understanding of multiple PEs that are applied over the course of the entire unit; (2) the issue is current and has an audience or stakeholder community that cares about the findings and possible solutions; (3) the issue has the potential to build upon local, everyday, or family experiences throughout the unit, helping students to see the relevance of the issue to their everyday lives; (4) the issue should be compelling to students from a wide range of communities, including students from varying educational, economic, and cultural backgrounds; and (5) the issue can be made observable to students through one or more of the following: (a) a case(s), scenario, data set, video, photographs, or a simple data visualization (e.g., a graph). To ensure the chosen issue worked with the sustainability theme, the developers also considered if the issue connected well across the NGSS science content addressed in the unit, that it could be significantly informed by scientific evidence relevant to the unit, and that the issue did not have an easy solution. The medium-width arrow in the flowchart indicates that occasionally, unit issues continued to be refined as development progressed. The issues and corresponding overarching questions for the introductory sequence and content units are shown in Table 1.

Table 1. The issues of sustainability used in *Science and Global Issues*.

Unit Title	Unit Issue	Overarching Question
Sustainability: Changing Human Impact (introductory sequence)	The ways that humans interact with the environment can cause dramatic changes over time.	How do humans affect the environment over time?
Ecology: Living on Earth	People rely on natural resources, including fish, for many reasons, including food, yet many fisheries are no longer sustainable.	How can we use our knowledge about ecology to make informed decisions about managing fisheries to be more sustainable?
Cell Biology: Improving Global Health	Human health is increasingly subject to emerging global patterns, including extreme heat events, changes in the frequency of disease, and climate effects on the food supply.	What are the challenges to human health in a changing world?
Genetics: Feeding the World	People rely on genetically engineered crop plants to maintain a global food supply, but the use of this technology can impact sustainability.	How do genetically engineered crops affect the sustainability of food production?
Evolution: Managing Change	Human activity can have evolutionary consequences for both biodiversity and ourselves.	How do human activities affect the evolution of other species, and what are the consequences for both biodiversity and for ourselves?

Table 1 presents the titles of the five units in Science and Global Issues, the unit issues, and the overarching questions that drive the storyline and learning sequences throughout the unit.

The sixth step entailed identifying investigative phenomena. Penuel and Bell argued that "Instructional sequences are more coherent when students investigate compelling natural phenomena (in science) or work on meaningful design problems (in engineering) by engaging in the science and engineering practices" [24]. This aligns well with SEPUP's instructional model. As such, the developers divided each unit into learning sequences that averaged approximately five activities, each driven by an investigative phenomenon. In SGI, the requirements for an investigative phenomenon are as follows: (1) it can be made observable to students through a case, scenario, data set, video, photographs, a simple data visualization (e.g., graph) or other appropriate means; (2) it involves something that is puzzling or instigates student questioning or wonderment; (3) it drives a sequence of learning and may cover one or more PEs because it is too complex to be explained in one activity; (4) it is connected and/or relevant to the sustainability challenge presented by the unit issue in a way that is obvious to students and allows them to engage in sensemaking as they build conceptual understanding or gather evidence that they will use to develop their solution or recommendation in response to the unit issue.

The final step in the redesign process was to develop a storyline that provides a coherent flow to the unit, moving from one learning sequence to the next. The SEPUP storyline is built around the science and engineering concepts needed to explain phenomena and solve problems related to the sustainability issue under investigation. By answering the driving question for each investigative phenomenon, students move through the storyline and deepen their understanding of how various science and engineering concepts and ideas are woven together across the entire unit and how they connect to the sustainability issue. As students work to answer the driving question posed in each learning sequence, they engage in active learning and sensemaking that integrate the three dimensions of the NGSS (disciplinary core ideas, science and engineering practices, and crosscutting concepts), gathering evidence from a variety of sources and investigations as they build an increasingly sophisticated explanation for how or why something happens in the natural world. Ultimately, students apply what they have learned to make a decision about or propose a solution to the sustainability challenge presented by the unit issue. As shown in Figure 3, this step is highly iterative and is modified as needed until the redesign is completed.

An additional component of the process not captured in Figure 3 was the goal of showing how some sustainability issues cross unit and content boundaries. To accomplish this goal, developers sometimes used specific contexts for addressing issues that would be revisited in subsequent units. This approach allows students to develop an appreciation for the complexity of problems in sustainability and the need to incorporate scientific knowledge from multiple disciplines when attempting to develop solutions. Table 2 shows the specific contexts for addressing issues through SGI. For example, the sustainability of fisheries is used as the primary context throughout the Ecology unit. Students explore what may cause a fishery's population to decline in numbers due to both natural and human-caused changes in the environment. They consider different approaches to promoting the sustainability of fisheries based on ecological, social, and economic perspectives. This fishery context is revisited again at the end of the Evolution unit, this time in the context of unintended evolutionary changes: human impact on the environment is causing fish species to evolve to a smaller body size, which also impacts the sustainability of the fishery. In another example, the Cells unit explores how climate change affects human health, specifically how global warming increases the prevalence of infectious diseases. The Evolution unit revisits this issue from the perspective of how global warming is affecting the evolution of the pathogens that cause these diseases.

Table 2. Contexts for addressing sustainability issues in *Science and Global Issues* that are aligned to the UN SDGs.

UN Sustainable Development Goals	Ecology Unit	Cells Unit	Genetics Unit	Evolution Unit
2: Zero Hunger	Sustainable fisheries	Climate effects on food supply, such as crop production and nutritional value of food crops	Crop production	Sustainable fisheries
	Aquaculture		Genetically modified organisms	
3: Good Health and Well-being		Climate effects on health, such as extreme heat and infections and non-infectious diseases	Modifying the nutritional content of genetically modified crops	Evolution of infections diseases
				Highlighting tuberculosis
6: Clean Water and Sanitation		Water stress and Infectious water-borne diseases		
12: Responsible Consumption and Production	Sustainable fisheries	Sustainable food production and consumption	Genetically modified organisms	
	Aquaculture		Pesticide and herbicide use	
13: Climate Action	Natural vs. human-caused CO_2 emissions	Impacts of the changing climate on human health and food production		Warming climate and changing evolutionary selection pressures
14: Life Below Water	Threats to coral reefs			Changing selection pressure on Chinook salmon
	Southern resident Orcas and threats to their ecosystem; threats to the Great Lakes ecosystem			
15: Life on Land	Disruptions in the Yellowstone ecosystem		Effects of genetically modified organisms on biodiversity	

Table 2 also shows how these contexts align with UN Sustainable Development Goals. Some of the contexts are more substantially aligned than others. For example, the Cells unit focuses on how climate change is affecting human health, with numerous opportunities for students to examine these connections. Thus, the unit is well aligned with SDG Goal 3: Good Health and Well-being. The unit identifies the cause of some infectious diseases as water-borne pathogens, which become a problem when people do not have access to clean drinking water. The unit does not delve into this specific sustainability issue in depth, so it is less deeply aligned with SDG Goal 6: Clean Water and Sanitation.

Table 2 presents the UN SDGs addressed in *Science and Global Issues*, and the contexts for addressing them in the four NGSS content units; specific contexts were sometimes used in more than one unit.

4.2. Unit Specific Example (Genetics)

Thus far, we have described the general process of developing a curriculum around sustainability-oriented socioscientific issues in order to provide a big picture view of how this approach might be embodied. However, in order to conceptualize in more detail how this might look in a classroom day-to-day, it is important to have a clear picture of a curricular unit from beginning to end. It is fairly easy to make meaningful connections between sustainability and some common topics covered in a traditional high school biology course, such as species loss due to habitat destruction. Other areas are less straightforward. What connections are there between mitosis and sustainability? How can one relate an understanding of sustainability to that of enzyme structure and function? Issue-oriented science allows students to approach these less straightforward areas and make more nuanced, subtle connections between sustainability and biology. It allows students to see firsthand the interconnectedness of sustainability and all aspects of biological science through examples from real-world contexts and stories that they can engage with. To make these seemingly abstract topics relevant and compelling, the Genetics unit examines the issue that although people rely on genetically engineered crops to maintain a global food supply, the use of this technology can impact sustainability. Specifically, students investigate how genetically engineered crops affect the sustainability of food production.

Students begin the unit with a basic introduction to genetic modification and examine data that show a significant increase in herbicide-resistant weed species in the United States since the introduction of genetically modified, herbicide-resistant soy plants in the mid-1990s. Students are then presented with a fictitious scenario that mirrors real-world situations in which a farmer has discovered "superweeds" in their fields. These superweeds are a common weed species that have acquired a genetically modified trait, such as herbicide resistance, that makes them more difficult to control. Students follow this scenario through three learning sequences which introduce genetics content alongside the problem faced by the farmer. As students deepen their understanding of the core content, they are simultaneously gathering evidence that will help them to evaluate potential solutions to the issue. Within individual activities, the developers consistently and explicitly provide opportunities for students to think through the connections between the core scientific concepts and the unit-specific issue related to sustainability. These connections are embedded throughout the activity procedures and questions that help them build understanding. The unit issue, which in this instance is genetic modification and sustainable food production, is always at the forefront of student learning. This intentionality provides a storyline for students to follow, and allows students to immediately see the applicability of the core genetics content in the "real" world. Coupling the issue with sustainability further serves to underscore the importance of understanding and applying the scientific content to global sustainability challenges, ideally leading to increased student engagement and scientific literacy. The context and examples for these development guidelines are detailed for the Genetics unit below.

The first learning sequence of six activities focuses on the investigative phenomenon of how superweeds were initially introduced to the farmer's field. Students learn what superweeds are and how genetically modified organisms are created, and they begin to understand the impact these plants can have on crop production. As students learn about mitosis and asexual reproduction, they make sense of how an organism with a genetic modification would carry that modification in all (or nearly all) cells of its body. Learning about basic genetic crosses for specific traits helps students figure out how a genetic modification might pass from one generation to the next. At the end of the learning sequence, students should have a better understanding of the potential challenge of superweeds in terms of the sustainability of the global food supply and at least an initial understanding of some of the ways that superweeds might have appeared in this farmer's fields.

The second learning sequence of the unit centers on the investigative phenomenon of superweeds appearing in different locations that are far apart from each another. Over the course of seven activities, students learn about protein synthesis, cell differentiation, gene expression, the molecular mechanism of enzymes, d how mutations can affect enzyme function (particularly how this can be harnessed to create herbicide resistance), meiosis, and sexual reproduction. They also learn how individual genes or gene sequences can be identified in an organism. Many herbicides target specific enzymes or sets of enzymes that plants require to grow. The genetic modification of crop plants for herbicide resistance often relies on using a mutation in a gene for an enzyme that prevents it from binding with an herbicide while remaining functional. Students can contextualize their understanding of protein synthesis (production of enzymes), enzyme function, genetic mutation, gene expression, meiosis, and sexual reproduction within the superweed scenario. At the conclusion of each activity, students work through questions that are designed to help them make connections between the core science content and how it relates to both the specific superweed scenario and the overall sustainability of global crop production. For example, at the conclusion of the activity on meiosis, students discuss the following:

> Farmer Green is still not sure if the superweeds in his fields are herbicide resistant because of a mutation or if they are the result of transgene migration from herbicide resistant corn, like the corn he grows, to a weedy relative. What question does Farmer Green need answered to determine which scenario occurred? Use what you know about DNA and genes leading to the formation of proteins to explain how the answer to your question would help Farmer Green figure out which scenario occurred. Hint: Think about what genes the superweeds would have in each scenario and if the genes would produce the modified EPSPS enzyme or a different type of protein.

This discussion leads to subsequent activities in which students learn more in-depth information about genetics (e.g., diploid versus haploid cells) and then about how gel electrophoresis can be used to compare genetic sequences and identify specific genes in DNA samples, all in the context of Farmer Green comparing the DNA from his superweeds to that from neighboring farms. This exploration helps students answer the question of whether the superweeds are the result of a spontaneous mutation or transgene migration.

The third and final learning sequence of the four activities brings together everything the students have been learning to examine the benefits and trade-offs of potential solutions for maintaining sustainable global and/or local food production. They focus on answering the driving question: Are genetically modified organisms the solution for sustainable global food production? The content in this learning sequence also brings together other areas students have studied in previous units (ecology and cell biology) and foreshadows topics in the final unit, which that follows genetics (evolution, especially natural selection). Students begin the learning sequence with an investigation into how superweeds can affect local biodiversity by analyzing and interpreting data on patterns of weed and insect populations prior to and after reports of superweeds being present in fields. The students' analysis of the data and what it means for local biodiversity requires them to incorporate what they learned about biodiversity in the ecology unit and begin to weigh what they have learned about genetic modification and the potential trade-offs involved in its use. Students then apply this understanding in the following activity, which involves reading about the benefits and trade-offs of genetic modification in several case studies, all involving food production (golden rice, disease-resistant rice, salmon modified for faster growth, and virus-resistant papaya). This provides students with a broader conception of the potential benefits and trade-offs of genetic modification as it relates to the sustainability of global food production.

The third activity of the sequence has students again apply their understanding of genetics, genetic modification, and relevant the benefits and trade-offs in an expansion of the Farmer Green scenario in which students are asked to analyze data about the sustainability of the agriculture of the entire area. Based on the patterns presented in the data, students make an evidence-informed recommendation as to whether the area should grow genetically modified soy. This activity supports students in applying their understanding of genetics and genetic modification to analyzing a specific scenario and potential solution in the context of sustainable food production. As students reflect on their analysis, the activity concludes with students answering the question *What information should policymakers evaluate when making decisions about genetically modified organisms?* Thus, they return to connecting what they are currently learning to real-world contexts. The students conclude the unit with an evaluation of four alternative farming proposals that address superweeds. Students focus on how the outcome of each proposal may affect the sustainability of agriculture in the area. Supported by evidence, the students construct a recommendation for the proposal of their choice, present it to the class, and independently write up their recommendation. As part of their recommendation, they answer the questions shown in Table 3. An example of one student's written answers to questions 1 and 2, collected during the field testing of the course, are shown as well.

Table 3. Questions and sample student responses from the Genetics unit.

Question 1: Describe Three Indicators You Would Recommend Using to Monitor the Success of the Proposal over the Next 10 Years if Your Recommendation . . . Were Implemented. These Indicators Can be any Observations That Will Help Determine if the Recommendation Is Successful.
Sample Student Response: I believe that diversifying crops would best support sustainable food production. First of all, monoculture is risky for crops. Due to growing the same crop in the same place, one disease or breakout of superweeds for example can wipe out all of the crops, allowing for none to grow. Therefore, getting rid of monoculture can increase profit due to making sure the farmers' crops are separated and diverse, meaning if one crop suffers, there will still be other crops in order to make a profit and produce food. Also, allowing for at least 25% of crops to be non-genetically modified can decrease the chances of transgene migration and other risks to the surrounding environment and animals. Furthermore, not all consumers trust GMOs in their food, meaning by producing crops that are also not genetically modified, farmers will make a profit due to having products that many people can eat. Finally, this proposal supports biodiversity allowing different types of crops to be produced to support many consumers, including animals and allow for a higher profit. One tradeoff of this decision is that there may be a risk to getting rid of monoculture. These farmers are not used to diversifying crops meaning the switch may be confusing and a lot more work to put into place due to never doing it before. Also, monoculture allowed for a maximized profit meaning switching to diversifying crops may decrease profit because of the possibility of it not being as effective profit wise. Genetically modified plants usually produce more profit as well meaning having at least 25% of crops to be non-genetically modified may decrease profit due to not earning as much.
Question 2: What social, economic, and environmental elements of sustainability were involved in your considerations about which proposal to choose?
Sample Student Response: The first indicator to make sure this proposal is successful is to monitor the farmers' overall profit to make sure it is increasing and is sustainable for them and their families. Another indicator is keeping track of how many crops die from disease or other factors compared to when they used monoculture. If the amount of crops that die is less than when they used monoculture, this is an indication that this proposal is a success due to allowing for more crops to be produced. Finally, looking at crop production will determine if this proposal is successful. If crop production increased compared to when the farmers used monoculture, this means that this proposal works and is benefitting society due to there being more food available.

Table 3 presents questions used with students in the *Science and Global Issues* Genetics unit and actual responses provided by a student during the field test of the program.

This student's responses clearly show that they were able to bring together their understanding of the core scientific content, the unit issue, and the concept of sustainability. Teachers can then use the concluding class discussion to delve more deeply into the students' explanation of how problems with monoculture relate to genetics and genetic diversity or why there would be a reduction in transgene migration, both of which are referred to in their written response. The field test teachers commented on the students' written and oral responses in their feedback, noting that students were consistently engaged and made connections between the traditional science content, sustainability, and the specific unit issue. One teacher summarized this by saying: "I think the activities nicely and clearly lead to the students developing understanding and skills that allow them to make evidence-based decisions at the end." Furthermore, the continuous storyline, which focused on the socioscientific issue of superweeds and their effects on the sustainability production, provided further motivation for students to make these connections. This was captured in another teacher's comment: "The investigative phenomenon provides a strong reason for students to understand why an understanding of genetics is important and a different perspective other than just what traits you inherit from your parents."

5. Student and Teacher Feedback

The first version of the redesigned program was field-tested with teachers and students from a variety of locations throughout the US. It should be noted that the field test took place in 2020–2021; due to the immense challenges of field testing during the COVID-19 pandemic, the amount of feedback received was less than what was received during field tests of other curricula in the past. Further, due to COVID-19 protocols in most schools, many of the activities were taught in an online environment. In total, nine teachers participated from across the United States, including the East Coast, West Coast, and Midwest. Their schools had student populations representative of diverse racial, ethnic, and socioeconomic backgrounds. On average, student work samples were received from approximately five students per teacher. Despite the challenges, the field test provided sufficient feedback to determine which of the approaches, strategies, and activities were working well, and which needed revising. Note that the feedback is presented here to illustrate how it was used to inform the revisions of the curriculum. The feedback was not part of a research study or used to evaluate the effectiveness of the *Science and Global Issues* curriculum.

Early feedback informed developers that using the three-pillar framework for sustainability remained helpful and insightful for students. Asking students to use this framework in specific sustainability contexts was largely successful. For example, in the Ecology unit, with the overarching issue of sustainable fisheries, students used the three-pillar framework to evaluate the role of aquaculture, specifically open-net salmon pens, as one possible sustainable solution. Below are some examples of student responses to the prompt: "List one indicator for each of the three pillars that could be used to monitor the impacts of your open net farm." Sample student responses are shown below:

(a) Environmental: "If you notice a large drop in wild salmon population, you could assume the farmed salmon are overcrowded and are polluting the water. This would be a negative environmental impact."
(b) Economic: "If my business is making money, while it sounds selfish when my business is doing good I can pay my workers more which means they will spend more which is better for the economy."
(c) Social: "If people are still recreationally fishing for wild salmon and also eating them."

Some feedback suggested ways to deepen student sensemaking with respect to sustainability in the context of the specific unit issue. For example, in the Ecology unit, students use computer simulations to investigate population growth patterns for a variety of organisms, including birds and trees. Teachers commented that the connection to sustainable fisheries was not always apparent to students. In response, additional questions explicitly tied to this issue were embedded throughout the student book. Other feedback suggested that components that did not help with student sensemaking and were sometimes confusing. For example, in response to the specific NGSS requirement to address the crosscutting concept of scale, students were initially asked to draw schematic diagrams to compare ecosystems at different scales. This step did not help students make sense of ecosystems or deepen their understanding of sustainability; therefore, it was removed. Still, other feedback was used to ensure that successful components and features were retained.

One tension we anticipated, based on feedback from teachers using the original SGI in classrooms, was how to design a program focusing on global sustainability issues while at the same time providing opportunities for local connections. It can sometimes be challenging for students to connect with issues that have little to do with their own lives at first glance and occur in other places, often far away. Ideally, the issues they study should be locally relevant and personally compelling [25]. To promote student engagement in the issue of sustainable fisheries, especially for students living in areas of the United States where access to fresh, commercial seafood is limited, we emphasized the role of recreational fishing as a hobby or social event at the outset. For example, when modeling for teachers in the field test how to launch the Ecology unit, we asked them the same questions we suggested they ask their students. First, we asked the teachers if they ate much seafood. Almost none of them did so, and little discussion was generated. Next, we asked them if they ever went fishing. In this case, nearly every teacher had a personal connection and story to tell. By providing a connection to the issue from the perspective of the social pillar, the sustainability of fisheries was better positioned to become relevant and compelling. As one teacher in an area where recreational fishing is common stated: "The questions made the students think and be able to bring their own life experiences into the classroom. The students enjoyed sharing their own fishing experiences with the class." Another teacher from an area where commercial fishing is a large part of the economy shared: "Even though we live in New England, it was interesting to me to see how the students did not understand how many people depend on seafood for a food source. It led to a great discussion about where people are most densely populated in countries, the lobster fishery and changes and a better overall understanding." Throughout SGI, we enhanced opportunities such as this for teachers and students to make local connections in addition to providing a global perspective. As one teacher offered: "[Students] really start to talk about how not everyone has the same accessibility to resources and start to ask why. I don't think before they see this until they really think beyond where they live too much and I like seeing them think about these ideas."

6. Lessons Learned

Feedback from teachers on the published third edition of *Science and Global Issues* has supported our conclusion that sustainability can be a powerful framework for students to make sense of complex biological scientific concepts as long as the context is relevant and compelling to them. Teachers implementing SGI for the first time offered several novel perspectives. They found the introductory sequence that launches the three-pillar framework for sustainability to be very effective in setting up the students for success in the four units with the NGSS content. Providing contexts from a global perspective but with opportunities to make local connections caught the students' attention from the outset—they quickly saw the relevance of the learning to their own lives and began to widen their understanding of the issues faced by people in other parts of the world.

Throughout the program, these teachers felt that by situating the science in the context of real-world sustainability issues for which the "answers" or "correct responses" are not obvious, all students were empowered to contribute—not just the students who traditionally did well and scored highly in science classes. Asking questions about, for example, how climate change might affect the nutritional value of food is accessible to all students. Intentionally crafted investigations, laboratories, case studies, and other hands-on experiences relevant to the issue provide common experiences that all students can use to inform their potential solutions to the problem. Teachers specifically mentioned that students who typically felt hesitant to share their ideas with other students became just as willing to speak up and argue in support of their position as the other students. The coherent storylines, which intertwined an ever-deepening understanding of scientific concepts with a developing appreciation for the sustainability issue, provided a leveling ground for all students to be successful.

Teachers very familiar with previous editions of SGI found the increased rigor demanded by the three dimensions and the PEs of the NGSS well-instantiated in the third edition. For example, the Framework emphasizes the role of mathematics and computational thinking as one of the eight science and engineering practices. The NGSS included this particular practice in three of the seven PEs addressed in the SGI Ecology unit. In doing so, students gained an appreciation for the ways in which ecologists study the real world and another tool to inform their potential solutions for promoting sustainable fisheries. In their feedback, teachers also highlighted that an additional benefit of incorporating this practice so explicitly was that this approach better prepared students for the high-stakes standardized state testing that often emphasizes it. While the curriculum was developed without regard to such testing, the development team was pleased that these teachers did not feel the need to deviate from the curriculum to incorporate test preparation into their classrooms because the authentic examples embedded throughout SGI were deemed sufficiently numerous and rigorous.

7. Going Forward

Using the US Sustainable Development Goals was a productive framework for re-designing Science and Global Issues. This conclusion aligns with the results from other work at both the secondary and post-secondary levels [26]. The value of this framework is that it can be used regardless of location; it works equally well in Barbados [17], the United Kingdom [27], or West Africa [28]. Further, the framework is applicable regardless of the specific grade level or content area; courses on chemistry, economics, and history can all be organized using the SDGs as a frame of reference.

As a biology program beholden to specific standards, in this case the NGSS, it was beyond the scope of this curriculum to include other fields of study. However, SEPUP acknowledges that solving problems in sustainability requires considering an issue from multiple perspectives. Different stakeholders may have very different objectives when addressing a particular problem and considering what constitutes a solution, As Jackson et al. (in preparation) states: “The array of issues and processes lumped together under the sustainability heading exposes an unfortunate fact: there is no single logic of sustainability, but many disparate logics” [29]. Failure for each stakeholder to define their objectives in more specific terms and to communicate those objectives to others can make finding solutions acceptable to all nearly impossible. Thus, building partnerships across stakeholder communities is essential. One of the UN Sustainable Development Goals, Goal 17, is to “Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development.” While SGI does not address this goal explicitly, the need to consider partnerships is incorporated throughout the program, and some examples are highlighted. For example, in the Evolution unit, there is a series of activities that examines the evolution of disease-causing pathogens and the role that human activity has on this process. While at first students may see disease outbreaks and pandemics as medical and public health issues, there is growing evidence that human impact on the environment, including deforestation, plays a role in the emergence and re-emergence of diseases. As we tell the students: “A growing number of researchers are advocating that ecologists and evolutionary biologists join infectious-disease researchers and public health officials in addressing emerging diseases. This group believes that pandemics are not just a health issue—they are an ecological and evolutionary issue” [23] (p. D-86).

Additionally, the question of how stakeholders work together to address issues of sustainability was an important aspect of the redesign of the Cells unit. The final activity in the original, field test version of the Cells unit utilized a previous approach in which students decided which of four world health initiatives to fund. The four proposals were in competition for limited funds and did not incorporate the need for local input. Feedback from a professional working in international public health highlighted that this approach did not reflect the most current thinking in the field. An integrated approach in which all possible stakeholders work together to develop solutions is more reflective of the current state of public health. For example, the Centers for Disease Control has a One Health initiative that is “a collaborative, multisectoral, and transdisciplinary approach—working at the local, regional, national, and global levels—with the goal of achieving optimal health outcomes recognizing the interconnection between people, animals, plants, and their shared environment” [30]. Based on expert input and additional research, the culminating Cells activity was rewritten. Now, students first read an example of how an integrated approach was employed in a case of yellow fever amongst howler monkeys in Bolivia. The importance of understanding the interaction of humans, animals, and the environment and the collaboration amongst people in different fields was essential to preventing the likely transmission of the disease to the local human population. Students applied their understanding of the unit concepts to first identifying how an emerging global pattern could be affecting health in their local community. They then brainstormed and role-played stakeholders who worked together to develop, evaluate, and refine a solution to their local health issue. In this way, updated thinking on sustainability, which emphasizes interlinked objectives and human collaboration, came to life in the classroom.

Moving forward, we believe that sustainability could be the focus of curricula and programs that cross traditional disciplinary boundaries. A transdisciplinary high school program in which teachers of science, math, engineering, and social science (including economics, geography, history, and more) all work together to examine issues in sustainability from different perspectives could be a way to better prepare and equip the next generation to address and solve these issues. Such an approach in the United States would require significant structural changes to the education system and a good deal of political will to enact them. However, given the ever-growing need for such a populace, and given our experience with our Science and Global Issues program, we consider that it is worth the effort.

Author Contributions: Conceptualization, W.M.J. and M.K.B.; writing—original draft preparation, W.M.J. and M.K.B.; writing—review and editing, K.G., M.H. and B.W.K.; visualization, W.M.J. and M.K.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of the University of California, Berkeley (protocol code 2019-07-12373 and 11/14/2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data are not publicly available due to privacy restrictions.

Acknowledgments: The authors would like to thank Janet Bellantoni for helpful comments on the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. National Research Council. *A Framework for Science Education: Practices, Core Ideas, and Crosscutting Concepts*; The National Academies Press: Washington, DC, USA, 2012.
2. National Research Council. *How People Learn: Brain, Mind, Experience, and School*; National Academies Press: Washington, DC, USA, 2000.
3. Newmann, F.; Marks, H.; Gamoran, A. Authentic pedagogy and student performance. *Am. J. Educ.* **1996**, *104*, 280–312. [CrossRef]
4. Pokerznik, M.A. Usefulness of nature of science, socioscientific issues and argumentation in achieving scientific literacy. *Sci. Educ. J.* **2011**, *40*, 1.
5. Sadler, T.D. Situating socio-scientific issues in classrooms as a means of achieving goals of science education. In *Socio-Scientific Issues in the Classroom: Teaching, Learning and Research*; Springer: Dordrecht, The Netherlands, 2011; pp. 1–9.
6. Sadler, T.D.; Dawson, V. Socio-scientific issues in science education: Contexts for the promotion of key learning outcomes. In *Second International Handbook of Science Education*; Springer: Dordrecht, The Netherlands, 2012; pp. 799–809.
7. Zeidler, D.L.; Nichols, B.H. Socioscientific issues: Theory and practice. *J. Elem. Sci. Educ.* **2009**, *21*, 49–58. [CrossRef]
8. Church, W.; Skelton, L. Sustainability education in K-12 classrooms. *J. Sustain. Educ.* **2010**, *1*, 1–13.
9. DeBarger, A.H.; Penuel, W.R.; Moorthy, S.; Beauvineau, Y.; Kennedy, C.A.; Boscardin, C.K. Investigating purposeful science curriculum adaptation as a strategy to improve teaching and learning. *Sci. Teach. Educ.* **2017**, *10*, 66–98. [CrossRef]
10. Evagorou, M.; Dillon, J. Introduction: Socio-scientific issues as promoting responsible citizenship and the relevance of science. In *Science Teacher Education for Responsible Citizenship: Towards a Pedagogy for Relevance through Socioscientific Issues*; Springer: New York, NY, USA, 2020; pp. 1–11.
11. STEM Teaching Tools. Available online: https://stemteachingtools.org/brief/47 (accessed on 30 January 2023).
12. Odden, T.O.B.; Russ, R.S. Defining sensemaking: Bringing clarity to a fragmented theoretical construct. *Sci. Educ.* **2019**, *103*, 187–205. [CrossRef]
13. Wals, A.E.J.; Benavot, A. Can we meet the sustainability challenges? The role of education and lifelong learning. *Eur. J. Educ.* **2017**, *52*, 404–413. [CrossRef]
14. Chankseliani, M.; McCowan, T. Higher education and the Sustainable Development Goals. *High. Educ.* **2021**, *81*, 1–8. [CrossRef] [PubMed]

15. Hsu, Y.-S.; Tytler, T.; White, P.J. (Eds.) *Innovative Approaches to Socioscientific Issues and Sustainability Education*; Springer Nature: Berlin/Heidelberg, Germany, 2022.
16. Sengupta, E.; Blessinger, P.; Yamin, T.S. (Eds.) *Integrating Sustainable Development into the Curriculum*; Emerald Publishing Ltd.: Bingley, UK, 2020.
17. Griffith, A.; Moore, W. A comparative analysis of approaches to integrating sustainability into the curriculum at a university in a small island developing state in the Caribbean. In *Integrating Sustainable Development into the Curriculum*; Sengupta, E., Blessinger, P., Yamin, T.S., Eds.; Emerald Publishing Ltd.: Bingley, UK, 2020; pp. 41–56.
18. van Harskamp, M.; Knippels, M.-C.P.J.; van Joolingen, W.R. Sustainability issues in lower secondary science education: A socioscientific, inquiry-based approach. In *Innovative Approaches to Socioscientific Issues and Sustainability Education*; Hus, Y.-S., Tytler, T., White, P.J., Eds.; Springer Nature: Berlin/Heidelberg, Germany, 2022; pp. 181–198.
19. NGSS Lead States. *Next Generation Science Standards: For States, by States*; The National Academies Press: Washington, DC, USA, 2013.
20. SEPUP. *Issues and Physical Science*; Teacher Resources; The Lawrence Hall of Science, University of California: Berkeley, CA, USA, 2012.
21. United Nations Sustainable Development Goals. Available online: https://sdgs.un.org/goals (accessed on 25 January 2023).
22. National Academies of Sciences, Engineering, and Medicine. *Operationalizing Sustainable Development to Benefit People and the Planet*; The National Academies Press: Washington, DC, USA, 2022.
23. SEPUP. Science and Global Issues: Biology. In *Third Edition Redesigned for the NGSS (Student Edition)*; The Lawrence Hall of Science, University of California: Berkeley, CA, USA, 2023; Available online: https://sepuplhs.org/high/sgi-third-edition/index.html (accessed on 2 February 2023).
24. STEM Teaching Tools: Qualities of a Good Anchor Phenomenon for a Coherent Sequence of Science Lessons. Available online: https://stemteachingtools.org/brief/28 (accessed on 30 January 2023).
25. STEM Teaching Tools: How to Launch STEM Investigations That Build on Student and Community Interests and Expertise. Available online: https://stemteachingtools.org/brief/31 (accessed on 30 January 2023).
26. Avelar, A.B.A.; Silva-Oliveira, K.D.D.; da Silva Pereira, R. Education for advancing the implementation of the Sustainable Development Goals: A systematic approach. *Int. J. Manag. Educ.* **2019**, *17*, 3. [CrossRef]
27. Amos, R.; Levinson, R. Socio-scientific inquiry-based learning: An approach for engaging with the 2030 Sustainable Development Goals through school science. *Int. J. Dev. Educ. Glob. Learn.* **2019**, *11*, 29–49. [CrossRef]
28. Jessel, M.; Baratoux, D.; Siebenaller, L.; Hein, K.; Maduekwe, A.; Ouedraogo, F.M.; Baratoux, L.; Diagne, M.; Cucuzza, J.; Seymon, A.; et al. New models for geoscience higher education in West Africa. *J. Afr. Earth Sci.* **2018**, *148*, 99–108. [CrossRef]
29. Jackson, W.M.; Brown, J.S.; Howe, H.F. *The Logic(s) of Sustainability*; SEPUP, The Lawrence Hall of Science, UC Berkeley: Berkeley, CA, USA, 2023; *manuscript in preparation*.
30. Centers for Disease Control and Prevention: One Health. Available online: https://www.cdc.gov/onehealth/index.html (accessed on 2 February 2023).