SIMOC-B2: A Computer Simulation of Biosphere 2

Grades 9-14 Next Generation Science Standards, Common Core Standards, and 21st Century Skills Alignment Document

WHAT STUDENTS DO: Use the SIMOC model to study and conduct experiments on the Biosphere 2 internal ecosystem.

Students use a free online simulation model to investigate the food, carbon, and water cycles inside Biosphere 2 and design and test ways to optimize them. They will actively engage in data analysis, computational thinking, and iterative innovation through collaboration and persistence.

NGSS CORE & COMPONENT QUESTIONS	INSTRUCTIONAL OBJECTIVES
How (and why) do organisms interact with their environment and what are the effects of these interactions? *LS2: Ecosystems: Interactions, Energy and Dynamics.* How do organisms interact with the living and nonliving environments to obtain matter and energy? *LS2.A: Interdependent Relationships in Ecosystems* How do matter and energy move through an ecosystem? *LS2.B: Cycles of Matter and Energy Transfer in Ecosystems* What happens to ecosystems when the environment changes? *LS2.C: Ecosystem Dynamics, Functions and Resilience*	***Students will be able to:*** IO1: **Explore and interpret data using computer models to describe and predict the interdependence of biotic and abiotic components of an ecosystem.**
How do engineers solve problems? *ETS1: Engineering Design* What is a design for? What are the criteria and constraints of a successful solution? *ETS1.A: Defining and Delimiting the Engineering Problem* What is the process for developing potential design solutions? *ETS1.B: Developing Possible Solutions* How can various design solutions be compared and improved? *ETS1.C: Optimizing the Design Solution*	***Students will be able to:*** IO2: **Use and modify a model limited by criteria and constraints to solve a complex science and engineering problem**

1.0 About this Activity

How Students Learn: Science in the Classroom (Donovan & Bransford, 2005) advocates the use of a research-based instructional model for improving students' grasp of central science concepts. Based on conceptual-change theory in science education, the 5E Instructional Model (BSCS, 2006) includes five steps for teaching and learning: Engage, Explore, Explain, Elaborate and Evaluate. The Engage stage is used like a traditional warm-up to pique student curiosity, interest, and other motivation-related behaviors and to assess students' prior knowledge. The Explore step allows students to deepen their understanding and challenges existing preconceptions and misconceptions, offering alternative explanations that help them form new schemata. In Explain, students communicate what they have learned, illustrating initial conceptual change. The Elaborate phase gives students the opportunity to apply their newfound knowledge to novel situations and supports the reinforcement of new schemata or its transfer. Finally, the Evaluate stage serves as a time for students' own formative assessment, as well as for educators' diagnosis of areas of confusion and differentiation of further instruction. This five-part sequence is the organizing tool for the SIMOC-B2 instructional series. The 5E stages can be cyclical and iterative.

The format for developing a question was guided by statements made by Bybee in "Scientific and engineering practices in K-12 classrooms: Understanding a framework for K-12 science education" published by NSTA. Here Bybee explained that the term "practices" was a much more accurate explanation of scientific inquiry. These practices "involve doing and learning in such a way that cannot be really separated." The process for reaching a scientific research question in this lesson has been discussed and vetted through scientists, researchers and administrators working on Biosphere 2.

Additionally, students engage in an engineering design activity using SIMOC. They use the engineering design process to carry out an investigation into an O_2 deficit in Biosphere 2, essentially recreating the landmark scientific study *Oxygen Loss in Biosphere 2* from 1993. A brief description of the engineering design process can be seen in this diagram. This diagram, along with the 5E Instructional Model, provides the organization for the activities.

Activity	5E Instructional Model	Engineering Design Process
(A) Designing a Biosphere	Engage	
(B) Identify the Problem	Explore	Identify the need or problem
(C) Research the Problem	Explain	Research the need or problem
(D) Develop Solutions	Elaborate	Develop possible solution(s)
		Select the best possible solution(s)
(E) Evaluate Solutions	Evaluate	Construct a Prototype
		Test and evaluate the solution(s)
(F) Communicate the Solution		Communicate the solution(s)
(G) Reflection		

2.0 Instructional Objectives, Learning Outcomes, Standards & Rubrics

Instructional objectives and learning outcomes are aligned with

- Achieve Inc.'s, *Next Generation Science Standards (NGSS)*
- National Research Council's, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*
- National Governors Association Center for Best Practices (NGA Center) and Council of Chief State School Officers (CCSSO)'s, *Common Core State Standards for English Language Arts & Interact in History/Social Studies, Science, and Technical Subjects*
- Partnership for 21st Century Skills, *A Framework for 21st Century Learning*

The following chart provides details on alignment among the core components NGSS questions, instructional objectives, learning outcomes, and educational standards.

- Your **instructional objectives (IO)** for this lesson align with the NRC Framework and NGSS
- You will know that you have achieved these instructional objectives if students demonstrate the related **learning outcomes (LO)**, also aligned with NGSS Framework and NGSS.
- You will know the level to which your students have achieved the learning outcomes by using the suggested **rubrics**.

Important Note: This lesson is color-coded to help teachers identify each of the three dimensions of NGSS. The following identifying colors are used: Practices are blue, Cross-Cutting Concepts are green, and Disciplinary Core Ideas are orange.

This color-coding is consistent with the NGSS Performance Expectations and Foundation Boxes.

Quick View of Standards Alignment:

This alignment document provides full details of standards alignment, and the way in which instructional objectives, learning outcomes, 5E activity procedures, and assessments were integrated to ensure maximal learning. For convenience, a quick view follows:

The following are the Disciplinary Core Ideas most associated with these lessons.

How (and why) do organisms interact with their environment and what are the effects of these interactions? *LS2: Ecosystems: Interactions, Energy and Dynamics.*

How do organisms interact with the living and nonliving environments to obtain matter and energy? *LS2.A: Interdependent Relationships in Ecosystems*

How do matter and energy move through an ecosystem? *LS2.B: Cycles of Matter and Energy Transfer in Ecosystems*

What happens to ecosystems when the environment changes? *LS2.C: Ecosystem Dynamics, Functions and Resilience*

How do engineers solve problems? *ETS1: Engineering Design*

What is a design for? What are the criteria and constraints of a successful solution? *ETS1.A: Defining and Delimiting the Engineering Problem*

What is the process for developing potential design solutions? *ETS1.B: Developing Possible Solutions*

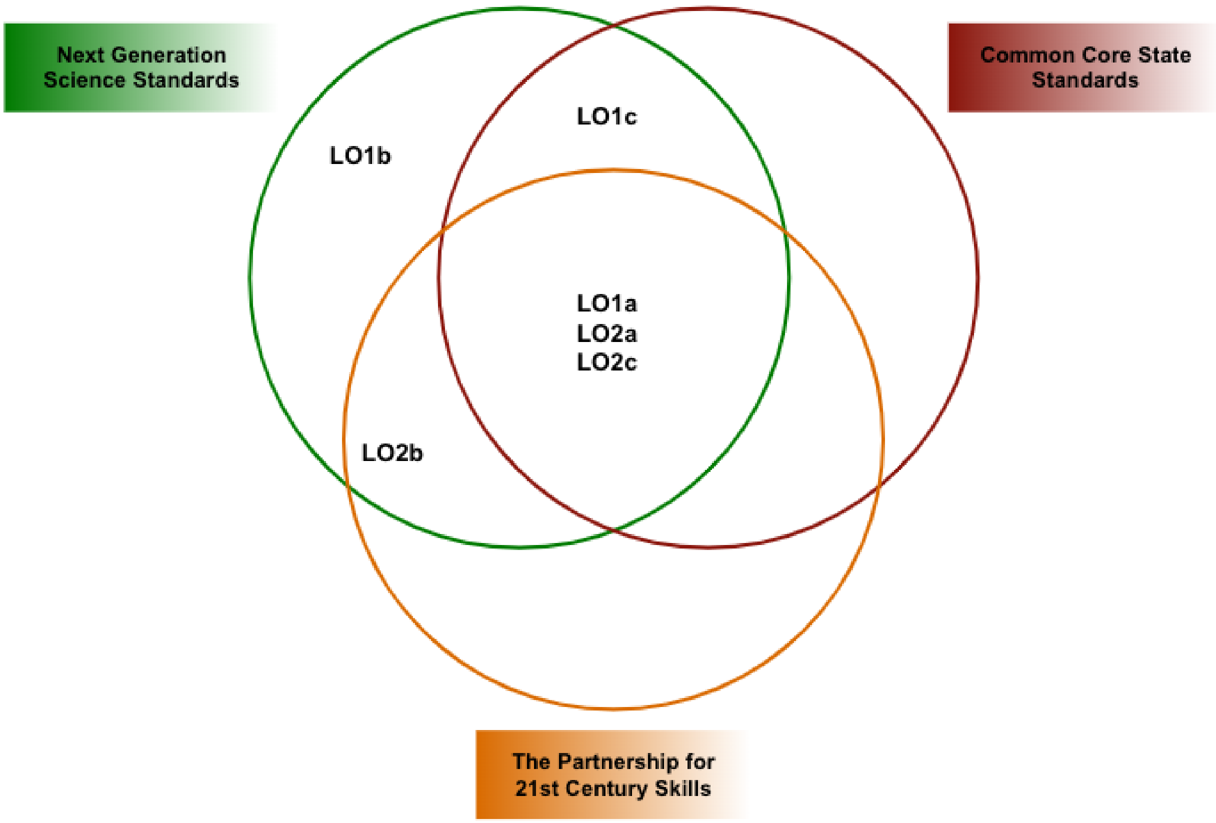
How can various design solutions be compared and improved? *ETS1.C: Optimizing the Design Solution*

Instructional Objective *Students will be able to*	**Learning Outcomes** *Students will demonstrate the measurable abilities*	**Standards** *Students will address*	
IO1: **Explore and interpret data using computer models to describe and predict the interdependence of biotic and abiotic components of an ecosystem.**	**LO1a: to enumerate criteria and constraints for an engineering problem with an awareness of cause and effect and interdependence.** **LO1b: to use a computer model to collect and analyze data in order to identify patterns and imbalances in an ecosystem.** **LO1c: to use mathematics and computational thinking to analyze and describe the structure, function and relative impact of individual sub-systems in an ecosystem.**	**DISCIPLINARY CORE IDEA:** **LS2.A: Interdependent Relationships in Ecosystems** **LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** **LS2.C: Ecosystem Dynamics, Functioning, and Resilience** **PRACTICES:** **1. Asking Questions** **2. Developing and Using Models** **3. Analyzing and Interpreting Data** **4. Using Mathematics and Computational Thinking** **5. Obtaining, Evaluating, and Communicating Information** **CROSSCUTTING CONCEPTS:** **1. Patterns** **2. Cause and Effect** **3. Scale, Proportion, and Quantity** **4. Systems and System Models** **5. Structure and Function** **6. Stability and Change**	**Rubrics in SIMOC Lesson**

Instructional Objective *Students will be able to*	**Learning Outcomes** *Students will demonstrate the measurable abilities*	**Standards** *Students will address*	
IO2: **Use and modify a model limited by criteria and constraints to solve a complex science and engineering problem**	**LO2a: to develop possible solutions to maintaining a healthy ecosystem in a closed system by understanding cause and effect, adjusting scale and quantities, and reasoning about interdependence.** **LO2b: to use and modify a model using evidence to establish stability over time in a dynamic engineered ecosystem.** **LO2c: to construct an explanation that includes qualitative and quantitative relationships using models of systems showing that organisms survive by obtaining necessary resources through interdependent relationships with other organisms and the physical environment.**	**DISCIPLINARY CORE IDEA:** **ETS1.A: Defining and Delimiting the Engineering Problem** **ETS1.B: Developing Possible Solutions** **ETS1.C: Optimizing the Design Solution** **PRACTICES:** 1. Developing and Using Models 2. Planning and Carrying Out Investigations 3. Analyzing and Interpreting Data 4. Using Mathematics and Computational Thinking 5. Constructing Explanations 6. Engaging in Argument from Evidence 7. Obtaining, Evaluating, and Communicating Information **CROSSCUTTING CONCEPTS:** 1. Patterns 2. Cause and Effect 3. Scale, Proportion, and Quantity 4. Systems and System Models 5. Structure and Function 6. Stability and Change	**Rubrics in SIMOC Lesson**

3.0 Learning Outcomes, NGSS, Common Core, & 21st Century Skills Connections

The connections diagram is used to organize the learning outcomes addressed in the lesson to establish where each will meet the Next Generation Science Standards, ELA Common Core Standards, and the 21st Century Skills and visually determine where there are overlaps in these documents.



4.0 Evaluation / Assessment

Use the (N) Design Rubrics as a formative and summative assessment, allowing students to improve their work and learn from mistakes during class. There are several different rubrics that you can use depending on the focus of your class and your goals.

5.0 References

Achieve, Inc. (2013). Next generation science standards. Achieve, Inc. on behalf of the twenty- six states and partners that collaborated on the NGSS.

Bybee, R., Taylor, J., Gardner, A., Van Scotter, P., Carson Powell, J., Westbrook, A., Landes, N. (2006) The BSCS 5E instructional model: origins, effectiveness, and applications. Colorado Springs: BSCS.

Donovan, S. & Bransford, J. D. (2005). How Students Learn: History, Mathematics, and Science in the Classroom. Washington, DC: The National Academies Press.

Miller, Linn, & Gronlund. (2009). Measurement and assessment in teaching. Upper Saddle River, NJ: Pearson.

National Academies Press. (1996, January 1). National science education standards. Retrieved February 7, 2011 from http://www.nap.edu/catalog.php?record_id=4962

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). Common Core State Standards. Washington, DC: Authors.

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

The Partnership for 21st Century Skills (2011). A framework for 21st century learning. Retrieved March 15, 2012 from http://www.p21.

SIMOC-B2 NGSS Alignment (1/5) **Teacher Guide**

Related Standard(s)

This lesson supports the preparation of students toward achieving Performance Expectations using the Practices, Cross-Cutting Concepts and Disciplinary Core Ideas defined below:

(HS-ETS1-1), (HS-ETS1-2), (HS-ETS1-4);
(HS-LS2-1), (HS-LS2-2), (HS-LS2-3), (HS-LS2-4), (HS-LS2-6);

Next Generation Science Standards Alignment (NGSS)

Instructional Objective	Science and Engineering Practices	Disciplinary Core Idea	Crosscutting Concepts
IO1: Explore and interpret data using computer models to describe and predict the interdependence of biotic and abiotic components of an ecosystem.	**Asking Questions** Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. **Developing and Using Models** Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. **Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze	**LS2.A: Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. (HS-LS2-1, HS-LS2-2) **LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of	**Patterns** Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. Mathematical representations are needed to identify some patterns. **Cause and Effect** Students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects. **Systems and System Models**

	data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Using Mathematics and Computational Thinking** Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. **Constructing Explanations and Designing Solutions** Design, evaluate, and/or refine a solution to a complex real- world problem, based on scientific knowledge, student- generated sources of evidence, prioritized criteria, and trade off considerations. **Engaging in Argument from Evidence** Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student- generated evidence. **Obtaining, Evaluating, and Communicating Information** Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence.	the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web, and there is a limit to the number of organisms that an ecosystem can sustain. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil and are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved; some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. (HS-LS2-3, HS-LS2-4) **LS2.C: Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-6)	Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. **Energy and Matter** Students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. **Structure and Function** Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. **Stability and Change** Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.

SIMOC-B2 NGSS Alignment (2/5) **Teacher Guide**

Next Generation Science Standards Alignment (NGSS)			
Instructional Objective	**Science and Engineering Practices**	**Disciplinary Core Idea**	**Crosscutting Concepts**
IO2: Use and modify a model limited by criteria and constraints to solve a complex science and engineering problem	**Developing and Using Models** Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. **Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Using Mathematics and Computational Thinking** Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. **Constructing Explanations and Designing Solutions** Design, evaluate, and/or refine a solution to a complex real- world	**ETS1.A: Defining and Delimiting Engineering Problems** Humanity faces major global challenges today, such as the need for sup- plies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) **ETS1.B: Developing Possible Solutions** Both physical models and computers can be used in various ways to aid in the engineering design process. Physical models, or prototypes, are helpful in testing product ideas or the properties of different materials. Computers are useful for a variety of purposes, such as in representing a design in 3-D through CAD software; in troubleshooting to identify and describe a design problem; in running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)	**Patterns** Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. Mathematical representations are needed to identify some patterns. **Cause and Effect** Students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects. **Systems and System Models** Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in

	problem, based on scientific knowledge, student- generated sources of evidence, prioritized criteria, and trade off considerations. **Engaging in Argument from Evidence** Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student- generated evidence. **Obtaining, Evaluating, and Communicating Information** Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence.	**ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS- ETS1-2)	the models. **Energy and Matter** Students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. **Structure and Function** Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. **Stability and Change** Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can

Next Generation Science Standards Alignment (NGSS)

Instructional Objective	Science and Engineering Practices	Disciplinary Core Idea	Crosscutting Concepts
LO1a: to enumerate criteria and constraints for an engineering problem with an awareness of cause and effect and interdependence.	**Asking Questions** Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. **Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Using Mathematics and Computational Thinking** Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.	**LS2.A: Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. (HS-LS2-1, HS-LS2-2) **LS2.C: Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species,	**Cause and Effect** Students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects. **Systems and System Models** Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. **Stability and Change** Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long

		overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-6)	periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.
LO1b: to use a computer model to collect and analyze data in order to identify patterns and imbalances in an ecosystem.	**Developing and Using Models** Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. **Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Using Mathematics and Computational Thinking** Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.	**LS2.A: Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. (HS-LS2-1, HS-LS2-2) **LS2.C: Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.	**Systems and System Models** Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. **Structure and Function** Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. **Stability and Change** Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.

		(HS-LS2-6)	
LO1c: to use mathematics and computational thinking to analyze and describe the structure, function and relative impact of individual sub-systems in an ecosystem.	**Asking Questions** Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. **Using Mathematics and Computational Thinking** Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. **Constructing Explanations and Designing Solutions** Design, evaluate, and/or refine a solution to a complex real- world problem, based on scientific knowledge, student- generated sources of evidence, prioritized criteria, and trade off considerations. **Engaging in Argument from Evidence** Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student- generated evidence.	**LS2.A: Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. (HS-LS2-1, HS-LS2-2) **LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web, and there is a limit to the number of organisms that an ecosystem can sustain. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil and are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved; some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. (HS-LS2-3, HS-LS2-4)	**Patterns** Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. Mathematical representations are needed to identify some patterns. **Cause and Effect** Students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects. **Structure and Function** Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem.

Next Generation Science Standards Alignment (NGSS)

Instructional Objective	Science and Engineering Practices	Disciplinary Core Idea	Crosscutting Concepts
LO2a: to develop possible solutions to maintaining a healthy ecosystem in a closed system by understanding cause and effect, adjusting scale and quantities, and reasoning about interdependence.	**Developing and Using Models** Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. **Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.	**ETS1.A: Defining and Delimiting Engineering Problems** Humanity faces major global challenges today, such as the need for sup- plies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) **ETS1.B: Developing Possible Solutions** Both physical models and computers can be used in various ways to aid in the engineering design process. Physical models, or prototypes, are helpful in testing product ideas or the properties of different materials. Computers are useful for a variety of purposes, such as in representing a design in 3-D through CAD software; in troubleshooting to identify and describe a design problem; in running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)	**Cause and Effect** Students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects. **Structure and Function** Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem.
LO2b: to use and modify a model using evidence to establish stability over time in a	**Developing and Using Models** Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems,	**ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS- ETS1-2)	**Systems and System Models** Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models)

dynamic engineered ecosystem..	and/or solve problems. **Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Using Mathematics and Computational Thinking** Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.		to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. **Stability and Change** Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.
LO2c: to construct an explanation that includes qualitative and quantitative relationships using models of systems showing that organisms survive by obtaining necessary resources through interdependent relationships with other organisms and the physical environment	**Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Obtaining, Evaluating, and Communicating Information** Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe	**ETS1.A: Defining and Delimiting Engineering Problems** Humanity faces major global challenges today, such as the need for sup- plies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS- ETS1-2)	**Scale, Proportion and Quantity** Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Patterns observable at one scale may not be observable or exist at other scales. **Stability and Change** Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems

	how they are supported or not supported by evidence.		can be designed for greater or lesser stability.

Next Generation Science Standards Alignment (NGSS)

Activity	Phases of 5E Instructional Model	Science and Engineering Practices	Disciplinary Core Idea	Crosscutting Concepts
Designing a Biosphere	**Engage**	**Asking Questions** Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.	**ETS1.A: Defining and Delimiting Engineering Problems** Humanity faces major global challenges today, such as the need for sup- plies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)	**Structure and Function** Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem.
Identify the Problem	**Explore**	**Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Using Mathematics and Computational Thinking** Create and/or revise a computational model or	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web, and there is a limit to the number of organisms that an ecosystem can sustain. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil and are combined and recombined in different ways. At each link	**Patterns** Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. Mathematical representations are needed to identify some patterns. **Stability and Change** Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They

		simulation of a phenomenon, designed device, process, or system.	in an ecosystem, matter and energy are conserved; some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. (HS-LS2-3, HS-LS2-4)	recognize systems can be designed for greater or lesser stability.
Research the Problem	**Explain**	**Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **Developing and Using Models** Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.	**LS2.A: Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. (HS-LS2-1, HS-LS2-2)	**Structure and Function** Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. **Cause and Effect** Students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects.
Develop Solutions	**Elaborate**	**Constructing Explanations and Designing Solutions** Design, evaluate, and/or refine a solution to a complex real- world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations.	**ETS1.B: Developing Possible Solutions** Both physical models and computers can be used in various ways to aid in the engineering design process. Physical models, or prototypes, are helpful in testing product ideas or the properties of different materials. Computers are useful for a variety of purposes, such as in representing a design in 3-D through CAD	**Cause and Effect** Students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have

			software; in troubleshooting to identify and describe a design problem; in running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)	equal effects.
Evaluate Solutions	**Evaluate**	**Using Mathematics and Computational Thinking** Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.	**ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS- ETS1-2)	**Systems and System Models** Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. **Stability and Change** Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.
Communi cate the Solution	**Evaluate**	**Engaging in Argument from Evidence** Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-	**LS2.C: Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem	**Systems and System Models** Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and

		generated evidence.	occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-6)	simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models.

Instructional Objective	Reading Standards for Literacy in Science and Technical Subjects (5-8)	Writing Standards for Literacy in Science and Technical Subjects (5-8)
LO1a: to enumerate criteria and constraints for an engineering problem with an awareness of cause and effect and interdependence. **LO1c: to use mathematics and computational thinking to analyze and describe the structure, function and relative impact of individual sub-systems in an ecosystem.** **LO2a: to develop possible solutions to maintaining a healthy ecosystem in a closed system by understanding cause and effect, adjusting scale and quantities, and reasoning about interdependence.** **LO2c: to construct an explanation that includes qualitative and quantitative relationships using models of systems showing that organisms survive by obtaining necessary resources through interdependent relationships with other organisms and the physical environment.**	**Key Ideas and Details** Grade 9-10: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. Grades 11-12: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. **Integration of Knowledge and Ideas** Grade 9-10: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. Grade 11-12: Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. Grade 9-10: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. Grade 11-12: Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text,	**Text Types and Purposes** Grade 9-10: Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that establishes clear relationships among the claim(s), counterclaims, reasons, and evidence. Grade 11-12: Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences the claim(s), counterclaims, reasons, and evidence. Grade 9-10: Develop claim(s) and counterclaims fairly, supplying data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns. Grade 11-12: Develop claim(s) and counterclaims fairly and thoroughly, supplying the most relevant data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form that anticipates the audience's knowledge level, concerns, values, and possible biases. **Research to Build and Present Knowledge** Grade 9-10: Gather relevant information from multiple authoritative print and digital sources,

	verifying the data when possible and corroborating or challenging conclusions with other sources of information.	using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation. Grade 11-12: Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

SIMOC-B2 Partnerships for 21st Century Skill Alignment

Teacher Guide

21st Century Skills		
Learning Outcomes	**21st Century Skill**	**Outcomes**
LO1a: to enumerate criteria and constraints for an engineering problem with an awareness of cause and effect and interdependence.	**Collaboration**	**Share ideas with others**
	Information Literacy	**Identify High-Quality Sources of Information Online**
	Critical Thinking	**Reason effectively about the requirements and solutions**
LO2a: to develop possible solutions to maintaining a healthy ecosystem in a closed system by understanding cause and effect, adjusting scale and quantities, and reasoning about interdependence.	**Collaboration**	**Exercise flexibility and willingness to be helpful in making necessary compromises to accomplish a common goal.**
	Creativity and Innovation	**Think creatively, work creatively with others, and implement solutions.**
LO2b: to use and modify a model using evidence to establish stability over time in a dynamic engineered ecosystem.	**Technology**	**Utilize technology to collect and analyze data to modify the model and improve its accuracy.**
	Flexibility	**Demonstrate adaptability and openness to change in modifying the model to ensure its stability over time.**
LO2c: to construct an explanation that includes qualitative and quantitative relationships using models of systems showing that organisms survive by obtaining necessary resources through interdependent relationships with other organisms and the physical environment.	**Media Literacy**	**Evaluate and use various forms of media to gather information about interdependent relationships within ecosystems.**
	Communication	**Effectively communicate the explanation of qualitative and quantitative relationships within ecosystems to diverse audiences using appropriate language and media.**

Related Rubrics for the Assessment of Learning Outcomes associated with the Above Standard(s):

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1a: to enumerate criteria and constraints for an engineering problem with an awareness of cause and effect and interdependence.	Identifies most human and plant constraints, as well as the need to balance the carbon and water cycles. Identifies specific solutions to many constraints from multiple reputable sources.	Identifies most human and plant constraints, as well as the need to balance the ecosystem. Identifies solutions to some constraints from multiple reputable sources.	Identifies most human constraints and some secondary constraints, such as plants or mechanical systems. Identifies solutions to some constraints using the references provided.	Identifies some human constraints such as food, water and oxygen. Identifies solutions to at least one constraint using references provided.
LO1b: to use a computer model to collect and analyze data in order to identify patterns and imbalances in an ecosystem.	Correctly charts O_2 and CO_2 and all thresholds in clearly differentiable styles with a legend. Describes behavior clearly and concisely using complete sentences.	Correctly charts O_2 and CO_2 and all thresholds, includes a legend. Describes behavior thoroughly and correctly using correct grammar.	Approximately charts O_2 and CO_2 with and some thresholds, includes a legend. Describes behavior accurately.	Includes multiple data points from simulation connected with a line. Makes accurate statements about the data.
LO1c: to use mathematics and computational thinking to analyze and describe the structure, function and relative impact of individual sub-systems in an ecosystem.	Finds the maximum for each agent/resource Describes behavior clearly and concisely. Identifies O_2 and CO_2 responses in all agents.	Finds the maximum for at least one agent per type. Describes behavior correctly. Identifies O_2 and CO_2 responses in multiple agents.	Finds near-maximum values for at least one agent of each type. Describes behavior accurately. Identifies at least one O_2 or CO_2 response.	Records at least one value for each agent of each time from the simulation. Identifies differences in behavior between different agents.
LO2a: to develop possible solutions to maintaining a healthy ecosystem in a closed	Lists all changes in Mission 1b and describes behavior of O_2 and CO_2 clearly and concisely.	Lists most changes to Mission 1b and describes the behavior of O_2 and CO_2 correctly.	Lists some major changes to Mission 1b and describes behavior of O_2 and CO_2 accurately.	Lists some major changes to Mission 1b, describes O_2 and CO_2 differently from Mission 1a.

system by understanding cause and effect, adjusting scale and quantities, and reasoning about interdependence.	LIsts at least 5 viable changes to configuration, predicts the impact correctly, and identifies at least one second-order impact for each.	LIsts at least 5 viables changes to configuration, predicts impact reasonably, identifies some second-order impacts.	LIsts multiple viable changes to configuration and predicts impacts reasonably, identifies at least one second-order impact correctly.	Lists multiple changes to configuration, may include some misunderstandings in estimated impact.
LO2b: to use and modify a model using evidence to establish stability over time in a dynamic engineered ecosystem..	Implement all of the solutions identified in (D). Identify the key agents responsible for changes in the outcome and describe their behavior correctly. Conduct and describe at least three (3) simulations, keeping detailed records and showing reasoned attempts at improving outcomes across multiple constraints (O_2, power).	Implement most of the solutions identified in (D). Clearly describe 3 agents whose behavior was different from the preset configuration. Conduct and describe at least two (2) simulations, keeping good records and showing a logical pattern to changes based on more than 1 constraint.	Implement some of the solutions identified in (D). Describe the behavior of at least 2 agents that were affected by the changes. Propose multiple changes to the configuration which could logically improve outcomes.	Implement at least one solution identified in (D). Describe the behavior of at least one agent directly affected by that change. Propose at least one change to the configuration which could logically improve outcomes.
LO2c: to construct an explanation that includes qualitative and quantitative relationships using models of systems showing that organisms survive by obtaining necessary resources through interdependent relationships with other organisms and the physical environment	Demonstrates multiple iterations in mockups, shows and understanding of clarity and composition. Includes all relevant agents from SIMOC-B2 with all correct flows. Illustrates and/or describes all O_2 and CO_2 response mechanisms: e.g. human thresholds, carbonation rates, etc.	Completes three distinct mockups, shows an awareness of groupings and directionality. Include all relevant agents from SIMOC-B2 with all correct flows. Illustrate and/or describe some O_2 and CO_2 response mechanisms.	Completes at least three mockups, shows a preference for one layout over another. Include all relevant agents from SIMOC-B2 with several correct flows. Illustrate and/or describe at least one O_2 and CO_2 response mechanism.	Completes at least two mockups, shows a preference for one layout over another. Include several relevant agents from SIMOC-B2 with flows. Illustrate and/or describe at least one O_2 and CO_2 response mechanism.