Students' Ideas about Sustainability of Agricultural and Fuel Production Systems

Elizabeth de los Santos, Sarah Riggs Stapleton, and Charles W. (Andy) Anderson

NARST, April 2, 2014

MICHIGAN STATE UNIVERSITY
College of Education
Department of Teacher Education

Why Sustainability?

From the *Framework for K-12 Science Education*:

From the earliest forms of agriculture to the latest technologies, all human activity has drawn on natural resources and has had both short- and long-term consequences, positive as well as negative, for the health of both people and the natural environment.

(National Research Council, 2012, p. 212)

Next Generation Science Standards Performance Expectations

Elementary School

- **K-ESS3-3.** Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment.
- **3-LS4-4.** Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.
- **4-ESS3-1.**Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.
- **5-ESS3-1.**Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Middle School

- **MS-LS2-5.** Evaluate competing design solutions for maintaining biodiversity and ecosystem services.
- **MS-ESS3-3.** Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
- **MS-ESS3-4.** Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.
- **MS-ETS1-1.** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

High School

- **HS-LS2-7.** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- **HS-LS4-6.** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
- **HS-ESS2-2.** Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
- **HS-ESS3-3.** Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.
- **HS-ESS3-4.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- **HS-ESS3-6.** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
- **HS-ETS1-1.** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **HS-ETS1-3.** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Decision-Making and Engineering Design

The inclusion of decision-making and engineering design in *NGSS* creates new demands for curricula and instruction that supports teachers and students as they engage in these new ideas and practices.

Purpose of the Study

- To investigate students’ ideas about sustainability of agricultural and fuel production systems.

- To develop an initial learning progression framework for sustainability based on interviews with middle school, high school, and college students.

Method

- Conducted semi-structured interviews in 2013 with:
  - 9 middle school students
  - 14 high school students
  - 10 college students
- Interview protocol was designed to elicit students' ideas and reasoning about:
  - Corn (agricultural production systems)
  - Transportation fuel (fuel production systems)

Corn Context

Small-scale, community garden

Large-scale, industrial corn

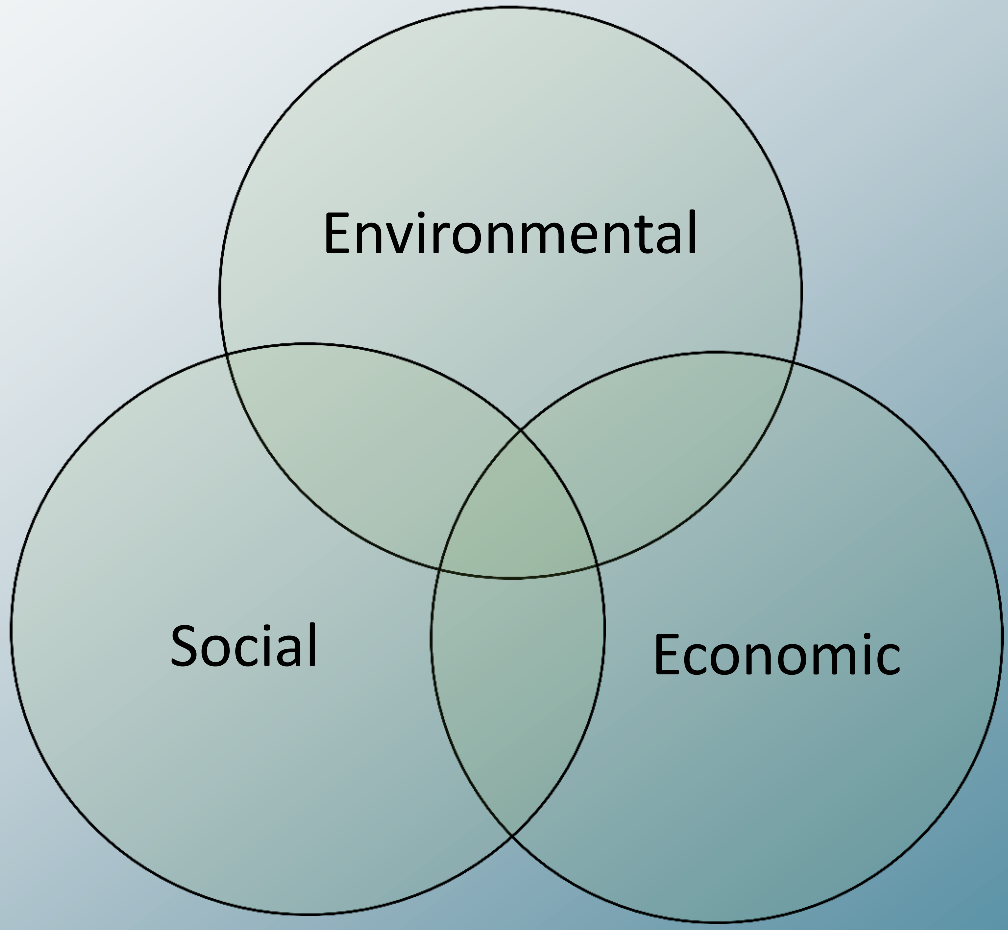
Native American "Three Sisters" method of growing corn, beans, and squash together

Fuels Context

Gasoline

Ethanol

Framework for Sustainability



Data Analysis

- Iterative process of design-based research, moving back and forth between the development of frameworks and empirical data.
- Goal is to describe patterns of student thinking and reasoning.

	Knowledge of Product Life Cycles	Value Judgments on Sustainability	Reasoning at Multiple Scales
High-Level Responses	Traces matter and energy through economic and environmental systems • Identifies basic components of the production systems and traces matter and energy through them at atomic-molecular scales	Judgments based on comparing costs or risks and benefits of different systems • Considers more than one cost or benefit and more than one domain • Considers balances between costs and benefits • Connects across domains and systems	Reasons at global, long-term scales • Considers social, environmental, or economic effects for long or indefinite time scales and for populations of people
Intermediate-Level Responses	Traces sequences of steps leading to a product • Identifies basic components of the production systems and connects them with mechanisms	Judgments based on single attributes of different systems • Defines sustainability using one objective • Identifies costs or risks and benefits	Reasons at local, short-term scales • Considers social, environmental, or economic effects for the production system and groups of people
Low-Level Responses	Has limited understanding of the production systems • Identifies basic components • Does not identify mechanisms, or identifies mechanisms with limited details	Broad value judgments without mechanisms • Defines sustainability in terms of dichotomies such as good/bad, natural/unnatural, or healthy/unhealthy	Reasons only at personal scales • Considers social, environmental, or economic effects for individuals rather than for production systems

	Knowledge of Product Life Cycles	Value Judgments on Sustainability	Reasoning at Multiple Scales
High-Level Responses	Traces matter and energy through economic and environmental systems • Identifies basic components of the production systems and traces matter and energy through them at atomic-molecular scales	Judgments based on comparing costs or risks and benefits of different systems • Considers more than one cost or benefit and more than one domain • Considers balances between costs and benefits • Connects across domains and systems	Reasons at global, long-term scales • Considers social, environmental, or economic effects for long or indefinite time scales and for populations of people
Intermediate-Level Responses	Traces sequences of steps leading to a product • Identifies basic components of the production systems and connects them with mechanisms	Judgments based on single attributes of different systems • Defines sustainability using one objective • Identifies costs or risks and benefits	Reasons at local, short-term scales • Considers social, environmental, or economic effects for the production system and groups of people
Low-Level Responses	Has limited understanding of the production systems • Identifies basic components • Does not identify mechanisms, or identifies mechanisms with limited details	Broad value judgments without mechanisms • Defines sustainability in terms of dichotomies such as good/bad, natural/unnatural, or healthy/unhealthy	Reasons only at personal scales • Considers social, environmental, or economic effects for individuals rather than for production systems

	Knowledge of Product Life Cycles	Value Judgments on Sustainability	Reasoning at Multiple Scales
High-Level Responses	Traces matter and energy through economic and environmental systems • Identifies basic components of the production systems and traces matter and energy through them at atomic-molecular scales	Judgments based on comparing costs or risks and benefits of different systems • Considers more than one cost or benefit and more than one domain • Considers balances between costs and benefits • Connects across domains and systems	Reasons at global, long-term scales • Considers social, environmental, or economic effects for long or indefinite time scales and for populations of people
Intermediate-Level Responses	Traces sequences of steps leading to a product • Identifies basic components of the production systems and connects them with mechanisms	Judgments based on single attributes of different systems • Defines sustainability using one objective • Identifies costs or risks and benefits	Reasons at local, short-term scales • Considers social, environmental, or economic effects for the production system and groups of people
Low-Level Responses	Has limited understanding of the production systems • Identifies basic components • Does not identify mechanisms, or identifies mechanisms with limited details	Broad value judgments without mechanisms • Defines sustainability in terms of dichotomies such as good/bad, natural/unnatural, or healthy/unhealthy	Reasons only at personal scales • Considers social, environmental, or economic effects for individuals rather than for production systems

	Knowledge of Product Life Cycles	Value Judgments on Sustainability	Reasoning at Multiple Scales
High-Level Responses	Traces matter and energy through economic and environmental systems • Identifies basic components of the production systems and traces matter and energy through them at atomic-molecular scales	Judgments based on comparing costs or risks and benefits of different systems • Considers more than one cost or benefit and more than one domain • Considers balances between costs and benefits • Connects across domains and systems	Reasons at global, long-term scales • Considers social, environmental, or economic effects for long or indefinite time scales and for populations of people
Intermediate-Level Responses	Traces sequences of steps leading to a product • Identifies basic components of the production systems and connects them with mechanisms	Judgments based on single attributes of different systems • Defines sustainability using one objective • Identifies costs or risks and benefits	Reasons at local, short-term scales • Considers social, environmental, or economic effects for the production system and groups of people
Low-Level Responses	Has limited understanding of the production systems • Identifies basic components • Does not identify mechanisms, or identifies mechanisms with limited details	Broad value judgments without mechanisms • Defines sustainability in terms of dichotomies such as good/bad, natural/unnatural, or healthy/unhealthy	Reasons only at personal scales • Considers social, environmental, or economic effects for individuals rather than for production systems

	Knowledge of Product Life Cycles	Value Judgments on Sustainability	Reasoning at Multiple Scales
High-Level Responses	Traces matter and energy through economic and environmental systems • Identifies basic components of the production systems and traces matter and energy through them at atomic-molecular scales	Judgments based on comparing costs or risks and benefits of different systems • Considers more than one cost or benefit and more than one domain • Considers balances between costs and benefits • Connects across domains and systems	Reasons at global, long-term scales • Considers social, environmental, or economic effects for long or indefinite time scales and for populations of people
Intermediate -Level Responses	Traces sequences of steps leading to a product • Identifies basic components of the production systems and connects them with mechanisms	Judgments based on single attributes of different systems • Defines sustainability using one objective • Identifies costs or risks and benefits	Reasons at local, short-term scales • Considers social, environmental, or economic effects for the production system and groups of people
Low-Level Responses	Has limited understanding of the production systems • Identifies basic components • Does not identify mechanisms, or identifies mechanisms with limited details	Broad value judgments without mechanisms • Defines sustainability in terms of dichotomies such as good/bad, natural/unnatural, or healthy/unhealthy	Reasons only at personal scales • Considers social, environmental, or economic effects for individuals rather than for production systems

	Knowledge of Product Life Cycles	Value Judgments on Sustainability	Reasoning at Multiple Scales
High-Level Responses	Traces matter and energy through economic and environmental systems • Identifies basic components of the production systems and traces matter and energy through them at atomic-molecular scales	Judgments based on comparing costs or risks and benefits of different systems • Considers more than one cost or benefit and more than one domain • Considers balances between costs and benefits • Connects across domains and systems	Reasons at global, long-term scales • Considers social, environmental, or economic effects for long or indefinite time scales and for populations of people
Intermediate -Level Responses	Traces sequences of steps leading to a product • Identifies basic components of the production systems and connects them with mechanisms	Judgments based on single attributes of different systems • Defines sustainability using one objective • Identifies costs or risks and benefits	Reasons at local, short-term scales • Considers social, environmental, or economic effects for the production system and groups of people
Low-Level Responses	Has limited understanding of the production systems • Identifies basic components • Does not identify mechanisms, or identifies mechanisms with limited details	Broad value judgments without mechanisms • Defines sustainability in terms of dichotomies such as good/bad, natural/unnatural, or healthy/unhealthy	Reasons only at personal scales • Considers social, environmental, or economic effects for individuals rather than for production systems

	Knowledge of Product Life Cycles	Value Judgments on Sustainability	Reasoning at Multiple Scales
High-Level Responses	Traces matter and energy through economic and environmental systems • Identifies basic components of the production systems and traces matter and energy through them at atomic-molecular scales	Judgments based on comparing costs or risks and benefits of different systems • Considers more than one cost or benefit and more than one domain • Considers balances between costs and benefits • Connects across domains and systems	Reasons at global, long-term scales • Considers social, environmental, or economic effects for long or indefinite time scales and for populations of people
Intermediate-Level Responses	Traces sequences of steps leading to a product • Identifies basic components of the production systems and connects them with mechanisms	Judgments based on single attributes of different systems • Defines sustainability using one objective • Identifies costs or risks and benefits	Reasons at local, short-term scales • Considers social, environmental, or economic effects for the production system and groups of people
Low-Level Responses	Has limited understanding of the production systems • Identifies basic components • Does not identify mechanisms, or identifies mechanisms with limited details	Broad value judgments without mechanisms • Defines sustainability in terms of dichotomies such as good/bad, natural/unnatural, or healthy/unhealthy	Reasons only at personal scales • Considers social, environmental, or economic effects for individuals rather than for production systems

Low-Level Student Responses

Knowledge about product life cycle	Value judgments on sustainability	Reasoning at multiple scales
[Plants need] sun, water, dirt, or specialized soil – that's pretty much all I can think of. *[The sun helps plants grow because] it causes photosynthesis.*	*[Ethanol] might not give off as much dangerous exhaust as compared to gasoline…because it's made from something concrete whereas oil is really kind of sticky and gross.*	*I'd actually choose a gasoline car because my favorite car runs on gasoline.*

Intermediate-Level Student Responses

Knowledge about product life cycle	Value judgments on sustainability	Reasoning at multiple scales
I think oil comes from...dead matter. So I mean, it builds up over time and I don't really know what happens to turn it into that…I'm not really sure how gasoline in a car works, but I know the stuff that comes out of the exhaust is mostly...I think it's carbon dioxide. Maybe methane.	*The soil's going to run out of nutrients [in the industrial system]. And so it's without soil so it wouldn't really be able to be used anymore. So that's not extremely sustainable. I'm not really sure what benefit of growing beans, corns, and squash together is, or if that's any better than anything else. So I'm not really sure about that. And as for a community garden, I guess you're growing a bunch of things, but I guess if you're doing that for a long, long time, eventually the soil's going to wear out.*	*The electricity [to power an electric car] can be very easily renewable because you just put some windmills up and get some waterwheels maybe next to a river or something and you're turning it all into electricity.*

High-Level Student Responses

Knowledge about product life cycle	Value judgments on sustainability	Reasoning at multiple scales
The ethanol is… an alcohol. So it would be a lot of carbon-hydrogen, carbon-carbon, carbon-hydrogen…When you break it down you'd probably release more of CO_2, I would guess, because there's carbon in it.	*Large-scale industrial farm was definitely not sustainable because fertilizer would go into runoff, which could cause eutrophication, which could potentially damage some ecosystems…and it requires more transportation. So, that puts more greenhouse gases into the air. The other two methods I would think would be pretty fair methods… I like …the growing corn, beans, and squash together because it's really elegant in that it has a nitrogen-fixing bacteria .... So, it would help the corn grown more easily. --Gina (HS)*	*For wind turbines you need enough average wind in order to make it worthwhile.... Then I've seen a lot of, actually fields that have solar panels in them too...I don't think it's big enough yet to power a gas station... I don't think right now it would be in enough large-scale to do that.* *-Undergrad*

	Knowledge of Product Life Cycles	Value Judgments on Sustainability	Reasoning at Multiple Scales
High-Level Responses	Traces matter and energy through economic and environmental systems • Identifies basic components of the production systems and traces matter and energy through them at atomic-molecular scales	Judgments based on comparing costs or risks and benefits of different systems • Considers more than one cost or benefit and more than one domain • Considers balances between costs and benefits • Connects across domains and systems	Reasons at global, long-term scales • Considers social, environmental, or economic effects for long or indefinite time scales and for populations of people
Intermediate-Level Responses	Traces sequences of steps leading to a product • Identifies basic components of the production systems and connects them with mechanisms	Judgments based on single attributes of different systems • Defines sustainability using one objective • Identifies costs or risks and benefits	Reasons at local, short-term scales • Considers social, environmental, or economic effects for the production system and groups of people
Low-Level Responses	Has limited understanding of the production systems • Identifies basic components • Does not identify mechanisms, or identifies mechanisms with limited details	Broad value judgments without mechanisms • Defines sustainability in terms of dichotomies such as good/bad, natural/unnatural, or healthy/unhealthy	Reasons only at personal scales • Considers social, environmental, or economic effects for individuals rather than for production systems

Patterns in Student Responses

- Generally, individual students could hold ideas at multiple levels.
- Most students, including college students, gave middle and low level responses.
- Few students provided high level accounts, particularly for *value judgments on sustainability* and *reasoning at multiple scales*.

Patterns in Student Responses

- Accounts of product life cycles
  - Upper level: Awareness of where products come from and where waste goes
  - Lower level: Vague understanding of supply and waste disposal chains
- Temporal and geographic scale
  - Upper level: Long term effects on large systems
  - Lower level: Personal heath, safety, price
- Basis for judgments about sustainability
  - Upper level: Considering costs and benefits in different systems
  - Lower level: Valuing desirable attributes

Differences Between Corn and Fuel

- Corn
  - The same product produced using three different production systems with different inputs, processes, and outputs.
- Fuel
  - Three entirely different production systems ending in different products.
  - Students much less familiar with content in general.

Discussion

- Preparation for future learning (Bransford & Schwartz, 2001)
- Students with high levels of ideas and reasoning are better prepared for future learning about complex topics such as sustainability—although they did not know enough to make well-grounded judgments about the relative sustainability of the systems, they knew what they didn't know.

Implications and Next Steps

- Curriculum design to support *NGSS* performance expectations
  - Content knowledge about human engineered systems
  - New practices, such as engineering design and decision-making
  - Students' reasoning across multiple scales and systems
- Developing and validating written items

Thanks to Contributors to this Research

- Dr. Joyce Parker
  - Michigan State University
- May Lee and Joshua Rosenberg
  - Michigan State University
- Environmental Literacy group at MSU
  - Jennifer Doherty, Jenny Dauer, Hannah Miller, Wendy Johnson, Allison Webster