FIELDS OF FUEL

Using a video game to support reasoning about sustainability

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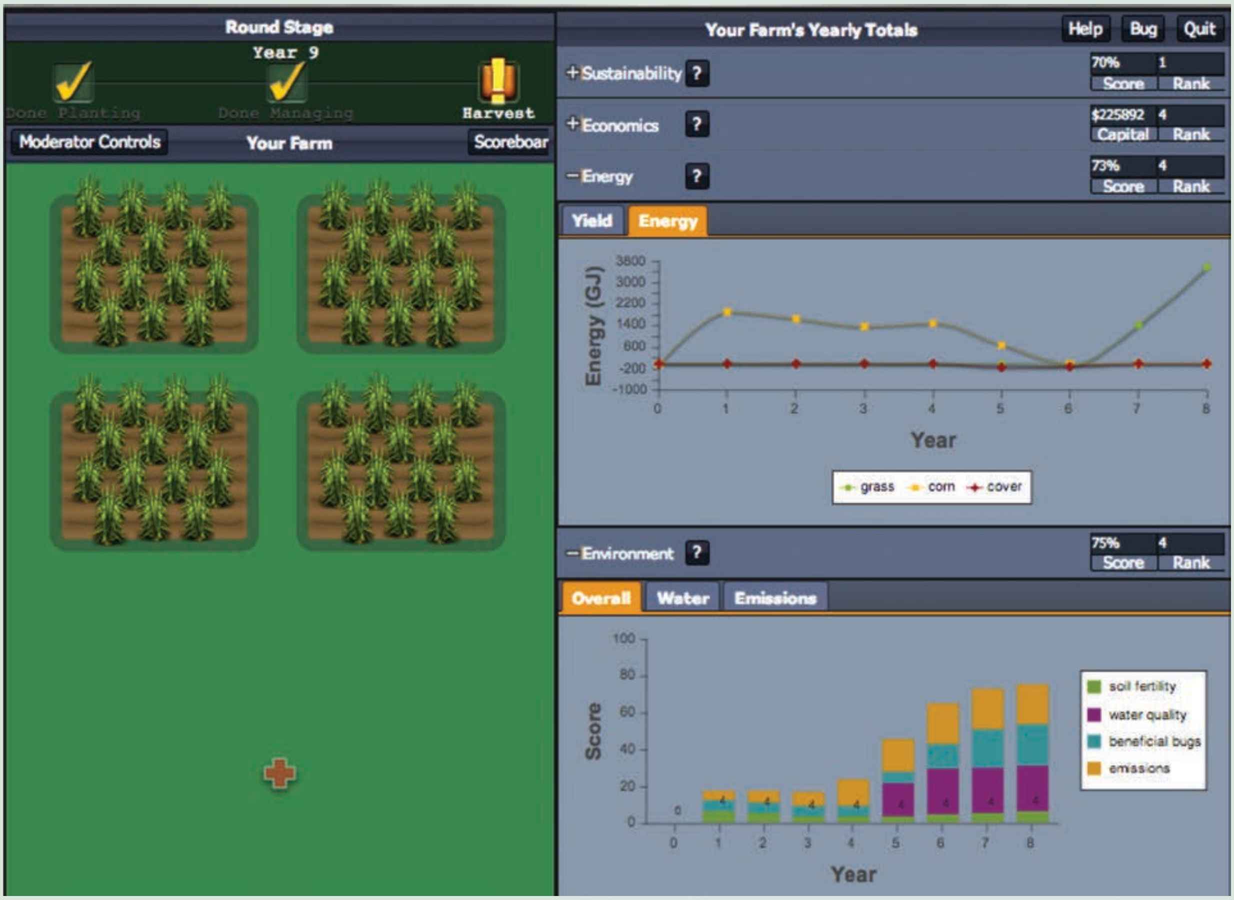
Imagine an Earth science teacher looking for an engaging activity that explores the costs and benefits of extracting natural resources. Now imagine an AP environmental science teacher needing a lesson that explores how everyday decision-making affects biodiversity and how that, in turn, can affect us.

In both scenarios, the classes are exploring science content that aligns with the *Next Generation Science Standards* (NGSS Lead States 2013) and that connects to larger issues of *sustainability*. Everyday we make choices that affect sustainability: Should we buy an electric car? Build a compost pile? Use a rain barrel? Become vegetarian? Buy only local meats? Our lawmakers face much bigger decisions about sustainability: What are the costs and benefits of instituting a cap and trade system to reduce sulfur dioxide or other harmful emissions? Will requiring power plants to burn natural gas instead of coal reduce greenhouse gas emissions?

What information do we need, at both the individual and community level, for making such decisions? How will we

FIGURE 1

Screen shot of player "your farm" after eight "years" of playing the game.



know whether our decisions are successful? Science students, such as those in the classes mentioned above, should engage in discussing these questions. But exploring issues of sustainability can be challenging for teachers and students alike. Effectively evaluating sustainability requires balancing tradeoffs using rich, complex data sets.

A sustainable system is commonly defined as one that is environmentally benign, economically viable, and socially acceptable. Sustainability then has to be understood and evaluated in the context of many dimensions (Feng 2012; Shepardson et al. 2007; Sternang and Lundholm 2012). For example, individuals and lawmakers have to balance environmental concerns with economic challenges and consider whether socially acceptable practices are environmentally appropriate. Reasoning about sustainability also requires thinking about processes that occur over both small and large geographic areas for various periods of time. For example, what is best for one farm today may not be best for all the nation's farms together in perpetuity. These different dimensions (economic, environmental, and social) and their interactions across multiple scales make reasoning in this domain incredibly challenging (Eberbach et al. 2012; Goh et al. 2012). Often, there are no simple, easily identifiable "right" answers to questions of sustainability.

What can teachers do?

To help teachers engage students in discussions about sustainability, we designed Fields of Fuel, a multiplayer, web-based simulation game that allows players to explore the environmental and economic tradeoffs of a realistic sustainable system. Computer-based simulations of real-world phenomena engage students and have been shown to support student learning (Gee 2003; Squire 2006) as players manipulate the inner workings of complex systems and receive real-time data about how the system behaves (Wilensky and Stroup 1999).

The Fields of Fuel game explores sustainability around the issue of fossil fuel consumption (Wood et al. 2004) and related climate change (IPCC 2013). Food crops like corn can be used to produce ethanol as a supplement to or replacement for fossil fuels. However, researchers are also working to make liquid fuel from inedible plants and plant parts, such as switchgrass *(Panicum virgatum)* and corn stalks. This "biofuel" could ultimately replace one-third of the oil we use for transportation (DOE 2011). There are still questions about how to produce large quantities of bioenergy crops in ways that are environmentally and economically acceptable for the global community.

In the game, students (or groups of students) take on the role of a farmer with multiple fields attempting to raise and sell crops (energy-dense corn, eco-friendly switchgrass, or cover crop), and manage fields sustainably, making decisions about such factors as fertilizer use and crop rotation. In multiplayer mode, several farmers interact in a shared environment; in single-player mode, students compete against automated farmers for the best scores. Individual player choices affect their own fields and those of the surrounding players. The game is freely available online (see "On the web") and can be played on most web browsers.

Each round of gameplay represents a year in real time and can take as much class time as the teacher allows, with students taking from 30 seconds to 10 minutes to make a planting decision. After each simulated year, players receive feedback about their choices calculated by models derived from current ecological and economic research. The feedback includes data such as crop yield, cash flow, soil fertility, water quality, insect diversity, and net energy production. Farmers are then ranked in individual environmental, economic, and energy well-being, which determines their overall sustainability scores. Players receive data about how both their individual fields and overall farms have performed according to the different metrics and scores. Students learn that sustainability depends on a web of interacting causes and effects that together affect soil quality, crop yield, biofuel production, and income (Figure 1).

Based on the instantaneous data they receive about the sustainability of their farming practices, students make choices for the next round of play. Rather than teachers providing students with historical, hypothetical, or simplified data, students generate their own personalized data to use in reasoning about sustainability.

Fields of Fuel is appropriate for various high school courses including environmental science, biology, economics, and agriculture. The game can support students as they:

FIGURE 2

Connections to the standards.

Depending on the teacher's emphasis, the *Fields of Fuel* activity could connect with some of the following dimensions found in the *NGSS* and *Common Core State Standards.*

Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**	**Questions students can explore using Fields of Fuel**
Life Sciences HS-LS2 Ecosystems: Interactions, Energy, and Dynamics			
• Developing and using models	LS2.A – Interdependent relationships in ecosystems	• Systems and system models	• What limits your farm's productivity? • How do you know if your farm can sustain a given level of productivity?
• Constructing explanations and designing solutions.	LS2.B – Cycles of matter and energy transfer in ecosystems	• Patterns • Energy and matter: Flows, cycles, and conservation	• How do choices you make on your farm influence the carbon cycle? • What choices can you make on your individual farms to reduce our overall greenhouse gas (GHG) emissions?
• Engaging in argument from Evidence	LS2.C – Ecosystem dynamics, functioning, and resilience	• Scale, proportion, and quantity • Cause and effect • Systems and system models	• How do annual versus perennial plants affect biodiversity and ecosystem functioning on your fields?
• Constructing Explanations and Designing Solutions	LS4.D – Biodiversity and humans	• Patterns • Cause and effect • Stability and change	• How does choosing crops that provide habitat for beneficial insects affect your crop yield?
Earth and Space Sciences HS-ESS3 Earth and Human Activity			
ESS3.C - Human impacts of earth systems	• Cause and effect • Scale, proportion, and quantity	• Using Mathematics and Computational Thinking	• What planting and management choices promote sustainable yields over long periods of time?
Engineering, Technology, and Applications of Science HS-ETS1 Engineering Design			
ETS1.B: Developing Possible Solutions	• Systems and system models	• Constructing Explanations and Designing Solutions	• What are the environmental, economic, and social impacts of using only corn for ethanol biofuel production?

Connections to Engineering, Technology, and Applications of Science

- Influence of Science, Engineering, and Technology on Society and the Natural World
- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

- Describe the key dimensions of sustainability within the context of bioenergy crop production.
- Identify ecological and economic factors that affect agricultural systems.
- Use graphs to make sense of long- and short-term trends in data.
- Explain the relationship between individual farmer management decisions and local ecological and economic outcomes.
- Explain the relationship between individual farmer management decisions and global ecological and economic outcomes.

Students who play the game examine the complex and dynamic nature of sustainability and use data to distinguish the impact of different features of sustainable systems. The game addresses mumerous elements of the *Next Generation Science Standards* (Figure 2).

Using Fields of Fuel in the classroom

Over months of development and testing, we played the game with students, educators, and researchers. Players found the game enjoyable and engaging, and it spurred critical conversations about sustainability grounded in rich data. In the following example, two students make their crop planting decisions only after repeatedly checking the fertility of their soil:

Erica: Let's see what our soil thingy [fertility] is. These two [switchgrass and cover crop] make them go up.

Tia: If we took out one of the corn it would make our economy like….

Erica: Our economy thing would go down.

Tia: You're right. Okay, so….

Erica: But then our soil health in the long run would go up.

Erica and Tia use data from the game to ground their decision-making and support predictions about expected outcomes. Checking the soil fertility, Erica points out that the switchgrass and cover crops seem to make the soil health go up. She notes that even a short-term drop in economic score from removing corn would perhaps be counter balanced by the longer term increase in their soil fertility that comes from planting perennial crops.

In this example, Erica and Tia are exploring the disciplinary core ideas of natural resources and the human impacts on Earth systems. This type of small group conversation could serve as an initial activity for the Earth science class mentioned in the introduction. For example, the teacher might introduce the game by asking students to use data to identify the costs and benefits of different crops on the environment and the economy.

In contrast, the AP environmental science teacher in the introduction could use the game as a concluding lesson in which students apply their knowledge of mechanisms governing biodiversity to make sense of the trends observed in the data. In looking at students' written reflections on their game play, we can see the potential of this approach when students articulate dynamic connections between various aspects of the sustainable system. For example, Julio and Andy explain: "Our soil health and environmental score stayed pretty consistent, thanks to alternating the fields between crops that increase soil health and crops that decrease soil health." And "Our soil health was deteriorating, so we wanted to raise the quality of our soil [by planting switch grass], in the hope that we'll get better yields in the future." Another group, Sebastian and Ian, describe the link between soil health and economic success: "The better the soil health," they state, "the more corn production, the more money. Good soil health will increase our production rate and overall capital."

These are but two short examples of conversations the game can foster. More extended interactions are possible. For example, to explore the concept of sustainable natural resource management, a teacher might have students complete a reading for homework and then begin class by defining sustainability and discussing potential environmental, economic, and social factors that might affect the sustainability of renewable and non-renewable fuels.

After the discussion, students play the game; the teacher pauses the game every few rounds, and students share strategies and their cost-benefit reasoning by pointing to evidence from the game's scores and graphs to support their assertions. As an assessment, students work in teams to construct an argument for the sustainability of one crop planting strategy supported by data gathered from gameplay. The teacher then moves on to detailed lessons on how scientists, engineers, and policy makers use cost-benefit analyses to evaluate the effectiveness of environmental technologies based upon environmental, economic, and social criteria.

Throughout these lessons, the class returns to their experiences in the game to contextualize their learning. Online

supplemental materials (see "On the web") support game play and provide assessment questions.

Conclusion

These kinds of conversations around Fields of Fuel can launch students in the further application of *NGSS* scientific and engineering practices during and after game play, as they interpret data, ask related scientific questions, and investigate answers as a class. For example, Tia and Erica's discussion of tradeoffs between planting corn and switch grass resembles the start of an argument in which they are making a claim (they should plant corn to keep their economic score) and considering possible counter claims (they should plant switchgrass to increase soil health).

Similarly, Julio and Andy's as well as Sebastian and Ian's reflections would serve as the starting point for developing a description of the underlying causal model in the system (soil health is causally related to yield, which is causally related to cash flow). Realistic, complex, multiplayer computer games like Fields of Fuel can provide a context for engaging students in discussion about sustainability and also provide them with data to engage in the critical practices of science and science learning. ■

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On the web

Fields of Fuel game site: *http://fieldsoffuel.discovery.wisc.edu*

Student worksheet, discussion questions, and assessment items organized by learning objective: *www.nsta.org/highschool/connections.aspx*

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