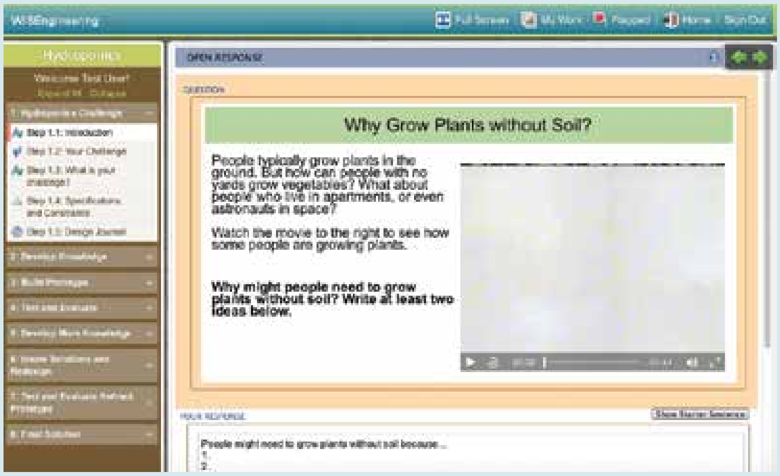
# WISEngineering Hydroponics

## A Technology-Enhanced, Life Science Engineering Design Unit

*by Amanda Gonczi and Jennifer Chiu*

The WISEngineering hydroponics project aims to help students develop their understanding of photosynthesis and cellular respiration. WISEngineering is a free online, engineering-design learning environment that scaffolds engineering design by guiding students through explicit design processes such as identifying specifications and constraints, and ideating, testing, evaluating, and refining design solutions (Figure 1). It draws upon the Web-based Inquiry Science Environment (WISE; Slotta and Linn 2009), the knowledge-integration learning perspective (Linn and Eylon 2011), and an informed engineering-design approach (Burghardt and Hacker 2004) to help students develop connected science and engineering understanding (Chiu and Linn 2011).

**FIGURE 1** WISEngineering scaffolds engineering projects by guiding students through design activities (left)




As part of the informed engineering-design approach, units are carefully developed so that specifications and constraints of the design challenge address common alternative ideas (e.g., Schnittka and Bell 2010), so that students' design solutions encourage thoughtful refinement of scientific ideas. Common pitfalls of engineering activities in classrooms include students focusing on superficial aspects of design or mindless tinkering without connection to scientific principles. An informed-design approach helps address these common pitfalls by making sure successful design solutions rely on accurate understanding of scientific concepts. For example, the hydroponics unit targets the common alternative idea that plants eat soil (e.g., Anderson, Sheldon, and Dubay 1990). By focusing students' design efforts around building a system for plants to grow without soil, students are motivated to reconsider and revise initially inaccurate ideas to meet the criteria of the project.

The design of the hydroponics unit went through multiple iterations, with feedback from science teachers and engineering and science experts. A major challenge that arose during development was finding sufficient classroom time for students to design and test solutions for living systems, as plants needed time to grow (or not grow) to determine the success of the students' designs. Working with the participating teachers, we developed the unit so that a week of total instructional time was distributed over four weeks, with students engaging with the project once a week. Students do not need any prior knowl-

**FIGURE 2** Embedded simulations in the WISEngineering hydroponics project

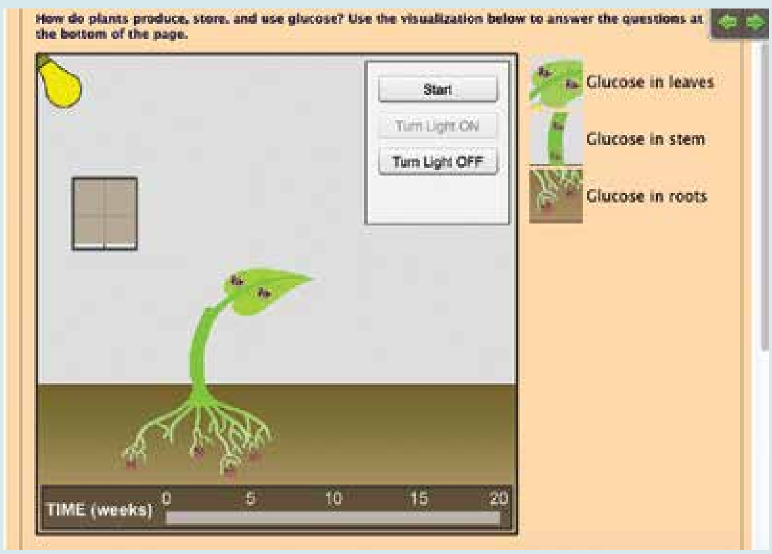


**FIGURE 3** Overview of initial prototypes for hydroponics systems

| | Design source | Instructions | Materials needed |
|---|---|---|---|
| **Prototype 1** | WISE design | Fill a plastic cup half full with water and place germinated seed in cup. | Plastic cup, water, geminated seed |
| **Prototype 2** | WISE design | Fill plastic cup (water cup) with water to a height of 1 cm. Using scissors, poke holes in the bottom of a second cup (seed cup) and thread roots through. Place the seed cup in the water cup and wedge a paper towel between the cups so the seed cup is above the water. | Two plastic cups, a pair of scissors, paper towel, water, germinated seed |

edge about the topic or engineering. The computer-based learning environment will, with the support of the teacher, guide students in grades 5–8 to develop understanding of photosynthesis and cellular respiration through a hands-on engineering design project.

## Classroom implementation

The hydroponics module starts with the introduction of a relevant real-world problem to motivate student learning (Mehalik, Doppelt, and Schunn 2008). At the beginning of the unit, students explore why people would need to grow plants without soil, giving example contexts of urban areas or space exploration. Teachers may want to provide a "hook" by showing a film or incorporating literacy by reading excerpts from a book that would interest students (e.g., *The Martian* by Andy Weir). Students define the problem by identifying specifications and constraints of the project, which include designing a system to keep plants alive for a week without soil and with limited time and materials (e.g., paper cups, paper towels, seeds, plastic bottles, cardboard, tape).

WISEngineering helps students engage in a range of design processes and scientific practices (Chiu et al. 2013). Students first define the problem, identify specifications and constraints of the challenge, and germinate seeds from beans to be used in their designs. Students develop understanding of how plants grow through embedded, interactive visualizations and simulations accompanied by prompts to help students explain underlying concepts. For example, after students use a simulation depicting photosynthesis and cellular respiration at the molecular level, they are asked, "What is the difference between cellular respiration and photosynthesis?" Another simulation (Figure 2) shows the relationship between light and food production in plants. Students are prompted to reflect on the visualization by answering the questions "How did the plant get glucose?" and "What happened to the glucose in the leaves when the light was turned off?"

After developing understanding, students design their own hydroponics prototype and test it against two other designs outlined in the module

**FIGURE 4** Students' initial designs

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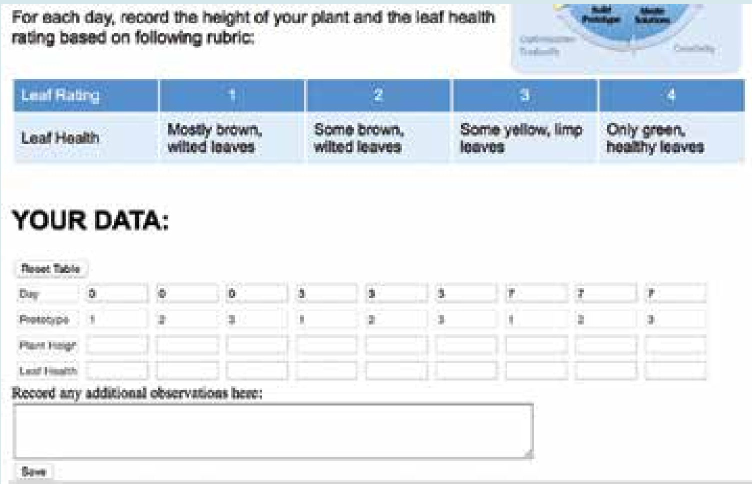
**FIGURE 5** Data collection spreadsheet



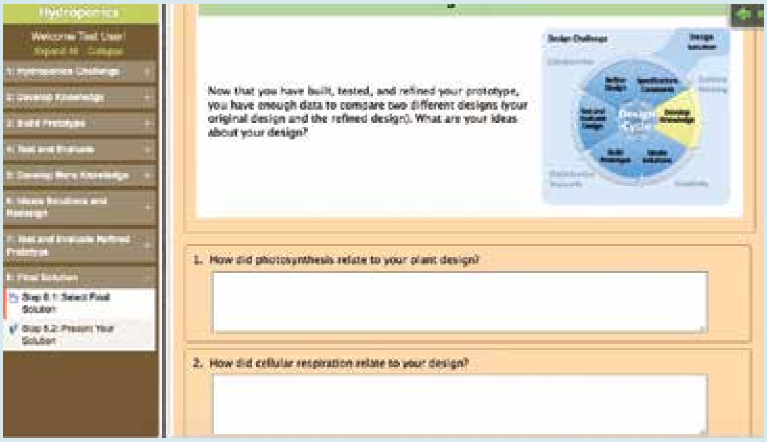

(Figure 3). The basic materials a teacher will need include paper and plastic cups, paper towels, scissors, straws, cotton balls, popsicle sticks, water bottles, and a bag of beans, which can be purchased at any grocery store. It is important to use the germinated seeds, as the materials do not include a nitrogen source, which is necessary for plant growth. Students practice developing and using models by building three initial physical prototypes in which to grow plants, using the available materials. To help scaffold the process, students follow directions for building two out of the three prototypes and then are prompted to build a third prototype of their own design. These physical models provide students an opportunity to observe and measure plant growth under various conditions and challenge students to consider whether soil is necessary for plant growth.

Students place their prototypes in a common area in the classroom that will allow plant growth, as well as safe and convenient storage (Figure 4). A tabletop that gets daily sunlight and is protected from dramatic changes in temperature is ideal. Students should be told to notify their teacher if there is any evidence of mold or mildew growing on seeds or plants, and these should be safely discarded to prevent allergies or breathing problems in students. Students should also be reminded to handle scissors safely and to always keep the sharp end pointed away from themselves and others when cutting materials or putting holes in the cups. Students then collect data related to plant growth each class day the following week, for approximately 10 minutes per day. The WISEngineering module supports data collection by providing a data table for students to record plant height and leaf health (Figure 5). This scientific inquiry allows students to collect and analyze data to ultimately evaluate the effectiveness of each prototype. Students make a conclusion regarding the optimal prototype before moving forward with the final design challenge.

As a last step, students use their findings from the initial investigation of the three basic prototypes to make improvements to the one prototype they deemed most successful. The final design challenge is to develop a hydroponics system that sustains plant growth for one week without student intervention. Again, the WISEngineering hydroponics module supports student engagement in scientific practices by providing a data collection spreadsheet. Students were again limited to the given materials in

**FIGURE 6** Student redesigns of hydroponic systems

**FIGURE 7** WISEngineering helps students reflect on their understanding of science and engineering design




the classroom. These final prototypes reflected more student creativity and a greater diversity in design compared with the initial student-designed prototypes (Figure 6). It was exciting to observe students develop confidence in their design skills.

## Assessment

The WISEngineering hydroponics module keeps track of student responses to question prompts, design ideas, and data for teachers to use for assessment purposes. Embedded questions allow teachers to assess students' conceptual understanding, as well as engineering skills and proficiency in scientific practices. For example, after reading about the overarching problem and the conditions that the student will have to work in, students are asked to describe the problem in their own words and identify constraints and specifications. Because student proficiency in science and engineering practices builds over time, it is useful for the teacher to provide formative and summative assessments that indicate where student ideas and practices can still improve. Couching feedback and assessment in terms of the potential for growth can help maintain positive student attitudes and effort (Cutts et al. 2010). Teachers can give feedback and score student responses directly within the WISEngineering module for constant formative feedback as time permits and to the extent the teacher desires. Teachers can also use the Hydroponics Assessment Rubric to rate student responses to module questions and engagement in scientific and engineering practices as a summative assessment (visit *www.nsta.org/middleschool/connections.aspx* to download the rubric).

## Modifications and extension

WISEngineering can be implemented in a range of classroom settings with various levels of technology integration. For example, students can each use a computer, if available, while collaborating with a partner. Students can also work in pairs or groups while sharing computers. If computer availability is limited, the teacher can also project and lead students through the module until students are ready to work in groups to plan and build their prototypes. WISEngineering allows students to answer questions either as individuals or as groups to facilitate various levels of assessment.

The WISEngineering hydroponics module could be used in any middle school science class that addresses cellular respiration, photosynthesis, or plant growth. The module was designed to scaffold student engagement in scientific and engineering practices. Depending on students' prior experiences, teachers may want to remove some of this scaffolding. For example, in classes in which students have conducted many investigations, the teacher may want students to independently identify key plant growth outcomes to measure, rather than directing them to measure plant height and observe leaf health. Students may also want to test their prototypes using more than one seed type to be able to make conclusions about possible use for food production or use more mature plants in comparison to seeds to start a more advanced discussion or inquiry about nitrogen fixation.

## Knowledge integration

One of the biggest hurdles in implementing engineering education is integrating science content and addressing education standards (Stohlman et al. 2011). The WISEngineering hydroponics module aids standards-based instruction by revisiting key science concepts after the design process (Figure 7). Students are explicitly prompted to consider how photosynthesis and cellular respiration informed their designs. Students are also encouraged to explain how they used their data to inform prototype revisions. Students explicitly answer these and other questions through the module. These responses are an ongoing opportunity for teachers to assess the depth of student understanding regarding the related science content (i.e., photosynthesis, cellular respiration, and plant growth), as well as the extent

## Connecting to the *Next Generation Science Standards* (*NGSS* Lead States 2013)

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

| | | |
|---|---|---|
| **Standard**<br>MS-LS1: From Molecules to Organisms: Structures and Processes<br>*www.nextgenscience.org/pe/ms-ls1-6-molecules-organisms-structures-and-processes*<br>MS-ETS1: Engineering Design<br>*www.nextgenscience.org/pe/ms-ets1-4-engineering-design* | | |
| **Performance Expectation**<br>MS-LS1-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of systems.<br>MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. | | |
| **Dimension** | **Name and *NGSS* code/citation** | **Matching student task or question taken directly from the activity** |
| Science and Engineering Practices | Asking Questions and Defining Problems | Students articulate an engineering problem and, through prototype testing, develop questions they answer through iterative design. |
| | Analyzing and Interpreting Data | Students record plant height and leaf health and collect and analyze data to evaluate the effectiveness of each prototype. |
| Disciplinary Core Ideas | ETS1.B. Developing Possible Solutions<br>• A solution needs to be tested and then modified on the basis of test results, in order to improve it. | Students make a conclusion regarding the optimal prototype before moving forward with the final design challenge. As a last step, students use their findings from the initial investigation of the three basic prototypes to make improvements to the one prototype they deemed most successful. |
| | PS3.D. Energy in Chemical Processes and Everyday Life<br>• The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen. | An embedded, interactive simulation shows students the relationship between light and food production in plants and prompts them to reflect on the visualization. |
| Crosscutting Concepts | Energy and Matter | Through simulation use and physical prototypes, students observe the critical importance of sunlight in photosynthesis and plant growth. |

to which students are applying their understandings to the engineering task. It is often difficult for students to transfer conceptual understanding to novel problems (Klein and Sherwood 2005) and student responses to these questions may provide an opportunity for class discussion to foster more integrated understanding.

## Positive learning outcomes

Seventh-grade life science students of two teachers ($n \sim 160$) in a public middle school worked through the hydroponics WISEngineering project as part of normal class activities. Students completed a pretest the day before the start of the project and an identical posttest immediately following the conclusion of the project. Assessment items were adapted from assessments designed to target the *Next Generation Science Standards* (*NGSS*) (NGSS Lead States 2013). Students' overall scores significantly improved from pretest to posttest, with a large effect size (see this article's online supplements for more information on test scores). Student responses shifted from non-normative ideas to partial, normative ideas, demonstrating improved understanding about plant growth and cellular processes.

## Conclusion

The WISEngineering hydroponics module provides students with an authentic life science design challenge and integrates digital technology and virtual and physical models, accomplishing multiple education goals put forth in the *NGSS*. In addition, the module helps students develop accurate conceptions related to photosynthesis, cellular respiration, and plant growth. The WISEngineering hydroponics module also can be used as an instructional scaffolding tool for teachers as they seek to gain confidence and experience implementing engineering design activities in their classroom. ■

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## Resources

Web-based Inquiry Science Environment—*http://wise.berkeley.edu*

WISE teacher and student tools—*http://wise.berkeley.edu/pages/teacher-tools.html*

WISEngineering—*http://wisengineering.org*

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