BUILDING A GREENER FUTURE

Using engineering design to connect classroom with community

Blake Baldwin, Kathleen Koenig, and Andries Van der Bent
Integrating engineering and science in the classroom can be challenging, and creating authentic experiences that address real-world problems is often even more difficult. A Framework for K–12 Science Education (NRC 2012), however, calls for high school graduates to be able to undertake more complex engineering design projects related to major global, national, and local issues. This article describes a partnership among a high school, college student group, and nonprofit organization that provides such an experience.

The high school involved is an urban, Midwestern STEM school where the student population is 77% minority and 72% economically disadvantaged. Juniors at this school were enrolled in a Principles of Engineering course closely tied to their science curriculum. The college-student partners were members of an Engineers Without Borders (EWB) chapter at a local university. EWB encourages members to use professional skills to improve quality of life in developing nations and serve as sustainability educators in their own communities.

In spring 2014, the EWB chapter was approached by a nonprofit that maintains a community garden with compost bins. The bins needed updating for larger compost loads and increased accessibility. Coincidentally, the EWB group was working with the high school’s technology teacher to develop an engineering design unit, which was a perfect match with the garden’s needs.

The resulting unit integrated science content with engineering practices and supports the Next Generation Science Standards (NGSS Lead States 2013) (see box, p. 82). The unit aims to help students

1. understand the importance of conservation, calculate a personal carbon footprint, and know how to reduce it;
2. understand the science behind composting to design an effective compost bin; and
3. engage in elements of the engineering design process and successfully meet the needs of their “client,” the nonprofit organization.

Most of the project was completed over 12 50-minute class sessions held on Fridays to accommodate the EWB students’ schedules; the other days of the week were devoted to a different unit.

Setting the stage

Our students had little prior experience with completing an engineering design project of this magnitude. Therefore, the first class session was led by the EWB group, who introduced students to managing a typical engineering project. The group provided examples of past EWB projects, which showcased various engineering fields while demonstrating the use of three specific components of a design process (Figure 1).
The project encouraged conversations on sustainability and global conservation. For example, early in the project, students used an online calculator to compute personal carbon footprints and then discussed in class what they could do to reduce them. These conversations set the stage for the composting bin activity.

**Defining the problem**
The EWB group and a representative from the nonprofit introduced the problem and constraints the students would work within (Figure 2). Unfortunately, inclement weather cancelled a planned site visit to the community garden, so EWB members provided pictures of the site that students used to take “field notes” to better understand the problem’s context and constraints.

**Developing solutions**
This component of the engineering design process involves breaking a major problem into smaller ones that can be solved individually. Students worked in groups of three or four to conduct internet searches to better understand composting, including the types of materials that can be composted (organic vs. nonorganic matter) and the role of air circulation and moisture.

Students then conducted internet research to evaluate existing compost bin designs for effectiveness of pest control, aesthetics, size, cost, durability, and practicality. Students were encouraged to select design features that addressed local constraints and consider how compost bin efficiency, which involves adequate moisture and turning the material to increase air exposure, is maintained over time. A worksheet guided their efforts (see “On the web”).

Following this activity, each group created a 3-D virtual model of their final design using SketchUp (Figure 3), a freely available software program (see “On the web”) that can introduce students to the basics of drafting and modeling. It took our students, who had used SketchUp before, one to two hours to create their model using the program.
Optimizing the solution

Due to the project’s nature, students were not able to build a prototype and test their designs. Rather, groups created a project proposal in the form of a PowerPoint presentation shared with the broader group (see “On the web” for a worksheet and PowerPoint template).

The proposal included their digital drawings and answers to questions such as:

- How does the compost bin hold heat?
- Does it keep the material moist?
- How easy is the material to turn?
- Is the bin accessible?
- What is the projected cost?
- Is the bin aesthetically pleasing?

Groups presented their proposals to the class, the EWB group, and the client. Students rated each other’s proposals based on the criteria and constraints of the problem. These ratings were provided to the client who, along with the EWB group, chose two final designs that best addressed the problem and were feasible for students to make. The two final designs were presented to the students, who discussed design optimization based on features that could be sacrificed for those deemed more important, such as cost reduction.

Final product

Once students agreed upon the two optimal designs, they created a materials list and estimated the cost of the project. The EWB group guided students in brainstorming a fundraising plan that would also engage the community and showcase the project. Each group developed a plan and presented it to the class. It was too late in the academic year to implement the fundraising plan, so EWB provided approximately $550 in funding and purchased the materials to build three bins.

Students were released from class for one full day and driven to the garden to construct the bins. Necessary tasks and important safety information were explained to them. All work requiring the use of power tools was done by the EWB students while the high school students did other work, such as threading bolts or holding pieces in place.
Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

<table>
<thead>
<tr>
<th>Standards</th>
<th>HS-ESS3 Earth and Human Activity</th>
<th>HS-ETS1 Engineering Design</th>
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**Performance Expectations**
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/activities outlined in this article are just one step toward reaching the performance expectations listed below.

**HS-ESS3-4.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

**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.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Name and NGSS code/citation</th>
<th>Specific Connections to Classroom Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Science and Engineering Practices</strong></td>
<td>Asking Questions and Defining Problems</td>
<td>Students conduct site visit of community garden and take appropriate field notes.</td>
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<tr>
<td></td>
<td>• Analyze complex real-world problems by specifying criteria and constraints for successful solutions.</td>
<td>Client outlines criteria for bins.</td>
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<td>Constructing Explanations and Designing Solutions</td>
<td>Students conduct web search to better understand the science of composting.</td>
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<td></td>
<td>• Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3), (HS-ESS3-4)</td>
<td>The design worksheet guides students in designing compost bins as students incorporate the science of composting (e.g., how organic matter in the bins will hold heat, be aerated through turning, and collect moisture).</td>
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<td><strong>Disciplinary Core Ideas</strong></td>
<td>ESS3.C: Human Impacts on Earth Systems</td>
<td>Student groups meet with client to determine how the compost bins will be of benefit to the community garden.</td>
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<td>• Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4).</td>
<td>Students use a template to create a PowerPoint presentation of their bin design and include information about cost, aesthetics, and how it meets the needs of the client.</td>
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<td>ETS1.B: Developing Possible Solutions</td>
<td>Students are presented with the two final designs, chosen by the client and EWB group, and they work together to optimize the designs with a particular focus on cost and ease of construction.</td>
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<td>• When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)</td>
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<td><strong>Crosscutting Concepts</strong></td>
<td>Systems and Systems Models</td>
<td>Students create computer models of compost bins and use their models to predict bin efficiency.</td>
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<td>• Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions.</td>
<td>Students use an online program to determine personal carbon footprints as a means of focusing their attention on the negative impact their actions may have on the environment. This leads into a whole-class discussion on the importance of recycling, composting, and conserving energy.</td>
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<td>Connections to Engineering, Technology, and Applications of Science</td>
<td>Students analyze the costs and benefits of their design proposals.</td>
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<td>Influence of Science, Engineering, and Technology on Society and the Natural World</td>
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<td></td>
<td>• 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. (HS-ETS1-3)</td>
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In the end, three compost bins, one rectangular and two cylindrical (example, Figure 4), were built and placed in the nonprofit’s community garden. The compost bins were unveiled on the garden’s opening day that spring, which included a presentation by the mayor and interviews with local media.

Assessing student work
The classroom teacher assessed each stage of the design process using student submissions of responses to provided questions, worksheets, or PowerPoint templates (see “On the web”). Each assignment was graded, some for completion credit and others using scoring rubrics, and feedback was provided to students. Students were also given group and individual participation grades throughout the project.

Lessons learned
Several aspects of the project worked well, and we will use them in future assignments. For example, the high school students became interested in learning more about engineering and the ongoing projects that EWB carries out overseas. However, as the project continued over 12 weeks, some students became less motivated to work on the activities. Providing credit-bearing, guided worksheets helped these students re-engage while narrowing students’ focus and providing structure for the more open-ended project activities. Students also responded well to physically building the bins and providing a service to their community.

Most of the challenges involved time. Although the unit was originally designed to integrate instruction from both science and engineering courses, this was impractical due to scheduling. All instruction for the project ended up occurring in the engineering class. Careful planning might alleviate this challenge in future projects. Some groups needed more time than others to complete each project phase. Timing was also off for conducting a fundraising plan.

Another improvement would be to have students build and maintain a simple compost bin on school grounds before starting the design phase to give them insights. Also, many students’ solutions were too expensive to consider. Although cost was an identified constraint, setting an upper limit would have been wise.

Conclusion
Students completed the project with a deeper understanding of how engineering and science fit together to solve a real-world problem. The project also connected lower-income, inner-city high school students with college engineering students. Although no formal survey was done, the high school students appeared highly receptive to the college students and were frequently observed asking questions about college life and engineering coursework, allowing for dialog that otherwise might not have been possible. This opportunity may guide these students as they make post-secondary education decisions and career choices.

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On the web
Engineers Without Borders: www.ewb-usa.org
PowerPoint template and worksheets: www.nsta.org/highschool_connections.aspx
SketchUp: www.sketchup.com

References