Refine by DESIGN

An Engineering Design Coaching Tool for Supporting Student Reasoning

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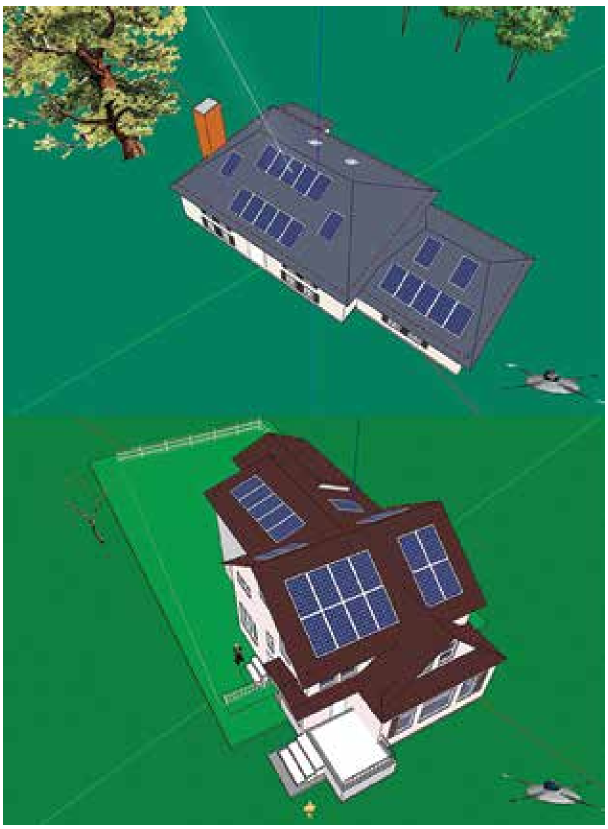
Design review sessions are commonly used in real-world design. These sessions bring together designers, clients, and supervisors to evaluate design options and review evidence in support of or against a design concept (Dong, Garbuio, and Lovallo 2014). Design review sessions are also common in undergraduate engineering education to help reveal students' decision-making processes necessary for informed design (Adams and Siddiqui 2016). Through design reviews, educators examine student reasoning, progress, and provide feedback as students carry out their design projects.

The purpose of the engineering design coaching tool

Observations of students' design practices make us wonder what might be going on in the minds of the students. Are they aware of the many decisions they are making? Are they aware of their use of science concepts? Are they aware of their trade-off decisions? How might the teacher elicit these deep ideas and underlying reasonings to help their students recognize qualities and fallacies in their decisions?

FIGURE 1

Two Solarize Your Home project examples in Aladdin



The *Engineering Design Coaching Tool* was developed to answer these questions based on theories of disciplinary discourse (Wolmarans 2016), prior research on the important role of teacher noticing (Johnson, Wendell, and Watkins 2017; Quintana-Cifuentes, Purzer, and Goldstein 2019), and feedback from K–12 teachers and design educators. We have used variations of this tool in high school, middle school, and college classrooms. Educators can employ the *Engineering Design Coaching Tool* as a pedagogical scaffold to promote student agency by eliciting student decisions, monitor student progress by formatively assessing student understandings and difficulties, and attend to areas that need review or whole-class discussion by reflecting on variations in student reasoning.

How to use the engineering design coaching tool

To illustrate how to use the *Engineering Design Coaching Tool,* we present the *Aladdin Solarize Your World* curriculum as a context for demonstrating the tool. *Aladdin* is a web-based computer-aided design (CAD) environment for designing renewable energy homes, systems, and communities, and provides a variety of embedded scaffolding to support science and engineering learning (Xie et al. 2018). *Solarize Your World* is an umbrella project curriculum with several unique design challenges. In the following sections, we describe two *Solarize Your World* design projects and detail how the *Engineering Design Coaching Tool* can be used in the context of these projects. Next, we present a dialogue between a teacher and a student to highlight the opportunities for design coaching that promote student learning. This conversation takes about five minutes when students are working on their design prototypes.

The design review tool provides a focus to informal teacher–student conversations. While the teacher may not be able to talk with each student, the coaching conversations provide input to the teacher on aspects that are clear or confusing to the students. If students are working in teams, questions can be posed to specific members of a team. During a class session, the teacher can conduct these informal review sessions with five to six students, and then invite whole-class discussions based on insights gained from the informal design reviews.

Solarize your home

Design challenge

In this project, you are tasked to model your home and design a small solar array system to meet the energy needs of your family. *Solarize Your Home* empowers you to explore the viability and energy potential of your home and share these insights with your parents. Figure 1 displays two example projects from other students.

Modeling your home

You can model your home in Aladdin (*https://intofuture.org/aladdin.html*). To get wall length and location information, import a flat image of your home to build upon. Use Tool –> Map from Main Menu to open a Google Map window. Then type the address to open a map of your home and select Satellite. Check "Image on the Ground" to show the image in the 3D scene. To find the height of your home, take a picture of it with a meter stick or ruler and use the ruler's length to estimate your home's height or you can get the data from Google Earth.

Design criteria and constraints

Your solar array system needs to maximize your solar offset (percentage of the home's total energy usage that is generated by the solar array) and have a low payback period (time required to cover initial cost of the system installation with costs saved from energy production). The solar array system also needs to have minimal negative impact on the curb appeal of your home. Your design will need to conform to several constraints including designing around existing obstacles such as chimneys or trees, and abiding by the fire codes that require panels to be at least 1/3 of a meter from roof edge lines.

Teacher Notes

Through *Solarize Your Home*, students engage in engineering practices of designing and evaluating solutions. Students learn and apply solar science concepts such as the sun's path with seasonal differences and the projection effect of the sun while engaging in graphing and system modeling (simulations of the system for energy and cost).

Solarize your school

Design challenge

In this project, you will design a large solar array system to generate energy for your school, engaging in similar engineering practices and science content as in *Solarize Your Home,* while undertaking a more complex design project. Figure 2 displays two example projects from other students.

Modeling your solar array

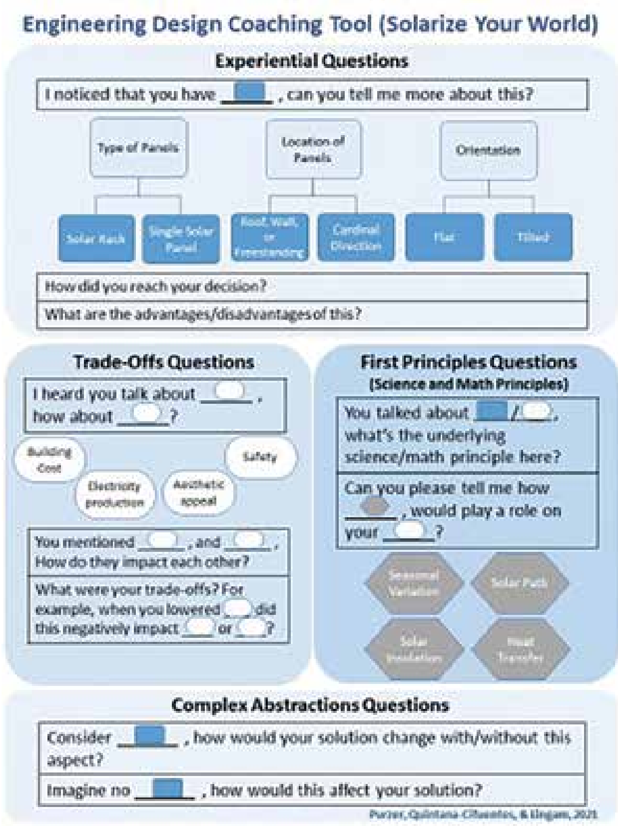
You can design and model your solar array in Aladdin.

FIGURE 2

Two Solarize Your School project examples in Aladdin.

FIGURE 3

Engineering Design Coaching Tool for Solarize Your School.



Design criteria and constraints

The design criteria for *Solarize Your School* resemble the criteria for *Solarize Your Home*. However, the solar offset will likely be lower than that of the solar array built for the Solarize Your Home project. Additionally, many schools have flat roofs, offering you the opportunity to use solar racks which can be tilted to face the sun. However, this introduces two additional constraints beyond those mentioned for *Solarize Your Home*. First, your racks with tilted panels will need to be spaced out to avoid shading that can reduce panel efficiency. Second, tilt angles of greater than 15° require stronger rack bases to withstand wind loads, and will therefore cost more but may offer greater energy generation.

Teacher Notes

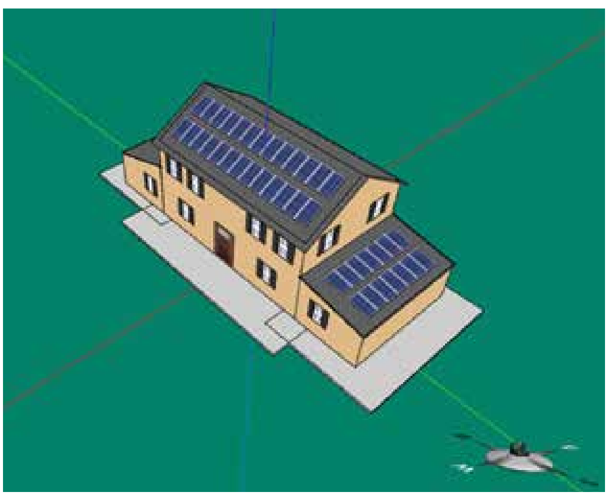
The *Solarize Your School project* offers several unique opportunities for learning. First, most schools have multiple buildings and parking lots on which students may design. Furthermore, different buildings will vary in height and roof structures, such as HVAC systems. These present students with a wide variety of possibilities for designing solar arrays, as well as challenges to mitigate such as shading. Second, in *Solarize Your School*, all students use the same model. Students can, therefore, directly compare their designs, share insights when working in teams, or engage in other peer-learning strategies. For more about *Solarize Your School*, see Chao et al. (2018).

A teacher-student dialogue facilitated by the engineering design coaching tool

The dialogue presented below occurs during a *Solarize Your Home* project. Imagine the teacher, Mrs. Endo, holding the *Engineering Design Coaching Tool*, depicted in Figure 3 and her student, Julio, solarizing a building using the Aladdin software. The coaching tool is made up of four blocks: experiential, trade-offs, first-principles, and complex abstractions. Each block represents a different form of reasoning being elicited. Within each block of the coaching tool, there are question stems as well as a selection of concepts. Question stems and key concepts can be used to dynamically generate questions. In general, the coaching tool is read from top to bottom, but questions do not need to be asked in a fixed order. Once an experiential question has been asked to initiate a conversation, the other question blocks can be flexibly used for follow-up questions.

FIGURE 4

Julio's Solarized Home Design (Note: the front of the house faces west).



The design review session starts with a statement highlighting a unique or overt feature of a student's design followed by an open-ended question (e.g., I noticed that you have feature X, can you tell me more about it?).

The design review session starts with a statement highlighting a unique or overt feature of a student's design followed by an open-ended question (e.g., I noticed that you have feature X, can you tell me more about it?). Such an initiation promotes student agency and welcomes responses regardless of students' ability level. After an experiential question, educators can pose questions from the other blocks to delve deeper into students' reasoning. These questions can elicit how the student balanced competing design criteria (i.e., trade-offs) or probe students' understanding of underlying science phenomena that influenced a design feature (i.e., first principles).

Mrs. Endo approaches Julio to check on his progress. She quickly notices that Julio has placed many of his solar panels on the west-facing side of his roof (see Figure 4). She wonders if Julio decided on the placement of the panels based on his understanding of the Sun's path, design constraints, or a different reason. Using the *Engineering Design Coaching Tool* as a guide, Mrs. Endo starts a conversation with Julio.

Mrs. Endo: Hi Julio, how is your design coming?

Julio: Pretty good.

Mrs. Endo: I noticed you have most of your panels on the west-facing side of your roof. How did you decide to put them there? *[Teacher opening the design review session with an experiential question highlighting a feature of Julio's design.]*

Julio: It seemed like it was the best part of my roof.

Mrs. Endo: I see. What do you mean by 'the best part of the roof'? *[Teacher following up for clarification toward a trade-offs or first-principles thinking.]*

Julio: The west side gets a lot of sunshine during the day.

Mrs. Endo: Would you say it's the best side of the roof for sunshine? *[Teacher shifting to a first-principles question to elicit science understanding of how solar insolation and sun's path influence solar energy.]*

Julio: No. The south side faces the sun most directly so it gets the most sunshine.

Mrs. Endo: Why is that? Why does the south side get more sunshine? *[Teacher following up with another first principles question.]*

Julio: That is how the Sun rises, and moves across the southern sky, and then sets.

Mrs. Endo: So, the west side doesn't get the most sunshine, but you decided to put solar panels there. Were there other reasons why you chose the west side for panels? *[Teacher notices that Julio understands the west side is not optimal for energy production, so asks a trade-offs question to confirm his understanding.]*

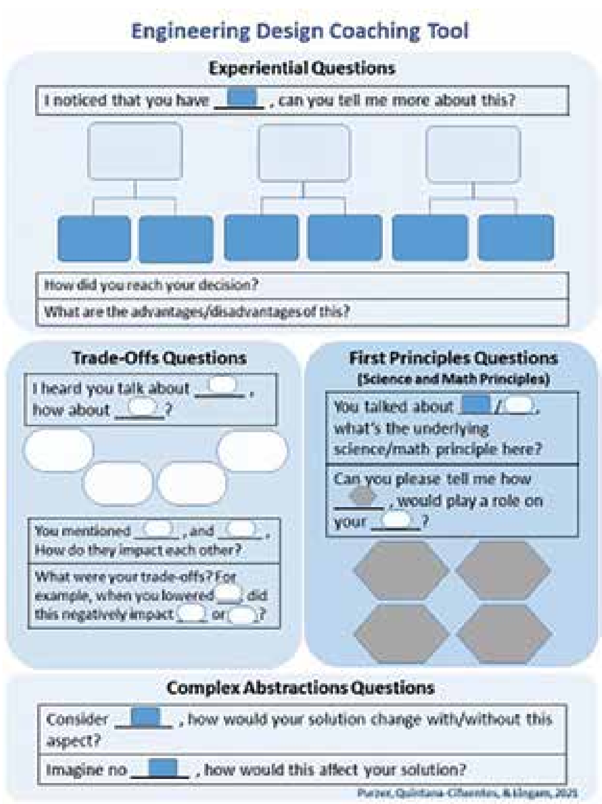
Julio: The roof on the south side was too limited. Even though I had panels there, I wasn't able to generate the energy that my family needed.

Mrs. Endo: Great. Now, let's imagine we built this house in Australia. What do you think would happen if your home was in the southern hemisphere? *[Teacher notices that Julio has a grasp of scientific reasoning and trade-offs that affect his solar design and decides to ask a higher-level, complex abstractions question.]*

Julio: Hmm. Southern hemisphere. I don't think it would affect the panels on the west side. The sun still sets in the west.

FIGURE 5

Engineering Design Capstone Tool Template.



This dialogue, between Mrs. Endo and Julio, takes about five minutes. While the conversation implicitly encourages Julio to think about his decision-making both from the perspective of scientific principles and trade-offs, it also provides critical information to Mrs. Endo about Julio's learning as he designs. Students, just like designers, make a diverse set of decisions when designing. A high-performing student would be able to fluently transition across different forms of reasoning. Asking questions on first-principles invites students to provide evidence from data and scientific principles, while asking questions on experiential observations invites evidence based on experience such as trial-and-error. Trade-off questions reveal whether students recognize how competing design criteria shape design. The coaching process aims to move students toward elaborate forms of reasoning supported by nuanced forms of evidence.

The flexible and gradually abstracted way of questioning allows for differentiation and inclusive teaching. In addition, the low-stakes, conversational format helps build rapport by positioning the student as the intentional creator of their designs, with agency in their decision-making. With such insight, the teacher can then build the bridge between what the student created and the disciplinary core ideas that undergird their design decisions.

How to adapt this coaching tool to different design projects

The *Engineering Design Coaching Tool* is adaptable to a wide variety of design challenges. To develop a version of the *Engineering Design Coaching Tool* for their project, educators can consult the following steps and the template provided in Figure 5.

Block 1. Experiential questions

Preparation: Brainstorm potential design features that students might incorporate into their design prototypes. These should be features that are obvious and easy to recognize. In *Solarize Your World*, we identified three main features that students can manipulate in Aladdin: type of panels, location of panels, and panel orientation. Based on these features, we created questions that provide an entryway into eliciting student reasoning.

Sample question prompt: "I noticed that you used _[tilted panels]_ as opposed to _[flat panels]_. How did you reach this decision?"

Definition: The experiential questions, as their name refers to, start with an observation of an overt feature of the designed artifact or system. The experiential questions help initiate design review sessions as they are open-ended and accessible.

Block 2. Trade-offs questions

Preparation: List the key design criteria students are expected to address in their design. Consider ways students may weigh the importance of some criteria over others. In *Solarize Your World*, we identified four key trade-off factors: cost of building, the amount of electricity produced, aesthetic appeal, and safety. Then, we developed questions that probe into how students balance multiple criteria and constraints.

Sample question prompt: "You mentioned _[building cost]_ and _[electricity production]_ in your design. How did you balance these two?

Definition: The trade-off questions elicit student reasoning in weighing benefits and disadvantages as they negotiate competing design requirements (criteria and constraints). For example, cost and quality are considered competing criteria (Purzer, Duncan-Wiles, and Strobel 2013).

Block 3. First-principles questions

Preparation: Identify a list of disciplinary core ideas that students are expected to or likely to apply in the design project. With these core ideas in mind, develop questions to uncover how students invoked or discovered these concepts while designing. In *Solarize Your World*, we identified four main scientific principles that are relevant to this project: seasonal variation, heat transfer, solar insolation, and solar path.

Sample question prompt: "You mentioned that your system has good _[energy performance]. How do you think _[heat transfer]_ played a role here?"

Definition: The first-principles questions aim to elicit deeper understanding of fundamental disciplinary concepts that the students applied or learned when designing. The term, first-principles, is purposefully used to be inclusive of disciplinary content knowledge such as the scientific and mathematical concepts but also principles from other disciplines.

Block 4. complex abstractions questions

Preparation: Imagine possible ways in which the current design may be needed in a different context with different constraints. Create questions that probe students' ability to abstract their reasoning across new contexts and to predict future scenarios.

Sample prompt: "Imagine you could not use _[solar panels]_ but can re-design the building. How would you change the __[windows]_ in this building?"

Definition: The complex abstraction questions build on students' answers to the trade-offs and first-principles questions and invite the students to imagine what would happen if the context of the project or a feature of their design changes. These questions elicit the most complex thinking of all engaging future thinking in situations where both first-principles and trade-offs would need to be imagined.

Conclusion

The integration of science and engineering, as promoted in the *Next Generation Science Standards* (NGSS Lead States 2013) necessitates effective ways to elicit students' design reasoning. We recommend the use of the *Engineering Design Coaching Tool* for eliciting student thinking and for formative assessment. Depending on teaching goals and time availability, the tool may be used intermittently as an informal check-in on students' progress or at specific design stages where students will have design solutions to share. ■

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ON THE WEB

Aladdin software: *https://intofuture.org/aladdin.html*

For an editable version of the Engineering Design Coaching Tool, please visit *https://purr.purdue.edu/publications/3628/1*

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