A BIOMEDICAL ENGINEERING TWIST TO SCIENCE FAIRS

by Carin Helfer, Brian Davis, and Tracy Davis

Incorporating the engineering design process into the middle school classroom may seem challenging, but it is necessitated by the *Next Generation Science Standards* (*NGSS*) (NGSS Lead States 2013). At the middle level, students should "learn to sharpen the focus of problems by precisely specifying criteria and constraints of successful solutions" (NGSS Lead States 2013). Students should also understand that engineering is critical to addressing future challenges in society, as described in *A Framework for K–12 Science Education* (NRC 2012).

Holding an engineering fair instead of a traditional science fair is one way of incorporating the engineering design process into the curriculum while providing students with the opportunity to solve a problem that is of interest to them. Focusing on medical problems will further engage students by providing a unique and more personalized venue for actively participating in engineering design. By middle school, students are aware of many medical problems, often through the personal experiences of friends and family members. Therefore, projects that involve engineering solutions to medical problems allow students to solve real issues in which they have a personal interest. Additionally, these projects allow students to learn about different career paths, including medical professions, biomedical engineering, and other engineering disciplines involved with solving medical problems.

This article explains how to run a biomedical engineering fair in a science class, beginning with the engineering design process and culminating in a final student display. The article provides examples of both a traditional fair that uses external judges and a noncompetitive fair in which the teacher judges students against a rubric (Rillero 2011). For the second style of fair, students present their work to parents, teachers, and other fair attendees. Teachers can design both types of fairs to address the three dimensions of the *NGSS* and the *Common Core State Standards*.

The engineering design process

The engineering design process is different from scientific investigations. In science, a question is asked, a hypothesis is formed, and new knowledge is discovered. Engineering uses science to solve problems in a new way (Handley, Marshall, and Coon 2012).

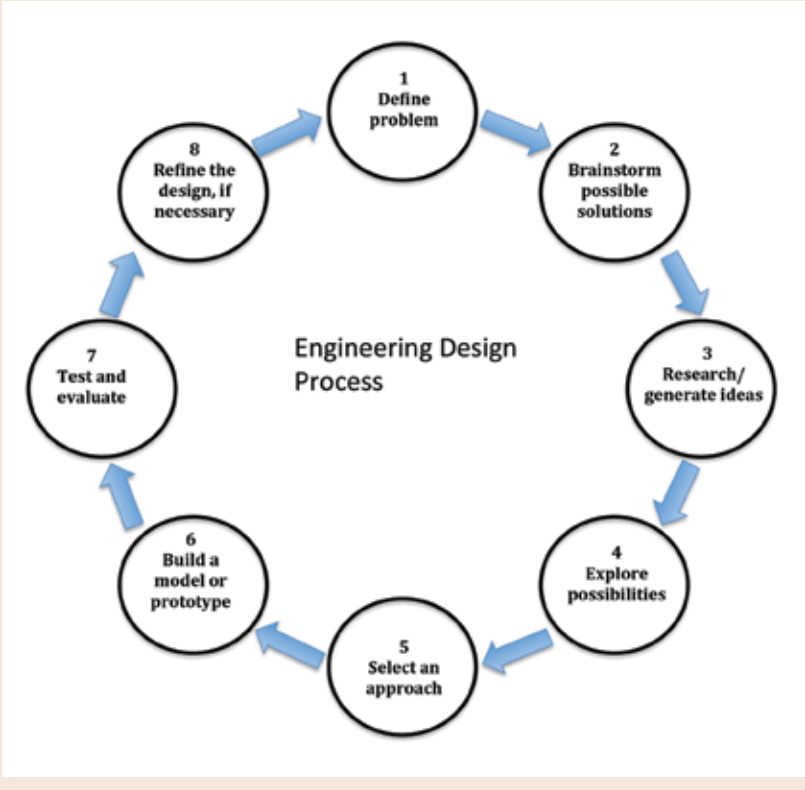
Although sometimes shown as a linear sequence of steps, the engineering design process (Figure 1) is not necessarily carried out in this manner. Often, a step backward may be needed when additional knowledge about the problem is gained. Students should also understand that the engineering design process is iterative and continues until the optimal design is achieved. Teachers should emphasize that innovation involves persistence and that the initial design often fails when tested. When students are working on real medical issues, however, they are more likely to push onward to a viable solution.

To begin their projects, students should choose a medical problem for which they would like to suggest a reasonable solution. Some design project ideas to share with students include:

- exercises for astronauts in space. If the load, or weight, on muscles is reduced, they will get weaker. In space, astronauts need to keep their muscles strong. Special machines are necessary for astronauts to exercise in space.
- a backpack that puts less stress on the spine. Backpacks put heavy compression on the cartilage discs, which can cause damage to the spine.
- a pill container that reminds patients to take their medicine. Elderly people often need to take several medications each day.
- a device that helps open jars for patients with arthritis.
- an improved wheelchair. Standard wheelchair designs have many problems involving weight, maneuverability, and pressure sores.
- simple, inexpensive medical devices for developing countries.

The World Health Organization and the Centers for Disease Control and Prevention have information on diseases and medical devices that can be useful to students (see Resources). An internet search of "Biomedical Engineering Lessons" or similar terms will result in additional ideas for projects. The websites Teach Engineering and BEST Medicine Engineering Fair (the fair hosted by this article's authors) also have several project ideas (see Resources). Students will likely be able to identify medical issues in which they have a personal interest.

FIGURE 1 The engineering design process



Pre-event preparation

The logistics for planning a biomedical engineering fair are similar to those of a science fair (see Figure 2 for a brief timeline and Resources for articles and websites that provide specific details on planning a fair). Before students begin to work on their projects, teachers should explain the fair and the engineering design process and offer possible project ideas. If there is a large disparity in students' economic backgrounds, teachers can set a cost limitation for project materials. Teachers should also address safety issues, because engineering

projects can pose potential hazards (Roy 2012). Teachers can then provide students with the Display and Safety Rules; an Approval Form, to be completed and signed by the student and a parent or guardian; a Risk Assessment Form, to be completed and signed by a supervisor or qualified scientist if the project poses any risks; and a Human Subject Consent to Research Form, to be completed and signed by any human testing subjects (download these materials online at *www.nsta.org/middleschool/connections.aspx*). Several middle school science and engineering fair websites have rules, guidelines, and additional forms that you can modify if you find you need further documentation for a student's project. If there is a question about safety beyond your or your administration's expertise, a more qualified scientist or engineer should be consulted, or the student should be redirected toward a less hazardous project.

If the engineering fair is held for longer than a class period, such as in the evening or on the weekend, teachers can invite STEM organizations to set up additional hands-on exhibits. Students' family members can visit the exhibits during the judging and students can visit after the judging while the scores are being tallied. Inviting these organizations and coordinating the logistics of the exhibits are tasks that can be assigned to parent volunteers.

FIGURE 2 **Timeline of tasks to be completed prior to the biomedical engineering fair**

	Tasks
Once the date and time are determined	• Inform school administrators of the date and other necessary details for the biomedical engineering fair. • Determine a location for the poster displays. • Create a one-page flyer for the biomedical engineering fair. • Recruit another teacher or a parent(s) to assist with planning. Having several parents to help will prove beneficial, especially if holding a traditional fair with judges.
Week 1	**Days 1–2:** • Introduce the biomedical engineering fair and the engineering design process to the class. • Have students start to think of project ideas. Encourage them to discuss their ideas with their families. **Days 3–5:** • Students determine the medical issue to solve for their projects.
Weeks 2–4	• Students brainstorm ideas for solutions to the problem, research their ideas, and select an approach to solve the problem. • If using judges, begin to recruit them.
Weeks 5 and 6	• Students build a model or prototype that they will test and evaluate. • If necessary, modify the rubric used to rate students. • Contact outside organizations, if planning to have hands-on displays.
Week 7	• Students redesign and test, if time permits. • Create a list of projects with project numbers. • Send flyer (inviting family members to the fair) home with students.
Weeks 8 and 9	• Students write reports and begin to create poster presentations. • Confirm judges and assign projects to judges. • Plan for snacks at the fair, if necessary. • Send second flyer (inviting family members to the fair) home with students.
Week 10	• Students finish poster presentations and practice oral presentations. • Print scoring sheets, name badges for judges, and signs for directing guests. • Prepare award certificates.
Week 11	**Biomedical engineering fair**

An engineering fair primer

For the past four years, Mrs. Davis has had her students compete in a local biomedical engineering fair, which is the highlight of her school year. When she first meets with students and their parents on back-to-school night, she explains that the Biomedical Engineering Project will be both challenging and exciting. She stresses to parents that students need to see the importance of science in their lives and that science can allow them to become entrepreneurs and "producers of new and exciting products," rather than simply consumers of goods. She explains:

> "My approach to science is to highlight the importance of problem solving as soon as the semester starts … by introducing a number of simple challenges that use the engineering process. Students respond with enthusiasm and some initial frustrations but are often surprised when I insist that 'failure' is absolutely an option. I tell them that it is the way that all engineers learn to improve their products. Some engineers may cringe [at my] 'quick-and-dirty' approach to engineering, not the ideal methodical approach favored by many. I believe that it is not feasible to expect students to be successful the first time they try to create a new product. However, they always come up with novel ways to look at a problem. They need to go through the process of trying to produce something before they are confronted with producing a novel device that can solve a human need for the biomedical engineering fair. In September, I give them 10 days to invent something with at least one rubber band. They must share their first prototype with the class, and they are encouraged to further develop the idea and enter it in the Rubber Band Contest for Young Inventors [see Resources]. I ask them to describe their frustrations, the difficulties, and the 'aha moments.' In this way, they are more prepared for the design process. A student in one of my classes became so frustrated with her lamp that she had made [using rubber bands] that she expressed real dislike for the invention and design process. She would, however, go on to excel in the school engineering fair and would win her category at the biomedical engineering fair. She

FIGURE 3 Student with a new wheelchair design being interviewed by a judge at the engineering fair

plans to enter the fair again this year, even though she is not in my class, because she already has a project idea."

In October, this teacher gives students a group project focusing on a real medical problem, which they must complete during a 90-minute lesson. A physician who visited her class explained that young children often put small items in their ears and are frantic by the time they get to the doctor's office, which makes it difficult for the doctor to extract the item with the tools available (see Resources). As a result, children need to be anesthetized to perform what could be a simple procedure. Students are provided with a number of materials to design a device to solve this problem. Students enjoy the competitive nature of the lesson and producing a prototype. Their work is supported by an engineering portfolio (see this article's online supplements) in which they show (1) a strong understanding of the problem, (2) information on the number of people affected, (3) the physiology of the ear, and (4) a brief drawing of the prototype. They also prepare a paragraph describing the device. Members of the team have to work together to be successful and are given clear directions on how to divide the workload.

In early November, Mrs. Davis has students read *Out of My Mind*, a novel by Sharon Draper about an 11-year-old who, as a result of cerebral palsy, cannot speak and is confined to a wheelchair. The novel presents problems and serves as a forum for discussing how an assistive device the patient receives makes a big difference. However, she still faces many obstacles, a fact that makes for engaging class discussions. Later in the month, students are given the opportunity to meet biomedical engineers from local universities, physicians, and a prosthetist. By December, students are ready to select the problem they will address for the biomedical engineering fair, a problem they can think of themselves or choose from the fair's website (see Resources). They also receive an engineering packet detailing every part of the project and when each part needs to be completed.

As part of their grade, students present a Topic Selection worksheet, Patent Search worksheet, Literature Review, Engineering Fair Proposal, and drawing of the prototype (see this article's online supplements). Before they begin building a prototype, students present their ideas to the class and receive feedback from their peers and the teacher. All work is shared on Google Drive so that teachers and students can communicate regularly about the project. The school engineering fair is held during the third week of January, and students are selected from this fair to participate in the regional biomedical engineering fair. This is when parents and students reap the benefits of their hard work. Mrs. Davis told us,

"I previously worked as a STEM enrichment teacher at several schools. We expected every student in sixth grade to produce a project. While many [other teachers] were skeptical [that all students would complete a project], the support from the administration was strong, and as a result, every sixth-grade student participated. More recently, the project has found further support in the form of a minigrant offered by my present administration. This afforded me the luxury of running a sixth-grade biomedical engineering fair [and] buying novels, display boards, and materials for the hands-on activities. We face many economic and academic challenges, as we offer over 75% of our students free lunch; however, this support provides a much-needed boost to this program.

"For me, this project allows for a disciplinary approach to teaching. Students are engaged in authentic problem solving, and this project fits seamlessly into the requirements of the *Common Core* and the *Next Generation Science Standards*. I am not an engineer, but I make sure I have the support of the community and experts in the field who are eager to work with teachers. The literacy component is very strong in terms of writing and reading, but of even greater importance is the speaking component. Students need to be able to interact succinctly and effectively with the judges/experts in the field."

Setting up for the event

Whether setup for the biomedical engineering fair takes place the day before, the evening before, or the day of the event will depend on the size of the engineering fair and the location. Allowing sufficient time to prepare makes the fair a less stressful experience (see Resources for more information about preparing for an engineering fair and managing on the day of the event). Judges and exhibitors should arrive with sufficient time to check in and prepare. Depending on the layout of the school, a few students or parent volunteers at the main door can direct outside guests.

At a judges' registration table, the judges should check in and pick up their scoring sheets (see this article's online supplements for an example scoring sheet). Because there may be some first-time judges, teachers should provide instructions and guidance. Tell the judges that they should provide students with positive feedback and constructive criticism. Every student should walk away having had an enriching ex-

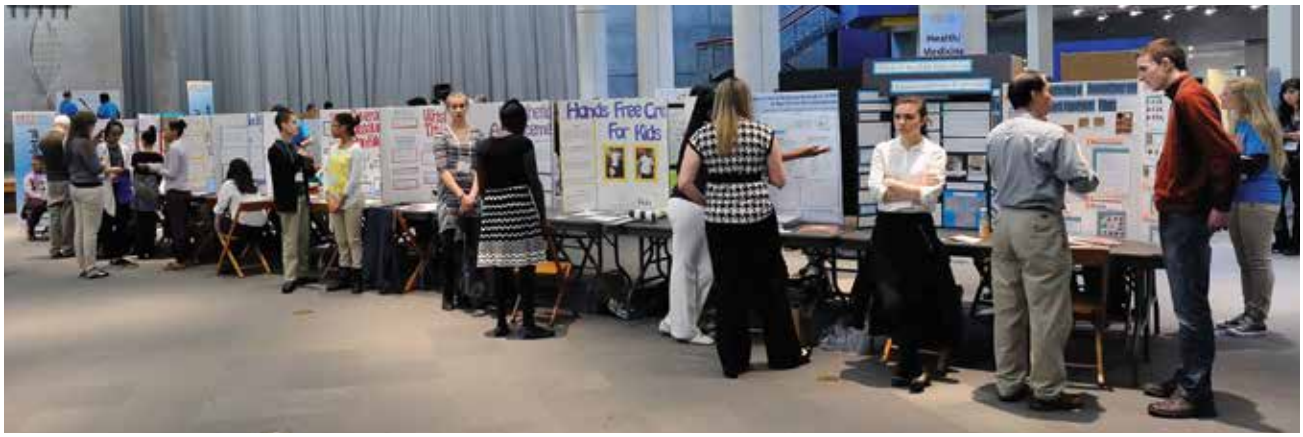
perience and looking forward to the next science or engineering fair. Judges should use numerical scores to help differentiate the quality of the projects. Any parent judges should not judge their own children, and all judges should be instructed to be unbiased. Teachers can send judges information (download this material with this article's online supplements) to review prior to the engineering fair, or guidance can be provided upon arrival or during a short information session prior to the start of the judging. If an information session is held, make sure the actual judging time is not shortened. Students can be judged on the following:

- knowledge achieved, relative to grade level;
- use of technological design;
- clarity of expression, which includes the written report, visual display, and oral presentation; and
- originality and creativity.

When judging begins, only students should be present at their posters (Figure 3). Although some eager parents may want to help students, their assistance should occur prior to the judging process. After judging is completed, the results are compiled. Students can visit the exhibits (Figure 4) and enjoy snacks during this time. A small awards ceremony can be held, during which certificates can be distributed, if desired. If recognition is given to the top projects, a certificate for participation can be provided to other students.

For the noncompetitive engineering fair, families, teachers, and invited guests can listen to students present their projects, ask questions, and provide helpful feedback. Hosting a noncompetitive fair can help teachers new to science and engineering fairs, because recruiting judges and tallying the projects' scores are both sizeable tasks without the help of reliable assistants. The noncompetitive fair will be less stressful for students too, especially for those who have not competed in a science fair before. Because the guests viewing students' presentations are not judging the projects, there may be increased dialogue between students and the audience. Grading of students against a rubric can take place during regular class periods. After successful completion of

FIGURE 4 Student at a biomedical engineering exhibit, which allowed students to simulate laparoscopic surgery



a noncompetitive engineering fair, it can be expanded to judges or additional classes or grades.

Teachers should remember that even with the best planning, a large event can always have minor glitches, which usually can be handled quickly. The fair will be successful if teachers remember that the goal is to motivate students to have positive attitudes toward STEM and STEM careers.

Conclusion

Holding a biomedical engineering fair is an excellent approach for teaching students about interdisciplinary science and the engineering design process. Local medical professionals and biomedical engineers attending the fair allow students to explore potential career opportunities and provide students with valuable feedback on their projects. Working on real medical problems of interest helps motivate students to persist in their efforts to solve human problems. ■

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Engineering packet—*www.uakron.edu/engineering/BME/bestmedicine/how-to-start.dot*

Information and forms for science/engineering fairs—*www.highlands.k12.fl.us/~sms/science.html*; *http://massscifair.com/fairs/middle-school/manual-forms*; *www.sciencebuddies.org*

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World Health Organization—*www.who.int*

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