Curriculum Exchange: "The Art of Engineering": a Four-Year Project-Based High School Curriculum

Dr. Sandra Hull Seale, UCSB

Dr. Seale earned the B.S.E. in Civil Engineering from Princeton University in 1981, the S.M. in Civil Engineering from MIT in 1983, and the Ph.D. in Civil Engineering from MIT in 1985. Dr. Seale is currently working as the Project Scientist and Outreach Coordinator for the Seismology Research Laboratory at UC Santa Barbara.

Mr. Amir Muhsin Abo-Shaeer, Dos Pueblos Engineering Academy
A Four-Year Project-Based High School Curriculum

Background: A teacher who is the recipient of a MacArthur Foundation Fellowship is implementing a new four-year project-based curriculum in Science, Technology, Engineering, Art, and Mathematics (STEAM). The program is designed to give students a real-world, interdisciplinary, project-based approach to learning. The program strives to create a balance between theory and application.

Motivation: Driven by what he perceived as a disconnect between formal education and engineering practice, a teacher in California has designed a high school curriculum that delivers project-based education to 400 students enrolled in the program at a public high school. In recognition of his visionary ideas and success in attracting students (the engineering program has 50% female enrollment, which far exceeds national averages), the teacher was awarded a MacArthur Foundation Fellowship in 2010.

The program is also designed to make students enjoy and be fully engaged in their own education. The projects are fun and personal and the resulting works of art are delightful to the eye and have a professional level of fit and finish. Students in the program learn concepts in physics, art, and engineering in a greater depth than in traditional theory-based classes. They also learn why they are studying theory by experiencing practical applications.

The implementation of the new curriculum is facilitated by the construction of a new 12,000 ft² facility, dedicated to the program, on the high school campus. The facility includes a conference room, computer laboratory, mechanical engineering classroom, electrical engineering laboratory, prototype space, and state-of-the-art machine shop. The new facility has its own servers and IT network.

The program has a team of five teachers, who are credentialed in physics, visual and performing arts, and engineering technology. The teachers hold other positions within the program; the machining teacher is the shop manager and the computer teacher is the IT manager for the facility. The founder of the program also serves as its director and the art teacher is the assistant director.

Curriculum: The STEAM curriculum consists of one class per day for the freshman, sophomore, and junior students. In the senior year the students have one engineering physics class during the day and take a robotics class in the evening. The students are otherwise fully integrated in the public high school.

The course sequence includes the following dedicated classes:

- 9th Grade: Engineering Technology
- 10th Grade: Engineering Sculpture and Design
- 11th Grade: Engineering Physics
- 12th Grade: Advanced Engineering Physics and FIRST Robotics (double-length class)
All classes apply project-based learning, *i.e.*, the use of classroom projects to facilitate learning and assess student competence. This instructional method provides students with complex tasks based on challenging questions or problems that involve the students’ problem-solving, decision-making, and investigative skills. Students develop valuable research and design skills. Project-based learning promotes new learning habits that emphasize creative thinking.

During their first three years of study, 100 students per grade are enrolled in an integrated project-based curriculum that collectively covers, in an interdisciplinary fashion, the content contained in 1) a standard laboratory science physics course, 2) a standard visual and performing arts sculpture course, and 3) an engineering elective course. Content is covered in a completely integrated, interdisciplinary fashion. The sequence provides credit for a year each of physical science, visual arts, and an elective.

During the class period, the 100 students in a grade are divided into four classes of 25 students. All 100 students are working on the same project. The curriculum is carefully staged so that students receive the content in an appropriate order for the design, manufacture, and assembly of the project. The curriculum for each project is divided into modules that address topics in a time period of weeks. The modules covered are design (art and physics), computer programming, machining, and assembly. At the end of a module, each group of 25 students rotates to the next unit. The 100 students finish their projects at the same time and then move onto the next project.

The projects build in design complexity as the skills and knowledge of the students grow. Upper class students (juniors and seniors) assist as mentors in the classes of the freshmen and sophomores. Local industry engineers also volunteer as mentors in the machine shop. Figure 1, below, shows a student in the machine shop operating a lathe.

**Figure 1.** Student operating a lathe in the machine shop of the new facility.
Projects: Three projects will be presented here:

1) Students construct a hanging mobile. The sculpture has multiple moving parts and is colored to enhance the form. Elements and principles of design include line, shape, color, movement, balance, and space. Students use tools associated with engineering technology such as calipers and electronic balances. Students calculate the force of gravity acting on each object and calculate all necessary torques and forces for balance. Students fabricate fasteners that allow elements of the mobile to be adjusted during assembly. In Figure 2, below, students are working on design and color studies. Figure 3, below, shows a student with her completed mobile.

Figure 2. Students working with the art teacher on design and color.
2) Students build a programmable light sculpture. The sculpture has a metal housing that is fabricated by the students. The sculpture consists of acrylic rods, which are machined by the students and then mounted in the housing. Students use soldering irons, build a DC circuit board, and wire the components together. The rods are lighted in color from below. The housing contains an Arduino computer (http://www.arduino.cc/) that controls the timing and color changes of the sculpture. The students use the open-source Arduino platform to program their light sculpture. Figure 4, below, shows students working on the programming of the light sequence for their sculptures. Figure 5 shows the project during construction and the completed light sculpture.
Figure 4. Students in the computer lab working together are programming the light sequence of their sculptures.

Figure 5. (a) The light sculpture during construction, showing the Arduino computer and circuit board in the housing. (b) The completed light sculpture.

3) Students design, program, and construct a wall-mounted moving sculpture. The sculpture consists of pulleys whose motions are controlled by an onboard computer. This project is a step up in complexity of concept, design, and execution for the students. A prototype of the project is shown in Figure 6, below.
Figure 6. Prototype of the pulley assembly that will drive a wall-mounted moving sculpture. Each student will design, fabricate, and assemble a sculpture.

Results: “The Art of Engineering” is in its second year of development. No formal assessments have been performed yet. Anecdotal evidence is strong that the approach is successful. Fully half of the enrolled students are female and more than 200 students in the school district apply in 8th grade for the 100 available spaces in the program.

Many students report that this is their favorite class of the day in high school. Many students who were not considering engineering as a career have said that they now plan to major in engineering in college.

This approach to project-based education can be delivered by any high school. The curriculum is portable and can be set up in a school that has a modest machine shop. It is possible to start with a single teacher and a small cohort of students and grow the program incrementally.