ProjectEngin™

ENGINEERING IN YOUR CLASSROOM

Some Basic Guidelines

CHANGING THE CULTURE: CREATING AN "ENGINEERING" ENVIRONMENT

It is important that students recognize that this learning space is different. The overall approach needs to focus on collaboration, planning, actively doing, and respect. The idea that there is no one right answer and that mistakes are okay is difficult for some students to accept. The following guidelines will help to establish a classroom "culture" of engineering and design.

1. **RESPECT.** Rule one is always respect. All ideas are worth considering and problems are more easily solved when everyone contributes. These ideas should be embodied in a classroom "mantra".

2. **DIVERGENT THINKING.** Strongly discourage the tendency to focus on the first idea for a solution. Divergent thinking is not highly valued in traditional education so this may take time. Student groups need to show evidence of brainstorming and consideration of multiple solutions before proceeding to a prototype.

3. **"JOBS" IN GROUPS.** It is really helpful to describe different roles or "jobs" for more involved projects. This mimics the real world, forces all to participate, and makes accountability easier to maintain. Most successful K-12 Engineering projects feature a good deal of role playing, since you are modelling real-world scenarios, challenges, and solutions. Students are pretty good at it if you encourage it early on.

4. **PROCESS!**! Engineering and design are processes and do not occur in a completely haphazard way. Discourage excessive "trying" without a plan and require some level of documentation. (A few forms or graphic organizers or a group Engineering Notebook). Your biggest role as a teacher in this type of class is to keep going back to connections to core curricular content. Designs and modifications should be justified by a scientific concept or by an engineering need (i.e. resources, fit, etc.). The Design Rationale Form and the Modification Form can help to keep students on track. Please note that although there is a process, it is often iterative and sometimes non-sequential.

5. **GROUPING.** This is highly class- and teacher-dependent. Most projects that we like and use are designed for groups of 4, although 5 will work. Some more complex projects (modelling systems) can be done in groups of 6, although monitoring and accountability can become more challenging. We tend to discourage groups of 3 in most cases since "the odd man out" syndrome seems to happen more frequently in this case.

6. **DOCUMENTATION/The Engineering Notebook.** All longer term projects should be documented. Most of the learning will occur in the process, not in the finished product. It is important that students document the process in order to insure that they are on track and to have a way to go back and use information and ideas discovered earlier. It is equally important that you as a teacher have a way to check on progress and quality of work and still have time to interact with students in class. There are a number of ways to organize and document work but the following seems to work best:

    - There should be one Engineering Notebook (ENB) per group and it should remain in your classroom. We have developed a set of core forms and organizers that are available to the schools and teachers that we work with.
    - ½ inch binders work well and can be decorated and reused if the cover has a clear plastic sleeve.
    - It is helpful to most students if they have some sort of timeline or a least a simple reminder at the front of the room each day concerning what forms should be completed. The forms end up serving as a process “roadmap”.
    - Students should also be encouraged to keep notes and observations in their ENB. You can provide blank forms, or blank loose-leaf or graph paper for that.

USING THE ENGINEERING DESIGN PROCESS

The Engineering Design Process consists of the following key components:

- Problem Definition
- Research; identifying criteria and constraints
- Generating solutions
- Design
- Building or Prototyping
- Testing
- Analysis and Troubleshooting
- Modification and Retesting
- Communicate results

We like to think of the overall process as consisting of four main phases. In Phase 1, students work to clearly identify the problem and map out the design space, determining constraints, criteria, and background information. In Phase 2, students consider multiple solutions and work toward choosing the one that best fits their design space.

Phase 3 is all about building a prototype or developing a model and testing it. The most important part of Phase 3 is the opportunity to modify the prototype with the goal of optimizing the design. And in Phase 4, students communicate what they have developed and learned.

None of this is strictly linear. Design is a fluid process and there is much overlap and iteration. The key things to emphasis are that in a well-designed product or process you need:

(1) **KNOW WHAT YOU ARE TRYING TO DO.**
In other words, have a very clear definition of the problem and all factors influencing it (criteria and constraints).
(2) **KNOW WHAT YOUR OPTIONS ARE.** Thoroughly consider all alternatives and approaches.
(3) **KNOW IF AND HOW WELL IT WORKS.** You need a model (prototype) that allows for reliable, documented testing.
(4) **KNOW HOW TO MAKE IT BETTER.** It is important to have clear analysis and modification.
(5) **KNOW HOW TO SPREAD THE NEWS.** Communicate your results.

Keeping these five points in mind may be easier for students and will help them get started.

ORGANIZATION IN THE MIDST OF CHAOS

The Engineering Design Process (EDP) is meant to give some organization to the often chaotic nature of creativity. In order to encourage innovative thinking, creativity must be paramount. But it is important for students to understand that all of that creativity can be lost if it isn't harnessed or brought in to focus at some point. As a teacher, you want to encourage divergent thinking to generate as many potential solutions as possible, but then shift to a more convergent approach to reach the agreed upon solution. This is new for many students (and teachers) since so much instructional time is spent focusing on very specific ideas in most courses. Most of thinking in a typical classroom is convergent, aimed at getting that one correct answer. While divergent thinking often comes naturally to young people, it may not be a technique they are comfortable using in the classroom. A good way to get students to think divergently is to ban the use of "if" and "but", encourage the use of "and" and "or", and have them try some of the techniques embodied in the SCAMPER acronym. This is a helpful guide to SCAMPER for Creative Thinking.

It is very important to have students document all their thoughts, discussions and modifications. An idea that was discarded early on may have value in the later stages of the process. Divergent thinking is exactly what it says it is, divergent. It is branching, messy, and decidedly non-linear. The adolescent brain is very good at this stream of consciousness approach, and often not so good at the convergent process that is needed to pull all the pieces together to get a final solution. In other words, students will find it natural once it is introduced, and they may have difficulty moving away from it. The practice of writing everything down lets students find a path (a linear process) back through all of that creativity to the final solution. Having a clearly defined problem and a logical process for summarizing and backtracking, frees them to allow thinking to spread out and then re-focus. Students can use Post-Its with simple phrases or sketches and notes on a large piece of paper. Brainstorming does not need to be neat, but it should be documented.

Although there is much fluidity in the design process, students need to be aware that it is not simply trial and error, but a well-documented process. The following example may help them to see the value in having a process.

If you want to get to a friend's house across town, you probably have several ways to get there. But if you don't first know where that house is, you will never find it (problem definition). You probably wouldn't use a trial-and-error approach of driving up and down every road looking for the right house somewhere in town. And if you get in a car and drive through houses, and backyards, and shopping malls, or if you run out of fuel, your attempt to get there will be unsuccessful because you will be arrested due to not following a process (roads) and or stopped because you are ignoring constraints (fuel, safety). You need to follow a process to get there. You identify where you need to go, you identify all the constraints, develop criteria for a successful trip (scenery, safety, time, etc.), consider all the alternatives, choose the best route, and implement your solution.

We follow processes all the time. Ask students to identify some that are part of their daily lives.

The Engineering Design Process is not meant be totally prescriptive and limiting. It is meant to help students frame a design problem and define the space they are working in. Basically, you can't solve a problem if you don't know what it is and what your options are. Processes give us structure and allow for freedom because they make our goal seem clear and attainable and often make alternative approaches more apparent.

ENGINEERING DESIGN PROJECT VERSUS SCIENTIFIC INVESTIGATION

There are more similarities than differences between the processes of Engineering Design and Scientific Investigation. The biggest differences can be thought of as being at the beginning and the end. Scientists begin with a question to answer, while engineers start with a problem to solve or a challenge to meet. Most scientific investigations end when a hypothesis is proven or disproven. The Engineering Design Process never really ends – results can always be modified and improved. Modification is often the most important step in the design process.

All experiments have certain hallmarks. Testing prototypes have similar defining parameters. Have students focus on dependent and independent variables. Involve students in the discussion about valid ways to measure performance in some cases (called “Design of Experiment” in industry and new product development).They should always be reminded of criteria and constraints at this point. It is also important that they are aware of issues relating to experimental design such as a reasonable number of trials, good reproducibility and sources of experimental error. In the long run, the skills needed to test either a scientific model or an engineered product focus on the ability to think critically and to make connections.

All testing procedures and requirements should be clearly defined early in the project, either by the teacher alone or with some input from the students. As a result, and in keeping with backwards design principles, it makes the most sense to follow the establishment of the goal with the development and description of how you will determine if you reach the goal. Scientists follow the development of a hypothesis with the determination of how to test for validity. In other words, they determine what can be done to offer proof that the idea is right or wrong. Designers always need to know what performance standards they are designing to, because success is probably defined in terms of whether or not they meet those standards.

Another area where students need to be reminded of good experimental procedure is during the modification stage. When students make modifications to their products, they should be reminded of the need to isolate the variable they are investigating and to therefore change only one thing at a time. The rationale here is the same as in the scientific method. It is impossible to determine causality if you change more than one thing. Retesting should adhere to the same conditions as the original testing for the same reason.

Data recording in engineering is similar to that in science labs. Everything should be noted. All ideas, observations, and data should be documented before making changes. Students frequently find sketches and photographs of their artifact or various aspects of it very helpful in troubleshooting, modifying and in compiling reports. It is sometimes difficult to predict outcomes and the ability to backtrack is often needed. Verbal, numerical, and visual data can all prove to be helpful.

As we mentioned, a big difference between conventional science labs done for verification and an engineering design project is how the outcome of testing is used. In verification labs, there is usually only one correct answer. Actually, in science in general, experimental results often have a yes or no role. They either verify the model or they show it to be false. Engineering focuses on the search for the best answer. In other words, results in science verification labs are often regarded as the end result and results in engineering experiments provide information that can be used to improve the end result, which is the product or process. It is, therefore, very important to allow for time for modification and retesting. Analysis is often troubleshooting in engineering, as the challenge is usually to determine how to improve or correct performance.

ASSESSMENT ISSUES

Formative assessment should occur throughout any project; students need a lot of feedback to work in groups and to work fairly unscripted. In most cases, project grades will form the bulk of summative assessments and should reflect both an individual (25-30%) component and a group grade (70-75%). A sample grading breakdown follows, but grading should be adjusted to reflect practices and standards in place in your school and classroom. The breakdown given here is for a large scale, longer term Engineering Design Challenge. This model can be applied to the Engineering or product design component of the STEM Fair. It can also be used for other projects that you may elect to do throughout the school year.

SAMPLE ASSESSSMENT COMPONENTS OF PROJECT

Individual	30%
Any Worksheets	10 pts
Individual Performance Review by Group Members	10 pts
Contributions during class time	5 pts
Contributions to report/presentation	5 pts
Group	70 %
Design Process Notes and Documentation	35 pts
Assessment of Product	15 pts
Report/Presentation	20 pts

Contact us for a 5-8 class lesson plan designed to introduce middle and high school students to Engineering and the use of the Engineering Design Process follows. It is suggested that you at least get students familiar with the process of Engineering before asking them to make it the framework of a longer design project.

Think about ways to include Engineering Design projects in your curriculum. Many of ours include application of several key science and math concepts, making them an ideal way to replace several traditional activities. We believe that E is key to STEM that works!