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ENGINEERING EVERYWHERE

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Introduction

Engineering is literally everywhere. It's a useful exercise to ask your students to make a list of all the things that they can think of that are not engineered. There are clear answers like almost every living thing, rocks, water and so on, but aside from that, there aren't many things that one encounters in everyday life that haven't been influenced by the engineering design process. Every product you can buy, the containers and packaging in which they are shipped, the cars we drive, the boats that delivered them and even the very electricity that runs the lights above you has been optimized and engineered in one way or another.

This highlights a need for a good definition of engineering. It's most easily defined as the application of science and technology to a problem to make the world a better place. Admittedly, that's pretty broad, but there are a great many branches under the umbrella of engineering. So at its core, engineering is the application of science and technology, which makes it a perfect vehicle for students to practice what they've learned, expand on the lesson, or learn something new. It's really just a matter of switching up a few things. The diagram below illustrates the potential use in a classroom.

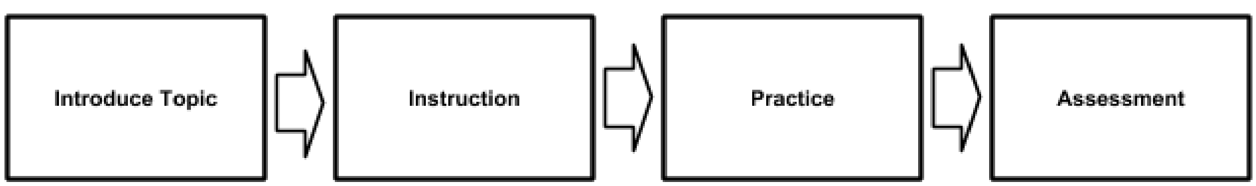

Figure 1. "Traditional" sequence of classroom instruction.

Clearly, I don't mean to imply that all teachers teach just this way, or that there aren't techniques like problem-based learning and labs and demonstrations, or that this is the only way to teach. But broadly speaking, this is generally how things happen. At each of these points, there are myriad ways to incorporate some of the principles of engineering or of the engineering design process (hereafter EDP). This will be the major focus of this session, and I'll break things down by these four broad areas so that you can include engineering in the best way possible for your classroom.

At this juncture, it's probably useful to quickly point out the major steps of the EDP, before we go about figuring out how we can fit it into any classroom or lesson. The graphic presented here is taken from a website published by the University of Colorado at Boulder called TeachEngineering. That website has a wealth of information from curriculum maps to lessons, all very well put together and all free! I highly suggest that you check it out for some resources that can compliment what we'll talk about today. There are a lot of great projects and smaller ideas that can get you started in the right direction.

In essence, the EDP is a way to apply science and technology to solve a problem. It takes into account the type of problem, information you need to collect and how you can use it to make a good decision about how to proceed. The first step is to identify the need, and characterize the problem. What measurements can you take? How will you know if the solution that you find is a good one? And most importantly, what are your criteria for success? That is, how do you know when you're finished?

The next step is to find a way to solve the problem that you've characterized. You've got to not only determine how to solve the problem, but select the right solution from among a bunch of different ones. Basically, you've got to figure out for which factor in the problem you're going to optimize. A cheap solution? A durable one?

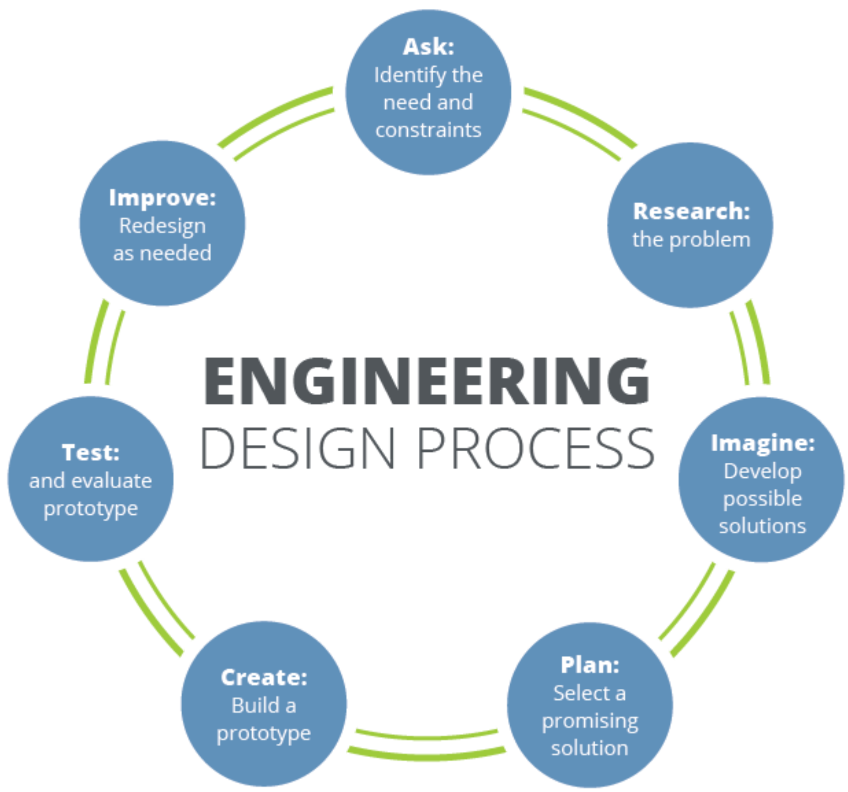

Figure 2. The Engineering Design Process

Then comes the fun part of building and testing and redesigning. Finally, if your design meets all the criteria for success that you set out at the beginning, you're done! Of course, you're never really done; there are always improvements that are possible. You'll just determine a new set of criteria for success, and keep moving along!

A QUICK NOTE ABOUT TIME

We all have a lot of things that we want to teach, and I have never had a year where I have been able to cover everything that I need or want to to the depth that I think is appropriate. To that end, it seems incredibly wasteful to add in one more thing to teach. However, think about engineering another way. The entire point of the field and of the EDP is to make products and processes more efficient. If you invest fifteen minutes (that's all it takes!) at the beginning of the year talking about logical decision-making with Pugh charts, then your students have a tool that they can use throughout the year (and their lives?!). If you spend a further fifteen minutes talking about actions and functions, then whenever they write a procedure for a lab, or think about a way to solve a problem, they'll be doing it with an engineering mindset, and they're much more likely to come up with an efficient process and/or solution that doesn't involve guessing and checking.

Further, the NYSSLS has, integrated within every standard, engineering practices! And if you head on down to page 80 (the last page), you'll find the high school level engineering standards. In the 21st century economy, it will be paramount that your students have these kinds of skills to make them employable and successful. Plus, won't it be a nice little feather in your hat when you can boast to your principal that you're covering all of all of the standards?

AN EQUALLY QUICK NOTE ABOUT SPREADSHEETS

If they are not already, spreadsheets should become your best friend. Frequently in the field of engineering, the first run of an experiment is not done physically, but rather, as the current lingo has it *in silico*: on a computer. The software and computing power that is necessary to model many complex physical phenomena is generally unavailable to schools, although some fairly useful tools do exist. Algodoo is a free program that can be used to simulate a lot of mechanics situations very accurately. Energy 2D is pretty slick for modeling heat transfer and thermodynamics-related concepts. MyPhysicsLab has some simple things that you can customize if you know some JavaScript. Desmos is a great graphing tool for pretty much everything. In the absence of anything else, an Excel spreadsheet or Google sheets can get you pretty darn close to what you need.

It will be another good investment of time if you can give your students some good spreadsheeting skills. They can easily collect data and graph it, and there won't be any tedious moving of data from lab notebook to computer. They can apply more rigorous statistical analysis, get more information, share with their groups and generally get a more realistic scientific experience. They can also create logic with formulas that can help them model complex situations and solve difficult equations that they might otherwise have to do multiple times. A few minutes or even a class period at the beginning of the year can save a lot of time.

BRAINSTORMING

Coming up with good ideas is essential in engineering. It turns out that according to a number of peer-reviewed papers, group brainstorming is detrimental to the idea-generation process. In short, in a group of people, those who are quieter or not as forceful but who have good ideas might be overpowered by people who are louder or more confident, but have less productive ideas. Further, people might assume that others will have better ideas than them, and not participate, or the group might latch onto one idea early on in the process, making other ideas less likely to surface. There is a great deal of research that suggest that brainstorming should start individually, with each person making a list of their ideas, and then moving to a group to narrow down the ideas. That's what I suggest.

Sticky notes are great for this. Have each student quietly brainstorm ideas to solve a particular problem, putting one idea on each sticky note. Go for volume, not quantity at this point. Then, have the students share all their notes, and group them. For example, if you were brainstorming ideas for a rotation-counter in a lab, you could group the electronic ones together, the mechanical ones together, ones that required a battery, ones that required the purchase of materials, etc.

Once you have the ideas grouped, you can start making sketches that incorporate these ideas. This is the phase where you take your ideas for how to fulfil your requirements within the constraints that you set forth. Students should make multiple drawings and then use some decision making techniques to decide on which works best.

REQUIREMENTS AND CONSTRAINTS

When engineering, ideally you'll have constraints within which you engineer, and requirements, toward which you engineer. Constraints are generally set by outside factors -- the materials available, costs, size, payload capacity, etc. So for a car key, it couldn't be so big or heavy that it wouldn't fit in a pocket, but it can't be so light that it would be easily lost. Requirements inform design decisions, too; if you're making a car key, it must actually unlock your car, and possibly start it and even send the windows up or down.

It's helpful to make sure that these requirements and constraints are as concrete and quantifiable as possible. In this way, you'll actually know if your proposed design meets your criteria for success. Try your hand at coming up with a list of requirements and constraints that can be measured for a car key:

Requirements	Constraints

Figure 3. Requirements and constraints for a car key.

DECISION-MAKING

One way to make a decision is to line up all of the available choices and then pick the best one. But what does "best" actually mean? Do you want to pick the most efficient, the least expensive, the most complex? A Pugh chart (named after Stuard Pugh, and pronounced "pew") is a rational and convenient way to actually make a decision based on data, and remove all those nasty and confusing emotions and feelings from the calculation. You can find a neat-o online version of an adjacent type of decision matrix (that's free and easy to use with your students in real time -- it's all web-based) tool called Rationalize.io online. You just put in your choices and criteria, and in no time you have your logical decision. The idea of a Pugh chart is that you compare new designs to an existing one. The online version is a little different in that it is not comparing all new ideas to an existing one; rather, it's comparing all the ideas against each other.

If your jam is more along the pencil-and-paper line, you can use a matrix like the one in figure 4.

Criteria	Weight	Design 1	Design 2	Design 3
Mass	4	+	++	+
Size	2	-	-	+
Shape	0.5	0	0	++
Average		2	6	7

Figure 4. A weighted Pugh chart.

You can see that we have three designs (of something) that we're comparing to some existing design. A plus means that the design is better than the original; a minus indicates that it's worse. A zero means that there isn't any measureable or effective difference. The weights reflect the fact that we're really trying to reduce the mass of this new design, so it's weighted more than other categories. In order to find the totals, add up all the plusses and multiply by the weight. Then do the same with the minuses and sum it all up. Here, design three seems to be the best given our criteria.

ACTIONS AND FUNCTIONS

When you're setting out to design a new product or solve a problem, it's important to figure out what *you, the person* needs to do, and what your *machine or tool* will do in response to that. Things that people do are called actions, and things that your tools do are called functions. When designing something, it's useful to separate these two things so that your classical notion of what a thing should do (function) when you do something (action) doesn't hamper the process of coming up with new ideas. For example, there are many ways to open a door -- and many ways that doors can respond. You can have a knob, handle or button, and the door can swing, slide or fold and flop. What the door does depends on what you do, and if you're designing a door, you've got to figure out if the necessary action on the part of a human is something appropriate. This is where an important concept called universal design. The basic idea is that anything that you design and build should be usable by anyone, regardless of their age, ability level or other factors. Getting your students to think about this helps them become more sensitive to the needs of those around them, and helps them think about how to make the built environment a better place for everyone.

A good way to try this for a project in your class is to make an action flow chart, and then pair functions with those actions. For example, a smartphone might require a user to pick it up, unlock it, swipe around for a while, turn off the screen, and put it back down. These are some rather vague actions. More specifically, we might say that the user needs to locate the phone, pick up the phone, place the required finger on the fingerprint sensor, re-orient the phone from unlocking position… you get the idea. The more specific you can be, the better you can define your functions.

Remember, though, that *Every action has a function!* Even something as benign as "pick up phone" has a function that the phone must do -- it must be able to be picked up. An engineer would want to respond to the noun-verb pair of the action with a similar noun and verb: "accept hand." The phone needs to be of a size, shape and texture that allows the user to pick it up. If you need to unlock it, then the phone must "reveal homescreen." Practice making an action flow chart and matching functions to those actions for a car in figure 4.

Action	Function	Notes

Figure 5. Actions and functions for a car.

BENCHMARKING

After you've got your requirements and constraints, it's important to see if they're reasonable. For example, if you set the requirement of the maximum size of a car key to be 10.0 cm, is that reasonable? You might go out and measure the hands of 25 people to see if the average hand size can hold a 10.0 cm key. Or measure 25 pockets to see if such a key could fit in a standard pocket. Be creative! What other things might need benchmarking? The force required to depress the buttons? The size of the lanyard? Keep in mind safety (if you needed to press the button in a hurry, could you do it? Could the lanyard pose a strangulation hazard if it is too long?), but also the concept of universal design. Generally, a simple list of what you need to test and what the results are works out well. You might go back at this point and redefine your requirements if something that you put down now seems unreasonable.

One thing that is often neglected is the fact that not everything is best done with a machine! If you're looking for the praise of the raspberry industry, design a raspberry-harvesting machine. It turns out that all raspberries destined for eating (frozen ones and those for making purees or juices are different) are picked by hand. Further, they all have to be grown under plastic hoop houses (it turns out that if the berries get wet, their shelf life is reduced to only a few days -- not enough to ship them across the country and get them into stores and sell them) to protect them from rain. Short story long, when benchmarking, don't forget to consider doing something by hand -- the cost of paying a person do to it might be less, and the quality might be greater, than doing it by machine. A homemade pie is always tastier, right?

Procedure

In this activity, you're going to need to apply the EDP to a number of different situations that you might encounter in a STEM class. I've provided these only as examples; when we're done here today, you should hopefully be able to apply the EDP to any topic that you'd like. Each group will get a card with a problem to solve, and they'll have to take some time to work with their group to solve the problem.

CARD I: Your team has an equation to solve: $2x^2+7x+3$.

CARD II: You team needs to find the best way to sort a large number of coins into their respective denominations.

CARD III: Your team needs to find an efficient way to count the number of times per minute that a disc rotates.

CARD IV: Your team needs to find a way to sound an alarm when the light in your bedroom gets to a certain level.

CARD V: Your team needs to determine how to measure what the knob on a toaster actually means.

CARD VI: Your team must figure out how to build a tower of a given height that can support a textbook.

ENGINEERING IN THE FOUR DOMAINS OF A LESSON

INTRODUCE TOPIC

To insert engineering into the part of your curriculum where you introduce topics, consider allowing students a small amount of time to do a part of the EDP. If you're going into a unit on fermentation, ask them how you might measure the rate of the reaction. There are lots of ways that teachers commonly get at this, from balloons on flasks to pressure sensors, and having the students to a bit of research, or make a action diagram for what they might do (hence forcing them to think of the functions that the yeast or the balloon must do!) to take a measurement.

What this would ideally lead to is students poking around online to find out how winemakers might measure fermentation rates, or finding things other than temperature and pH that might affect the rate of fermentation. If your unit is on projectile motion, instead of just having the students launch a ball and determine its landing spot, have them determine what kind of launcher would be best. A solenoid? How much force do you actually need to get the acceleration necessary to produce the initial velocity that you desire? Can a solenoid do this?

INSTRUCTION

Have students make models using Sheets or other programs to help them understand and find patterns. Does a line on a graph come out straight or curved? What does that tell you about the data? Are there better ways to collect data?

PRACTICE

Students can use their skills of finding actions and functions and apply them to the human body or to a chemical reaction. What is the purpose of an enzyme? What action does it do, and what function is the result of it? Framing questions in the guise of the EDP can help students think like engineers and therefore solve problems efficiently.

ASSESSMENT

Students can create any number of engineering-themed projects or assessments, it could be as simple as making your lab reports into engineering reports, and including a section on why the decisions were made, and which decision-making technique was used to make it. You might consider including the requirement of a short piece of code or a spreadsheet for every lab.

Materials

Arduino Super Starter Kit: This is a great starter kit for all your electronics projects. It comes with wires, an Arduino (knockoff...but it works just the same!), even a battery! The kit is about $35.00 here, but you can also find it for a bit more from Flinn if Amazon is not an option. One kit can last you a while, and can be shared by many students because there are so many different items in it. You can buy separate boards for about $10.00 here, and have multiple students working from one kit.

Vernier: If you haven't explored this company yet, do so as quickly as you can! See if you can contact your BOCES or other departments to collaborate on purchases. Your elementary school teachers are great resources, and the earlier that you can hook the kids on data collection, the better!