The STEM fields

Science, Technology, Engineering, and Mathematics

• **The Scientific Method** is a strategy employed by scientists (and other critical thinkers) to pose and test the validity of a question, as a means to construct an accurate (reliable, non-arbitrary, consistent) representation of the world:
  • Observation and description of a phenomenon
  • Formulation of an hypothesis to explain the phenomenon
  • Use of the hypothesis to predict the existence of other phenomena, or to predict the results of new observations
  • Performance of experimental tests of the predictions, by several independent experimenters
The STEM fields

Science, Technology, Engineering, and Mathematics

• The Engineering Method is a strategy employed by engineers (and other critical thinkers) for causing the best change in a poorly understood situation within the available resources
  • Problem definition
  • Generation of possible solutions
  • Deciding the course of action
  • Implementing and evaluating the solution
The STEM fields

Science, Technology, Engineering, and Mathematics

Example:

When Ronald Reagan was President, he promoted a new generation of space weapons to create a defensive shield and called upon the "scientific community" to develop the Strategic Defense Initiative (SDI or "Star Wars"). He actually meant to call upon the "engineering community."

He did not want to see whether a defensive shield will violate or obey the known Laws of Physics - he wanted a system to be designed and built. Engineers determine whether such a system is feasible - not scientists, who do not know the definition of feasibility.
The STEM fields

Science, Technology, Engineering, and Mathematics

Question: Why don’t we blend Business into the STEM realm?

At many schools, new programs that include Arts courses in STEM programs -> STEAM curriculum
The STEM fields

Science, Technology, Engineering, and Mathematics

Question: Why don’t we blend Business into the STEM realm?

At many schools, new programs that include Arts courses in STEM programs -> STEAM curriculum

Answer: Because most Engineering programs believe their work is independent of the Business world!
The Engineering Method is employed to do the following:

• Carry out the engineering design process
  • New things – iPhone
  • Improved things – iPhone7, iPhone8,…, iPhone11

• Carry out the engineering problem-solving process
  • New problems – How do we repurpose the desert from agricultural farms to solar farms?
  • Re-examined problems – How do we protect the desert?
The Engineering Method

The Five Building Blocks of the Problem-Solving (or Design) Heuristic (Fogler and LeBlanc)

1. Define the Problem
2. Generate Solutions
3. Decide Course of Action
4. Implement Solution
5. Evaluate the Solution
Heuristic?

- A heuristic is any procedure that helps learning or leads to discoveries

- It can be a mathematical development, a graph or flow-chart, a rule-of-thumb, a “Fermi calculation”

- The heuristic shown on the last page is a systematic approach that serves as a guide through the solution process
The Engineering Method

For the Learning Lab, F’18

1. Define the Problem
2. Generate Solutions
3. Decide Course of Action
4. Implement Solution
5. Evaluate the Solution
Important Considerations (G. Voland)

• Engineering is an iterative process; one should be prepared to reconsider assumptions, decisions, and conclusions reached during the earlier stages of the design process if any new results indicate the need to do so.

• The initial problem statement may be too vague, ill-conceived, or simply incorrect.

• An incorrect problem statement is very unlikely to lead to the optimal solution of a problem.
First thing to consider:

Are you trying to solve the **real** problem or the **perceived** problem?
Example 01: (Fogler and LeBlanc)

Cell phone makers have been increasing the quality of phone cameras, so won’t digital cameras lose market share?

Perceived problem: How can camera makers produce a less expensive camera to compete with cell phone cameras?

Real problem: How can camera makers produce a camera of such high-quality that a consumer would want to buy it in addition to the lower-quality cell phone camera?
Example 02:
(Fogler and LeBlanc)

Impatient Guests

Shortly after the upper floors of a high-rise hotel had been renovated to increase the hotel’s room capacity, guests complained that the elevators were too slow. The building manager assembled his assistants. His instruction to solve the perceived problem was “find a way to speed up the elevators.”

After calling the elevator company and an independent expert on elevators, it was determined that nothing could be done to speed up the elevators. The manager then issued new directions: “Find a location and design a shaft to install another elevator.” An architectural firm was hired to carry out this request.

Ultimately, neither the shaft nor the new elevator was installed because shortly after the firm was hired, the real problem was uncovered. The real problem statement was “find a way to keep guests happy with the current elevators.” Instead of putting effort into decreasing wait time, effort was placed on taking the guests’ minds off their wait. The guests stopped complaining when mirrors were installed on each floor in front of the elevators.² Few people can resist taking the time to check or admire their appearance in the mirror.
Example 03: (Learning Lab, F’17)

The City of Tempe wants to eliminate its dependence on fossil and nuclear fuels for its energy needs

**Perceived problem:** How can Tempe move to a 100% renewable energy portfolio?

**Real problem:**
The Engineering Method - Problem Definition

Approaches to Problem Definition:

1. The Duncker Diagram

2. Statement-Restatement process

3. Critical Thinking techniques
The Duncker Diagram

1. One begins by specifying (as best as one can) the present or problem state (PS), and then the desired or solution state (DS).

2. The descriptions are reworked until all concerns and needs identified in the present state are addressed in the desired state. (The desired state should not contain solutions to problems not in the present state)

3. Two sides to the Duncker Diagram
The Engineering Method - Problem Definition

The Duncker Diagram
Dead Rats Decaying in the Water

A new water supply system was installed in a western state. Part of the system was a large outdoor holding tank placed in the ground near a farm field. Shortly after installation, unacceptable levels of contamination were found. An investigation revealed that the contamination was caused by dead rats decaying in the holding tank. The problem statement that went out was find a way to keep the rats out of the tank.
The real problem statement should have been "Stop rats from dying and decaying in the tank." The solution implemented was to install a ladder that allowed the rats that fell into the tank to climb out. Once the ladder was installed, dead rats were no longer found in the tank and contamination levels fell to acceptable levels.
Statement-Restatement

- Perceived Problem
- Restatement
- Relax Constraints
- Restatement
- Make Opposite Statement
- Restatement
- Final Problem Statement

Fuzzy Mess

Generalize
Hitting ‘Em Where They Aren’t

The Situation: During WWII, a number of aircraft were shot down while engaging in bombing missions over Germany. Many of the planes that made it back safely to base were riddled with bullet and projectile holes. The damaged areas were similar on each plane.

The instructions given to solve the perceived problem: “Reinforce these damaged areas with thicker armor plating.”

Present State | Desired State
--- | ---
Many bullets/projectiles penetrating aircraft. | Fewer planes being shot down.

Discussion: This is not a match because there are planes that are surviving that still have bullet holes. There is not a one-to-one mapping of all the needs of the present state being addressed and resolved in the desired state.

Present State | Desired State
--- | ---
Many bullets/projectiles penetrating aircraft. | Fewer bullet holes.

Discussion: These states are matched, but the distinction between the present state and the desired state is not clear enough. It may take only a single bullet hitting a critical area to down a plane.

Present State | Desired State
--- | ---
Many bullets/projectiles penetrating aircraft in critical and noncritical areas. | Fewer bullets/projectiles penetrating critical areas.

Discussion: These two statements now match and the distinction between them is sharp, opening up a variety of solution avenues such as reinforcing critical areas, moving critical components (e.g., steering mechanism) to more protected locations, providing redundant critical components, etc.

Note: The original instructions given to solve the perceived problem would have failed. Reinforcing the areas where returning planes had been shot would have been futile. Clearly these were noncritical areas; otherwise these planes would have been casualties as well.
The Engineering Method - Problem Definition

Deciding Whether the Problem Should Be Solved

Real Problem Defined

Is the problem worth solving?
No → Stop
Yes

Is it our responsibility to solve it?
No → Stop
Yes

Does a suitable solution already exist?
Yes → Implement It → Stop
No

Can the necessary resources to solve the problem be assembled?
No → Change Constraint? → No → Stop
Yes

Does sufficient time exist to solve the problem?
No → Change Constraint? → No → Stop
Yes

Begin generating solution alternatives
### The Engineering Method – Solution Pathway

First Steps in Solution Concept Generation: (Ulrich & Eppinger)

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Clarification</td>
<td>Understanding</td>
</tr>
<tr>
<td></td>
<td>Decomposition</td>
</tr>
<tr>
<td></td>
<td>Critical subproblems</td>
</tr>
<tr>
<td>External Search</td>
<td>Experts</td>
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<td></td>
<td>Patents</td>
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<td></td>
<td>Literature</td>
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<td></td>
<td>Benchmarking</td>
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<tr>
<td>Internal Search</td>
<td>Individual</td>
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<tr>
<td></td>
<td>Group</td>
</tr>
<tr>
<td>Systematic Exploration</td>
<td>Classification tree</td>
</tr>
<tr>
<td></td>
<td>Combination table</td>
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<tr>
<td>Reflection</td>
<td>Constructive feedback</td>
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</tbody>
</table>
Problem Clarification

Problem Decomposition - Divide a complicated problem into simpler subproblems.

- **Decomposition by function**
  - The problem is represented as a *black box*.
  - Material, energy, signals, etc., are accepted as inputs, then manipulated, and then delivered as outputs.
  - The black box is further divided into subfunctions showing the relations among the various inputs.

- **Decomposition by user actions**
  - The problem is described by a sequence of actions.
  - This is useful for products with simple technical functions with a lot of user interaction.
External Searches

There are several possible ways to find information that may lead to solutions of critical subsystems/subfunctions. These include:

- **Interview lead users**
- **Consult experts**
- **Search patents**
- **Search relevant websites**
- **Search published technical literature**
- **Benchmark related projects**
## External Searches - Confirm findings:

<table>
<thead>
<tr>
<th>Fact</th>
<th>“On August 16th, 45 fish were found dead in the river.”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Facts</strong> usually come from measurements, reports, tables, figures, firsthand observations, and other data.</td>
<td></td>
</tr>
</tbody>
</table>
Internal Searches

This is the use of personal and team knowledge and creativity to generate solution concepts.

- Suspend judgment
- Generate a lot of ideas
- Welcome even ideas that appear infeasible
- Use graphical and physical media
- View the problem firsthand
Potential Pitfalls

Solution concept generation can be halted prematurely

- Defining the problem too narrowly
- Attacking the symptoms and not the problem
- Assuming there is only one right answer
- Getting hooked on the first solution that comes to mind
- Getting hooked on a solution that almost works
## Reflection - Ask Critical Socratic Questions

| 1. Questions about the question or problem statement | • What was the point of this question?  
• Why do you think I asked this question?  
• Why is it important you learn the answer to that question?  
• How does that question relate to our discussion?  
• Where did the problem originate? |
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>The purpose of this question is to find out why the question was asked, who asked it, and why the question or problem needs to be solved.</td>
<td></td>
</tr>
</tbody>
</table>

| 2. Questions for clarification | • What do you mean by __________?  
• Why do you say that?  
• What do we already know about that?  
• Could you explain further?  
• Could you put that another way? |
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>The purpose of this question is to find missing or unclear information in the problem statement question; identify multiple interpretations and ambiguous words and phrases.</td>
<td></td>
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</tbody>
</table>
### The Engineering Method – Solution Pathway

**Reflection - Ask Critical Sochratic Questions**

<table>
<thead>
<tr>
<th>Questions that probe assumptions</th>
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</thead>
</table>
| The purpose of this question is to find out if there are any hidden, misleading, or false assumptions. | • What could we assume instead?  
• How can you verify or disapprove that assumption?  
• Explain why_________. (Explain how________.)  
• What would happen if _________?  
• What are the strengths and weaknesses of that assumption? |

<table>
<thead>
<tr>
<th>Questions that probe reasons and evidence</th>
<th></th>
</tr>
</thead>
</table>
| The purpose of this question is to explore whether facts and observations support an assertion or conclusion. | • What would be an example that supports the evidence?  
• What are you assuming to be true when you say this is evidence?  
• What do you think causes _________? Why?  
• What evidence is there to support your conclusion?  
• Have you examined the evidence for any fallacies in logic? |
**Reflection - Ask Critical Sochtratic Questions**

<table>
<thead>
<tr>
<th>5. Questions that probe viewpoints and perspectives</th>
<th>6. Questions that probe implications and consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>The purpose of this question is to learn how things are viewed or judged and consider things not only in a relative perspective but also as a whole.</td>
<td>The purpose of this question is to help understand the inferences or deductions and the end result if the inferred action is carried out.</td>
</tr>
</tbody>
</table>

<p>| | |</p>
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<thead>
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</thead>
<tbody>
<tr>
<td>• What is a counterargument for _______?</td>
<td>• What are the consequences if that assumption turns out to be false?</td>
</tr>
<tr>
<td>• What are the strengths and weaknesses of that viewpoint?</td>
<td>• What will happen if the trend continues?</td>
</tr>
<tr>
<td>• What are the similarities and differences between your point of view and someone else’s point of view?</td>
<td>• Is there a more logical inference we might make in this situation?</td>
</tr>
<tr>
<td>• Compare _______ and _______ with regard to _______.</td>
<td>• How are you interpreting her behavior? Is there another possible interpretation?</td>
</tr>
<tr>
<td>• What is your perspective on why it happened?</td>
<td>• Could you explain how you reached that conclusion?</td>
</tr>
<tr>
<td></td>
<td>• Given all the facts, is that really the best possible conclusion?</td>
</tr>
</tbody>
</table>
Since engineering and business are inherently creative undertakings, you probably (no, definitely) have a creative streak as part of your make-up. Please describe one of the most creative things you have done so far. It could have been solving some interesting problem, or building a masonry wall, or designing a crossword puzzle. It doesn’t have to be a very complicated or challenging thing - just some activity in which your own creativity was highlighted.
The Engineering Method

References

• G.Voland, **Engineering by Design**, Pearson, 2004

• H.S.Fogler, S.E.LeBlanc, and B.Rizzo, **Strategies for Creative Problem Solving**, 3rd Ed, Pearson, 2014
  • [www.umich.edu/~scps](http://www.umich.edu/~scps)