This is a low-resolution printable version of the teacher-presentation information. The original PowerPoint slides are clearer and animated to assist the teacher in delivering quality content to the students.

Licensed users of the EST Foundations curriculum have access to:

- the original animated PowerPoint files
- accompanying handouts
- detailed homework assignments
- lesson plans including online reading and research assignments, and
- suggestions on integrating this project-based curriculum.

Topic 6 (ver 1.0) Conceptual Design

Content of this module

- Bell work 6.1
- Discuss the goals of the Conceptual Design Phase
- Create draft conceptual problem statement
- Define the function structure for the draft problem
- Bell work 6.2
- Brainstorm concepts to address overall problem
- Categorize the solutions
- Define possible "Solution Approaches" from Categories
- Bell work 6.3
- List advantages/disadvantages of each Solution Approach
- Define Factors based on observed advantages/disadvantages and design criteria
- Bell work 6.4
- Learn to use a decision matrix
- Use a decision matrix to choose Solution Approach
- Bell work 6.5
- Rewrite problem statement and sub-functions
- Brainstorm solutions to each sub-function
- Combine ideas and choose a final Solution Path

6.1 An Abstract Problem Statement and Function Structure

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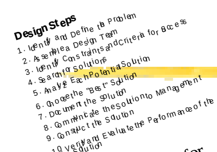
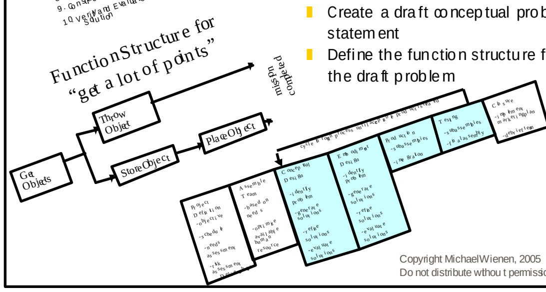
Bell Work 6.1

- In your journal...
- Describe the overall function that the machine must perform according to what you know about the engineering challenge.
- Describe the sub-functions (or steps) that a machine must perform to achieve that overall function.



Today's Agenda

- Discuss the goals of the conceptual design phase of the design project
- Create a draft conceptual problem statement
- Define the function structure for the draft problem



Goals of Conceptual Design Phase

Specific goals for every project phase should have been defined during the project planning phase of the project.

- The goals of the Conceptual Design Phase should have been something like:
  - clearly define the need (including function structure and required test performance),
  - document possible solution concepts, and
  - choose the conceptual solutions that best addresses the need.

Important: If at the end of the Conceptual Phase you have a picture in your mind of what the design looks like, then you have NOT done your job in this phase. You must remove all biases and choose only the general operating "principle" and the basic path that the team will pursue.

We will deviate from expert protocol...a little bit

Expert Process

- Problem Identification: Create a abstract problem statement
- Conceptual Design
  - Establish function structure by clearly defining the overall function and the sub-functions that the design must perform
  - Search for solution principles to fulfil each sub-function
  - Combine solution principles to fulfil the overall function
  - Select suitable combinations to define conceptual alternatives
  - Evaluate the alternatives against previously defined criteria
- Embodiment Design

Our Modified Process

Distinguishing an "abstract" concept from a "biased" specific description is difficult for most novice designers. To help, we will proceed as follows:

- Create a draft problem statement and function structure
- Brainstorm general concepts to address the overall problem
- Separate the solutions into different categories (solution approaches)
- Evaluate and choose a general solution approach
- Re-write the problem statement and the sub-functions to be biased towards this solution approach (but not any specific designs within the category of solutions)
- Brainstorm ideas to address each sub-function
- Evaluate and combine sub-function concepts to form different variations to solve the overall problem
- Make a final evaluation of these variations to choose a final solution path
- Then proceed to Embodiment Design

Defining the Problem: More than just a problem statement

- Before we begin contriving solutions, we should be sure that we are solving the right problem.
- You should thoroughly define the problem. This is called the "Problem Identification" or "Clarification of Task" phase of a design project. (these slides assume that it is the first step in the conceptual design phase of the project)
- Things included in the Problem Definition:
  - A single sentence that makes a clear and concise **Problem Statement** (e.g. the cat keeps knocking over the plant which causes a mess)
  - **List of Constraints** (limitations the design and development must conform to)
  - **List of Criteria** (performance specifications that the design must meet)
  - **List of Wishes or Desires** (prioritized characteristics that would be preferred)
  - **Needed Information** (questions that someone needs to answer before the final evaluation and solution choice can be made)
- Sketches of the Problem should be included...but NOT sketches of potential solutions.

Creating the Problem Statement: Caution

- It is important that a designer understands every aspect of the problem and seeks to identify the true source of the problem and not simply how the problem first presented itself.
- Consider these two Examples:
  - The objective of a basketball team is NOT to score a lot of points...it is to score more points than the opponent. If the team is a professional team at the beginning of the season, the objective is to score more points than the opponent without compromising the team's ability to perform well in future games (i.e. key players are not expendable).
  - The objective of one charitable organization might be to provide fish for a hungry population while the objective of another charitable organization might be to teach a hungry population to fish for their own food.

Creating the Problem Statement: Abstraction

Again, let's use an example to explain the importance of abstraction

- A design team was told that their objective was to design a robot to remove specific items from a conveyor belt...so, they did just that. They found out all the specifications (weight and size) of the items to be removed and they design an expensive multi-jointed robot to pick these items up from a moving conveyor.
- Afterwards, they find out that the items to be removed are actually the boxes on the conveyor that were accidentally missed by the loading-filling crew. In other words, they are empty boxes to be thrown away. The designers slap themselves on the forehead because they could have simply installed an inexpensive air jet that would automatically blow any un-weighted boxes off the conveyor without affecting the loaded boxes.

- The designers made two mistakes. When they heard the term "robot" they stuck that image in their minds and forgot to ask the detailed questions about the real problem.

Creating the Problem Statement: Let's do it (10 min)

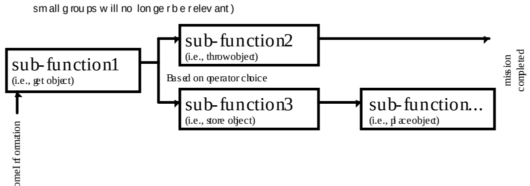
- Working in groups of four, create a **Problem Statement** based on the information that you have been given regarding the engineering competition. (i.e., describe the overall required function of the machine)
- Also list the generic sub-functions (or steps) that work together to fulfil the entire function.
  - Example: The sub-functions of "change a non-working light bulb" might include:
    - Secure replacement light bulb.
    - Remove the old bulb intact.
    - Install the new bulb.
    - Test that the installed bulb is working.
  - Notes:
    - "Safety" is not part of this problem statement, but instead might be listed as part of the constraints or criteria.
    - "Gain physical contact with the bulb" is NOT listed because that would presume that there is no new technology that could be developed using non-contact means like magnetism or pneumatics. Do you know why we shouldn't list "get a ladder?"

Adopting a draft Problem Statement

- We'll start with one group's problem statement on the board.
- Then, based on suggestions from the class (only suggestions that are generally accepted by the class) modify the statement until it is clear, thorough, and independent of all solutions and solution strategies.

Adopting a draft Function Structure

- Using the results of the small group discussions, define the sub-functions that the overall function can be decomposed into. Sub-functions are generally steps that must be accomplished to accomplish the overall task.
- The sub-functions must be immediately relevant to the overall function adopted by the entire team on the previous slide. (some functions defined by small groups will no longer be relevant)



6.2 Search for Conceptual Solutions

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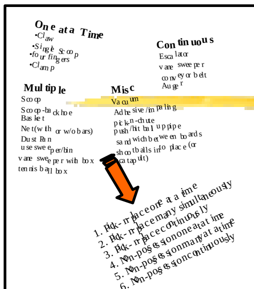
Bell Work 6.2

- Review the rules for brainstorming. We will be brainstorming today and everyone needs to know the rules…

Today's Agenda



- Brainstorm general concepts to address the overall problem
- Separate the solutions into different categories
- Use the categories to define possible "Solution Approaches"

Our Modified Process

Distinguishing an "abstract" concept from a "biased" specific description is difficult for most novice designers. To help, we will proceed as follows:

- Create a draft problem statement and function structure
- Brainstorm general concepts to address the overall problem
- Separate the solutions into different categories (solution approaches)
- Evaluate and choose a general solution approach
- Re-write the problem statement and the sub-functions to be biased towards this solution approach (but not any specific designs within the category of solutions)
- Brainstorm ideas to address each sub-function
- Evaluate and combine sub-function concepts to form different variations to solve the overall problem
- Make a final evaluation of these variations to choose a final solution path
- Then proceed to Embodiment Design

You are here

Brainstorming (15 minutes)

- In small groups of 5-8, brainstorm solutions for the overall function of the machine
- Brainstorming Rules:
  - Focus on one specific topic for the duration of the session.
  - All team members participate in turn.
  - Only one idea per person per turn (additional ones can be jotted down quickly less they be forgotten).
  - Accept all ideas at face value. Do NOT edit, discuss, evaluate, reinforce, criticize, ridicule, or belittle any idea during the brainstorming session. The more outrageous an idea, the better (pigs CAN fly).
  - Record all ideas generated (try to avoid pictures or sketches as much as possible but use verbal descriptions instead).
  - A member may elect to "pass."
  - Continue until all members "pass."
- Record every single idea <u>without</u> criticism!

Compiling Brainstorming Results

- Starting with any small group, read the ideas and categorize the ideas on the board (teacher should write them on the board)
- All recorded thoughts are put somewhere and categories are named/renamed as necessary (naming the categories is the biggest challenge)

Example

- when given a problem statement "balls need to be collected and placed into various scoring bins," the small groups came up with these ideas:

One at a Time
- Claw
- Single Scoop
- four fingers
- Clamp

Continuous
Escalator
vane sweeper
conveyor belt
Auger

Multiple
Scoop
Scoop-backhoe
Basket
Net (with or w/o bars)
Dust Pan
use sweeper/bin
vane sweeper with box
tennis ball box

Misc
Vacuum
Adhesive/impaling
pick-n-chute
push/hit ball up pipe
sandwich between boards
shoot balls into place (or catapult)

General Aims/Goals
Arm Moves
Use gears as necessary
might have multiple grippers

Non-possession
Golfer
sweep directly into bin

Using Categories to Define Alternative Solution Paths

- Now, try to describe the solution categories without regard to any specific solution in the category.
- Note that some of the "categories" on the previous slide might be more appropriately listed as "constraints" or "wishes/desires."
- Example (Con't from previous)
- The categories in the example on the previous slide led the example class to define the following "solution approaches":
  1. Pick-n-place one at a time
  2. Pick-n-place many simultaneously
  3. Pick-n-place continuously
  4. Non-possession one at a time
  5. Non-possession many at a time
  6. Non-possession continuously

6.3 Defining Design Factors

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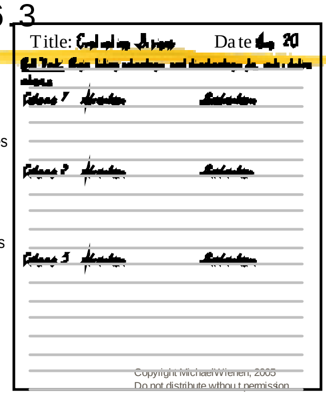
Bell Work 6.3

- In your journal...
- List each of the solution **categories**, LEAVE five spaces in between each item in the list.
- For each item, begin listing what you think are the advantages and disadvantages inherent to the category.



Today's Agenda

1. Pick-n-place one
Advantages
Can segregate/differentiate gamepieces
More precise (in selection and placement)
Specificity of gamepieces
Disadvantages
Inherently slower
Requires higher driver skill

5. Non-possession many
Advantages
Increased odds over categories 4./6.
Disadvantages
Low control
Especially for hidden gene
Hard to keep points (balls bounce out)

- Discuss the advantages and disadvantages of each of the solution categories (or "solution approaches")
- Classify the advantages and disadvantages to determine "Factors by which to evaluate the alternatives"

A. Specificity of Game Piece Selection
B. Independent of Driver Skill
C. Ability to protect pieces from other teams
D. Potential for High Speed Scoring
E. Predictable scoring outcome
F. Ease of Handling each game piece type
G. Simple Design (leads to robust design)

Anyone Lost?

Our Modified Process

Distinguishing an "abstract" concept from a "biased" specific description is difficult for most novice designers. To help, we will proceed as follows:

- Create a draft problem statement and function structure
- Brainstorm general concepts to address the overall problem
- Separate the solutions into different categories (solution approaches)
- Evaluate and choose a general solution approach ← You are here
- Re-write the problem statement and the sub-functions to be biased towards this solution approach (but not any specific designs within the category of solutions)
- Brainstorm ideas to address each sub-function
- Evaluate and combine sub-function concepts to form different variations to solve the overall problem
- Make a final evaluation of these variations to choose a final solution path
- Then proceed to Embodiment Design

Analyzing the Alternatives

- As a class we will list the advantages and disadvantages of each general solution concept.
- Things to consider include (but not limited to):
  - predictability of the outcome
  - flexibility of the strategy to accommodate uncertainty in the environment
  - expected simplicity of category of machines
  - ability of the strategy to be precise (in manipulating game pieces)
  - dependence on operator skill
  - amount of control throughout the process
- We will use the constraints, criteria, and desires as a guide.

- Record the advantages/disadvantages here....

Factors: Classifying the Advantages/Disadvantages

- Look at the advantages/disadvantages that were listed for each solution category.
- Look for characteristics that seem to differentiate the various designs. If a characteristic is important then list it as a "Design Factor."
- Particularly helpful are Factors that seem to be mutually exclusive like:
  - if a machine moves fast, it is often difficult to be precise;
  - if a machine is strong, it is usually not light weight;
  - if a machine has a huge bucket, it usually can't differentiate small parts;
  - if a machine has a lot of working parts, it is usually not easy to build.
- As a class let's define the factors by which we will evaluate all design alternatives.

- Record the defined Design Factors here...

Example factors that might come from generalizing advantages/disadvantages (written positively to facilitate strategy evaluation)

	As a Class rate the importance of each identified factor…i.e. How important is each one? (Total=100)
A. Specificity of Game Piece Selection	A. 6
B. Independent of Driver Skill	B. 24
C. Ability to protect pieces from other teams	C. 6
D. Potential for High Speed Scoring	D. 24
E. Predictable scoring outcome	E. 16
F. Ease of Handling each game piece type	F. 14
G. Simple Design (leads to robust design)	G. 10

6.4 Decision Matrices

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Bell Work 6.4

- In your journal…
- Review our list of solution categories and think about how you would rate each one of them in each of the "Design Factors" that we defined yesterday.

Today's Agenda

- Learn to use a Decision Matrix.
- Example: Choosing a solution approach

Our Modified Process

Distinguishing an "abstract" concept from a "biased" specific description is difficult for most novice designers. To help, we will proceed as follows:

- Create a draft problem statement and function structure
- Brainstorm general concepts to address the overall problem
- Separate the solutions into different categories (solution approaches)
- Evaluate and choose a general solution approach ← Still Here!
- Re-write the problem statement and the sub-functions to be biased towards this solution approach (but not any specific designs within the category of solutions)
- Brainstorm ideas to address each sub-function
- Evaluate and combine sub-function concepts to form different variations to solve the overall problem
- Make a final evaluation of these variations to choose a final solution path
- Then proceed to Embodiment Design

Category	A	B	C	D	E	F	G **	Total
1	6	0	6	0	16	14	5	47
2	3	12	6	24	16	14	5	80
3	0	24	6	24	16	0	5	75
4	6	12	0	12	0	7	10	47
5	0	24	0	24	8	7	10	73
6	3	24	0	24	8	0	5	64
Max	6	24	6	24	16	14	10	

Let the Math Decide!

Decision Matrices

- The purpose of a decision matrix is to aid a designer to make decisions when there are multiple options and each option must be evaluated in many different area (or criteria)
- It is very important to use a decision matrix for all complex decisions because human nature is to choose "favorites" based on our past experience instead of choosing the best idea based on ALL the facts.

Category	A	B	C	D	E	F	G **	Total
1	6	0	6	0	16	14	5	47
2	3	12	6	24	16	14	5	80
3	0	24	6	24	16	0	5	75
4	6	12	0	12	0	7	10	47
5	0	24	0	24	8	7	10	73
6	3	24	0	24	8	0	5	64
Max	6	24	6	24	16	14	10	

Alternatives that must be evaluated are listed in the first column

Design Factors are listed across the top

Each design is scored in each factor (values are high, medium, and low only)

Total of all factors must be 100

Relative importance of each Design Factors is listed at the bottom

The winner is the one with the highest total

Steps to Creating a Decision Matrix

1. Narrow the design alternatives in informal discussions. Favored traits can be combined to form fewer-better design alternatives.
2. Generate a list of independent factors that effect how well the design will address the original problem statement.
3. Specify the relative importance of each factor by assigning it a maximum-point value (last row in the matrix). The sum of all these factor weightings should be 100.
4. Rate each design in each factor category. Only use high, medium or low values in each cell of the matrix. Engage team discussions for each cell until consensus is reached.
5. Designs with the highest totals should be further developed and their cell values scrutinized. Look for a natural break in the total scores.
6. (If necessary to further separate the final candidates) Specifically compare the top three alternatives to each other. In each category, assign a "high" to only one idea, "medium" to only one idea, and "low" to the remaining idea. Eliminate ties in each category by slightly modifying each idea with traits from other designs if possible.

Caution: do NOT use majority rule in filling out the values of a decision matrix. It is extremely important to the team to reach consensus on each of the individual values

Below is an Example... as a class, let's make our own Decision Matrix

A. Specificity of Game Piece Selection
B. Independent of Driver Skill
C. Ability to protect pieces from other teams
D. Potential for High Speed Scoring
E. Predictable scoring outcome
F. Ease of Handling each game piece type
G. Simple Design (leads to robust design)

1. Pick-n-place one at a time
2. Pick-n-place many simultaneously
3. Pick-n-place continuously
4. Non-possession* one at a time
5. Non-possession* many at a time
6. Non-possession* continuously

* define possession as more than the piece temporarily "resting" on robot part…including significant lifting and precise motion control

Category	A	B	C	D	E	F	G	Total
1	6	0	6	0	16	14	5	47
2	3	12	6	24	16	14	5	80
3	0	24	6	24	16	0	5	75
4	6	12	0	12	0	7	10	47
5	0	24	0	24	8	7	10	73
6	3	24	0	24	8	0	5	64
Max	6	24	6	24	16	14	10	

Only a guide...not a final decision

- As you can see in the decision matrix, if each of the options have any merit at all, then the final results can be very close.
- Don't think of the results as an absolute decision rather a distinction between the poorer and better ideas.
- Certainly the lowest scoring ideas are eliminated while none of the top few ideas should be casually dismissed.
- Your design intuition might still be the most important factor…

6.5 Combining Ideas and Choosing Final Solution Path

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Bell Work 6.5

- In your Journal...
- List the rules for group brainstorming sessions.

Today's Agenda

Repeating with More Information

Was: "get a lot of points"

Now: "capture all sizes of balls and transport to correct scoring areas based on operator preference in a multi-ball or continuous fashion"

Our Modified Process

Distinguishing an "abstract" concept from a "biased" specific description is difficult for most novice designers. To help, we will proceed as follows:

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- Brainstorm ideas to address each sub-function
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- Make a final evaluation of these variations to choose a final solution path
- Then proceed to Embodiment Design

- Rewrite our problem statement and sub-function to reflect our chosen solution approach
- Brainstorm solutions to each sub-function
- Combine ideas into working systems and choose one to develop in the Embodiment Phase

Finally your here

Final Problem Statement

- Now that we've selected the general approach that we will follow, as a class let's re-write the problem statement to limit the types of ideas that we will consider.

- Record final statement here...
- and final function structure here...

Brainstorming (5 minutes per sub-function)

- In small groups of 5-8 Brainstorm solutions for each sub function
- Brainstorming Rules:
  - Focus on one specific topic for the duration of the session.
  - All team members participate in turn.
  - Only one idea per person per turn (additional ones can be jotted down quickly less they be forgotten).
  - Accept all ideas at face value. Do NOT edit, discuss, evaluate, reinforce, criticize, ridicule, or belittle any idea during the brainstorming session. The more outrageous an idea, the better (pigs CAN fly).
  - Record all ideas generated (try to avoid pictures or sketches as much as possible but use verbal descriptions instead).
  - A member may elect to "pass."
  - Continue until all members "pass."
- Record every single idea without criticism!

Combine Into Working Systems

- List the ideas on the board under each sub-function
- With all the unique ideas listed on the board, solicit ways to combine them into working systems
- In many cases a single idea will perform multiple functions.
- List all the viable combinations…

Example: with functions being collect, store, and place balls, viable **combinations** might be:

Collect	Store	Place
shovel	in shovel	dump shovel
shovel	basket on machine	catapult from basket
pincer	in pincer	open pincer
pincer	basket on machine	conveyor to bins
pincer	basket on machine	2nd auto pincer
backhoe	in backhoe	dump backhoe
scissors scoop	in scoop	open scoop
scissors scoop	chute	tilt chute

Narrow the Alternatives

- As a class, quickly narrow the combinations by allowing each person rate their top three choices (top choice gets three points, 2nd choice gets 2 points, and 3rd choice gets 1 point).
- Tally the points for each composite system. The top 3-5 choices should be entered into a decision matrix.

- You are now ready to enter the Embodiment Phase of the Project where you will flush out all the material choices and dimensions of the design.