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.

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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.
Goals of Conceptual Design Phase

Specifying sales for every product aims should have been defined during the project planning phase of the project.

The goals of the Conceptual Design Phase should have been something like:

1. Clearly define the need (including function structure and required test performance).
2. Document possible solution concepts, and choose the conceptual solutions that best address 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 conceptual problem statement
- Define Conceptual Design
  - Establish function structure by clearly defining the overall function and the sub-functions that the design must perform
  - Search for solution principles that fulfill each sub-function
  - Combine solution principles to fulfill the overall function
  - Select suitable combinations to define conceptual solution alternatives
  - Evaluate the alternatives against previously defined criteria
- Embodiment Design

Our Modified Process

- Distinguishing an “abstract” concept from a “biased” specific design is a difficult form for novice designers. To help, we will proceed as follows:
  - Create a setup problem陈述 and function structure
  - Define general concepts to address the overall problem
  - Separate the solutions into different categories (solution approach)
  - Evaluate the problem statement and the sub-functions to be the sole low end and the solution is a generic (but let one specific design within the category of solutions)
  - Brainstorm ideas to address each sub-function
  - Evaluate and combine solution principles to form different solutions to solve the overall problem
  - Make a final decision on these variants 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 resolving the right problem.
- You should thoroughly define the problem. This is called the "Problem Identification" or "Clarification of Task" phase of a design project.

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 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 with the objective of another charitable organization might be to teach a hungry population to fish for their own food.

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 (priced 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: 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. As they did just that, they found out that:

- There were actually 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 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 specification.

- Also list the generic sub-functions (or steps) that work together to fulfill the entire function.

- Example: The sub-functions of "change a non-working light bulb" might include:
  - Base on operator choice
    - Select replacement light bulb.
    - Remove the old bulb intact.
    - Replace the new bulb.
    - Test 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.
  - "Give any information about the bulb" is NOT listed because there is not enough information that allows us to expand using it as a base in the form of a replacement procedure.

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 are difficult to gather in large groups.

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6.2 Search for Conceptual Solutions

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".

Compiling Brainstorming Results

Starting with any small group, read the ideas and categorize the ideas on the board as you write them.
All recorded thoughts are put somewhere and are named/renamed as necessary.

Using Categories to Define Alternative Solution Paths

Now, try to describe the solution categories without regard to any specific solution in the category.

Example:
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

Example (Different from previous):
The categories on the previous slide were more appropriately listed as "constraints" or "wishes/desires."
6.3 Defining Design Factors

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

- 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”

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:

1. Create a draft problem statement and function structure
2. Brainstorm general concepts to address the overall problem
3. Separate the solutions into different categories (“solution approaches”)
4. Evaluate and choose a general solution approach
5. 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)
6. Brainstorm ideas to address each sub-function
7. Evaluate and combine sub-functions to form different variations to solve the overall problem
8. Repeat the selection of these variations to choose a final solution path
9. 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.

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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.

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

- 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)

As a class rate the importance of each identified factor:

<table>
<thead>
<tr>
<th>Factor</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>6</td>
<td>24</td>
<td>6</td>
<td>24</td>
<td>24</td>
<td>16</td>
<td>14</td>
</tr>
</tbody>
</table>

6.4 Decision Matrices

Today's Agenda

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

<table>
<thead>
<tr>
<th>Alternatives that must be evaluated are listed across the top</th>
<th>Each design is scored in each factor (values are high, medium, and low only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternatives that must be evaluated are listed in the first column</td>
<td></td>
</tr>
</tbody>
</table>

| Total of all factors must be 100 | Relative importance of each Design Factors is listed at the bottom |

**Steps to Creating a Decision Matrix**

1. Narrow the design alternatives in informal discussions. Favor e-trains 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 one in each category by slightly modifying each idea such that trials from other ideas 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.

**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...

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

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>16</td>
<td>14</td>
<td>5</td>
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<td>16</td>
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<td>35</td>
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<td>16</td>
<td>05</td>
<td>75</td>
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<tr>
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<td>6</td>
<td>12</td>
<td>0</td>
<td>12</td>
<td>7</td>
<td>10</td>
<td>67</td>
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<tr>
<td>5</td>
<td>6</td>
<td>24</td>
<td>0</td>
<td>24</td>
<td>8</td>
<td>0</td>
<td>54</td>
</tr>
<tr>
<td>Max</td>
<td>6</td>
<td>24</td>
<td>6</td>
<td>24</td>
<td>16</td>
<td>14</td>
<td>35</td>
</tr>
</tbody>
</table>

1. Pick-in-place one at a time
2. Pick-in-place many simultaneously
3. Pick-in-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

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<td>1</td>
<td>6</td>
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<td>0</td>
<td>16</td>
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<tr>
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<td>6</td>
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<td>16</td>
<td>14</td>
<td>35</td>
</tr>
</tbody>
</table>

**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

- 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 you're 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.

Brainstorming (5 minutes per sub-function)

- In small groups of 5-8 Brainstorm solutions for each sub-function
- 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 but will be forgotten).
- Accept all ideas at face value. Do NOT edit, discuss, evaluate, mince, 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."
- 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:

<table>
<thead>
<tr>
<th>Collect</th>
<th>Store</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>shovel</td>
<td>bucket on machine</td>
<td>robot arm</td>
</tr>
<tr>
<td>pincer</td>
<td>pick up</td>
<td>open pincer</td>
</tr>
<tr>
<td>scoop</td>
<td>scoop in machine</td>
<td>2nd arm scoop</td>
</tr>
<tr>
<td>scoop</td>
<td>scoop in machine</td>
<td>scoop</td>
</tr>
<tr>
<td>chute</td>
<td>open chute</td>
<td>2nd arm chute</td>
</tr>
</tbody>
</table>

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.