Engineering Design Process

1. Needs Statement/Identification of the Problem
2. Data and Information Collection
3. Identify Design Constraints & Criteria
4. Generate Solution Ideas
5. Analyze Solution Ideas
6. Evaluate & Select Solution for Implementation
7. Evaluate Solution for Continuous Improvement

Teamwork + Communication
The following case study is based on a student design project in “Introduction to Engineering” at University of South Alabama and continued at Western Michigan University.

Need Statement: A 7th grade teacher need class activities to support teaching the unit on light. Presently, there are little resources to support the instruction of optics phenomena.
Other Examples of Design
Other Examples of Design
Other Examples of Design
Other Examples of Design
Other Examples of Design
Data and Information Collection

- From *Literature Research*, we learn the following about the need:

- From 7th grade *textbook* – Light reflection and refraction are described by the following figures

  ![Diagram of light reflection and refraction](image)

  Angle $ACD = \alpha$

  Angle $BCD = \beta$

  Law of Reflection

  $\alpha = \beta$

  ![Diagram of light refraction](image)

  Angle $ACD = \alpha$

  Angle $BCE = \beta$

  Law of Reflection

  $\sin \alpha = \sin \beta$

- There is no figure to demonstrate absorption or transmission of light.
From *State Guidelines*

• Topic of communication by optics

• Science skills: collect, organize, analyze data, and present results; handle equipment; read and follow instructions in manual

• Science habits: carefulness and thoroughness of work

Effective science instruction should provide students not only with content knowledge but also skills and habits of science
• From **Market Research**: A company in Oregon sells an instructional kit on light reflection consisting of building towers to support reflecting mirrors to relay light from a source to a final target. There is a software package to help students do the calculations on where to place the towers.

• From **Expert on Science Education**: Learning science is best when there is
  • Has an interesting introduction to attract attention of students
  • Provides an opportunity to practice and apply skills and content knowledge
  • Instructional demonstration kit should include: equipment, manual with figures, charts, examples, etc.

• From **Client**: The following characteristics are identified:
  ➢ Related to the subject of light reflection, refraction, and absorption
  ➢ “Hardware” needs to be durable, easy to use, safe, inexpensive supplies. “Software” needs to be easy to use and inexpensive to make copies
**Design Project Problem Statement:** This defines the scope and work of the design project and spells out the objectives that lead to measurable outcomes. The scope of the design project should not be too narrowly defined (this restricts creativity and innovation) nor too broadly defined (project cannot be completed by deadline).

“Our team will deliver to client on June 2, 1996 a set of instructional activities and the “hardware” to support introductory and developmental activities based on light reflection, refraction, absorption, and transmission.”
Identify Design Constraints and Criteria

Design constraints and criteria are used to evaluate the potential solution ideas to select the optimum solution(s) for implementation.

Design Constraints can be defined as the conditions/properties/objectives that must be achieved by the solution. The solution idea is evaluated against the design constraints on a “Go” or “No Go” basis. A solution idea must meet all constraints to be considered further.

Design Criteria can be defined as the conditions/properties/objectives that are desirable for the solution.

Design criteria may sometimes counteract against one another, so the solution will involve trade-offs.

To evaluate a solution idea against the design criteria, each criterion is first assigned a weight based on its relative importance to other design criteria. The solution idea is given a rating based on how well the idea meets the criterion. A score is then calculated by multiplying a criterion’s weight by the solution’s rating, summing over all design criteria.
In this Case Study, the following **Design Constraints** were chosen:

- Equipment must support activities that meet state guidelines on content subject
- Cost

In this Case Study, the following **Design Criteria** are chosen:

- User friendly – Weight = 10
- Interesting – Weight = 8
- Durable – Weight = 4
- Safe – Weight = 6
Generate Solution Ideas:

*Activity Idea #1:* Demonstrate light reflection, refraction, and absorption are not discrete phenomenon (textbook) but all four phenomena can take place concurrently.

*Activity Idea #2:* Demonstrate communication by optics: i.e., generate, transmit, and receive light beam.

*Activity Idea #3:* Compare communication by photons versus electrons: generate, transmit and receive light and electron.

*Activity Idea #4:* Demonstrate how to overcome the barrier to communication via optics due to leakage of signal caused by light refraction.
Analyze Solution Ideas

*Idea #1:* will need a laser source and a medium to reflect, refract, absorb and transmit the laser beam. A transparent medium can be used to demonstrate front and back-reflections, and transmission of the laser. To see both reflected beams, the distance between the front and back-reflected beams must be wider than laser beam length.

![Diagram of laser beam interaction](image)

- **A** is the incident beam
- **DB** is reflected beam from front face
- **DE** is refracted beam
- **EH** is back-reflected beam within medium
- **HC** is reflected beam from back face
- **F** is the transmitted beam

Beam separation between reflected beams

\[ = DG + GH = 2DG = 2t(\tan \beta) \]

Where \((\sin \alpha)/(\sin \beta) = n = \text{refractive index}\)

Therefore, beam separation depends on medium thickness, the types of medium (through \(n\)), and the angle of incidence, \(\alpha\), (which affects \(\beta\))
Idea #1 (cont.): If you place multiple plates of the medium together, you will get multiple reflected beams as well as multiple transmitted beams. The intensity of these beams will decrease as they move away from the incident beam due to absorption as the laser beam transverses the medium.

Idea #2: will need a laser source and an optical fiber. Remove the plastic cover of the optical fiber to reveal the fiber. Shine a laser at one end of an optical fiber and you will notice the other end lit up, but the sides of the fiber exposed by removing the plastic cover will not lit up.

Idea #3: will need a power source, a copper wire, and a signal generator and receive, in addition to equipment needed in Idea #2. The signal generator can be an on-off switch, and the receiver can be a light bulb. To compare communication by photons versus electrons, create a game in which one team of students would convert the number to a combination lock into binary codes corresponding to “on” or “off” of a laser or electrical power source, and another team would receive the signal and decipher it to open the lock. To perform the task, students must be able to convert numbers based on 10 to binary numbers and back. The signal generator could be an on-off switch, and the receiver that counts the on-off sequence.
Idea #4: will need a laser source, a U-shaped hollow glass tube, and water. Bend a hollow glass tube into an U-shape if one does not exist. When you shine a laser source at one open end, the laser would leak out at the bottom of U-shape due to refraction because of the differences in the refractive index of air and glass, and consequently no laser would be detected at the other open end. Now fill the hollow glass tube with water. When you shine a laser at one open end, the laser could be detected at the other open end because the refractive indexes of water and glass are close enough to promote total internal reflection in the water, and no leakage through refraction at the water-glass interface at the bottom of the U.
Evaluate and Select Solution for Implementation

A decision-making matrix is set up as shown below to evaluate the solution ideas:

<table>
<thead>
<tr>
<th>Constraints</th>
<th>Idea #1</th>
<th>Idea #2</th>
<th>Idea #3</th>
<th>Idea #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meets State Guideline</td>
<td>Go</td>
<td>Go</td>
<td>Go</td>
<td>Go</td>
</tr>
<tr>
<td>Cost</td>
<td>Go</td>
<td>Go</td>
<td>Go</td>
<td>Go</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Wt.</th>
<th>Rating</th>
<th>Score</th>
<th>Rating</th>
<th>Score</th>
<th>Rating</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>User friendly</td>
<td>10</td>
<td>8</td>
<td>80</td>
<td>10</td>
<td>100</td>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>Interesting</td>
<td>8</td>
<td>10</td>
<td>80</td>
<td>8</td>
<td>64</td>
<td>8</td>
<td>64</td>
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<tr>
<td>Safe</td>
<td>6</td>
<td>10</td>
<td>60</td>
<td>10</td>
<td>60</td>
<td>8</td>
<td>48</td>
</tr>
<tr>
<td>Durable</td>
<td>4</td>
<td>10</td>
<td>40</td>
<td>10</td>
<td>40</td>
<td>6</td>
<td>24</td>
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<tr>
<td>Total Score</td>
<td></td>
<td></td>
<td>260</td>
<td></td>
<td>264</td>
<td></td>
<td>196</td>
</tr>
</tbody>
</table>

Based on total score, Ideas 1 & 2 will be selected for implementation
Implementation

**Optical Experiment**

This experiment demonstrates how the laser beam travels through a fiber optic filament. The second picture shows the laser beam escaping from only the end of the filament.

This diagram shows how the four dots in the second picture are formed due to reflection and refraction. (The diagram is using one glass plate, while the experiment is using two. Therefore, the number of laser beam dots are doubled.)
Evaluate Solution for Continuous Improvement

Industrial Design Capstone Design Project – ID 443/447

“Design a carrying case and produce a working prototype which hold optical components that can be dialed into positions to eliminate the need for setting up the demonstration.”
# Bill of Materials

## Optical Components

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Material</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plates</td>
<td>Acrylic</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Tube</td>
<td>Plastic</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Laser</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Laser Base</td>
<td>ABS</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Laser Track</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Screen</td>
<td>Card Stock</td>
<td>2</td>
</tr>
</tbody>
</table>

## Optical Case

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Material</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shell</td>
<td>ABS</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Side Panel</td>
<td>ABS</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Activation Button</td>
<td>Acrylic</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Hinge Mechanism</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Base Plate</td>
<td>ABS</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Handle</td>
<td>Coated Plastic</td>
<td>2</td>
</tr>
</tbody>
</table>

- **Optical Demonstration Kit**
- **CMD 443/447**
- **Kylee Nielsen Paul Reinhart**
User Interface
Marketing Studies –Summer I-2003, MGMT 301 Class Project

- Survey: 100 surveys sent to Berrien & Kalamazoo counties and the Detroit Area. 49 returned survey (49%)

- Demonstrated Need: 100% indicated a need for a new way to teach optics; 90% indicated product useful for multiple lessons; 78% want product in their classrooms

- Suggested Price of Product: 84% $50-100; 14% $100-200

- Chose Manufacturer: $151 for batch of 5,000

Present Status: Redesign carrying case to reduce tooling and mold set-up cost to arrive at unit price of $50-$100 for a batch size of 5,000