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Launch It!

The Tech Challenge 2016 Flight Lesson 5:
Developed by [The Tech Academies of Innovation]

I. Lesson Overview

How can you design a launch system to optimize distance and accuracy?

Lesson Description: Students work in teams to design, build, and test various launching systems and compare results to determine the optimal solution.

Grade Levels: 4-8

Education Outcomes:

Students will:
- design, build, test, and modify a launcher to optimize distance and accuracy
- generate, compare, and evaluate multiple launchers
- analyze data from tests to determine the best characteristics of each launcher
- [6-8th] identify and explain the trade-offs between distance and accuracy in relation to materials and design.

Education Standards

Met: (Note: bolded parts of the standards are fully met by this lesson)

Next Generation Science Standards (NGSS) Performance Expectations (PE)

3-5-ETS1-2: Generate and **compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.**

MS-ETS1-2. **Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.**

NGSS Disciplinary Core Ideas (DCI)

3-5-ETS1.A: Defining and Delimiting Engineering Problems
- **Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria).** Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.

3-5-ETS1.B: Developing Possible Solutions
- **Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved.**

NGSS Science and Engineering Practices (SEP):

3-5 SEP 6: Constructing explanations and designing solutions
- **Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem.**

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6-8 SEP 7: Engaging in Argument from Evidence
- **Evaluate competing design solutions based on** jointly developed and agreed-upon **design criteria.**

NGSS Crosscutting Concepts (CCC):
3-5-CCC-6. Structure and Function - The way an object is shaped or structured determines many of its properties and functions.
- **Different materials** have different substructures, which can sometimes be observed.

ELD Standards
ELD.PI.4-8.9: **Expressing information and ideas in formal oral presentations on academic topics.**

Addressed: (The following standards are practiced in this lesson but are not explicitly taught and assessed)

Next Generation Science Standards (NGSS) Performance Expectations (PE)
MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

NGSS Disciplinary Core Ideas (DCI)
MS-ETS1.C: Optimizing the Design Solution
- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.

NGSS Science and Engineering Practices (SEP):
6-8 SEP 2: Developing and Using Models
- Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.

Common Core Standards:
Math
6.SP.B.5: Summarize numerical data sets in relation to their context.

English Language Arts
RI.4-8.2: Determine the main idea of a text and explain how it is supported by key details; summarize the text. (Wording for this standard varies slightly by grade level.)

W.4-8.2: Write informative/explanatory text to examine a topic and convey ideas and information clearly.

W.4-8.2.D: Use precise language and domain-specific vocabulary to inform about or explain a topic.

SL.4-8.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on *grade 4-8 topics and texts*, building on others' ideas and expressing their own clearly.

English Language Development Standards

Part 1A.1: Exchanging ideas and information with others through oral collaborative discussions on a range of social and academic topics.

Part 1A.3: Offering and supporting opinions and negotiating with others in communicative exchanges.

Part 1C.9: Expressing information and ideas in formal oral presentations on academic topics.

Part 1C.11: Supporting opinions or justifying arguments and evaluating others' opinions or arguments

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II. Advanced Prep & Set-Up for Lesson

Move It! Advanced Set-Up

Materials (per team of 2-4 students; team sizes can be varied to accommodate your classroom set up.)

- 1 round object to move (such as ping pong ball or foam balls).
- 6 inches of masking tape
- Structural support materials that could be used for framing or support of devices (e.g. tongue depressors, straws, tinker toys, pencils, etc.) - approximately 5 pieces
- 1 rubber band, size 32 to 38
  - Rubber band should be ¼ inch thick and approximately 4 inches long. Do not use the thinner ones, they will break under tension.
- 1 plastic spoon
- 1 straw
- 1 pencil

Move it! Set-Up

1. Prepare a whiteboard/chart paper/projector to display information about the challenge:
   - Goal: Using the objects in your basket, come up with as ***many different ways*** as you can to move the ping-pong ball. MOVE IT! MOVE IT!
   - Think about:
     - This is a fast/quick design challenge: Simple is ok.
     - Come up with as many different ways using different materials to move the ball.

2. Materials:
   - Set up supply baskets or boxes for the teams with each team getting a set of the listed supplies.
   - Students can design in groups of 2-4 students. Consider moving chairs out of the way to encourage student movement.

3. Work areas:
   - Have an area to design/build prototype for each group of students.
   - Students can design in groups of 2-4 students.
   - Consider moving chairs out of the way to encourage student movement.

4. Data Collection:
   - Students will test and record as many different ways as possible to move a ping-pong ball across a flat surface.
   - Have students record their observations and descriptions on their data collection tables (“Move It! Data Collection Table,” appendix C).

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- See sample data table:

	Materials used and quantity	How did you get the object to move?	Observations on objects movement.	Sketch/label design
Design 1	rubber band (1)	*I created a sling shot by putting the rubber band on my index/thumb, pulling the ping-pong ball back and releasing it.*	*The ball moved very fast and traveled 7 feet.* *The ball moved forward but it was hard to keep from falling out of the rubber band, and it had a lot of spin so it came backwards after it landed.*	
Design 3	pencil (1)	*I hit the ball with the eraser end of the pencil like a pool ball.* *I struck the ball like a baseball.*	*The ball rolled across the whole table steadily in a straight line.*	
Design 4	straw (1)	*I used a straw to blow at the ball.*	*The ball traveled quickly across the whole table.* *In some trials it didn't move at all (wasn't aimed right).*	
Design 5	spoon (1)	*I put the ball on the spoon. Holding the bottom part of the spoon, I cocked the top part backed and then released the top part of the spoon*	*The ball was launched into the air and actually went half way across the table before landing.*	

Note: For K-4th grade you can give students a hand-out or have them copy the table from the overhead. For 5th-8th grade level you can give them the headings and have them create their own data table.

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Launch It! Advanced Set-Up

Differentiation options:
- One option for scaling up for middle school is to launch objects of two different masses.
- Limiting available materials can result in more varied designs and more creative solutions to the design challenge. If you are limiting materials, be sure to discuss with students to avoid arguments or feelings of unfairness, and have a strategy for distributing materials. Some ideas:
    - Make supply kits for the groups and put different materials in different kits. Decide ahead of time if trading between groups is allowed.
    - Give each team a budget of how many total pieces they are allowed to choose when they come up to gather supplies.

Materials (for class of approximately 32 students)
The quantities below will result in limiting some supplies for the groups, so all groups will not get the same supplies. If not limiting supplies, increase numbers of supplies.
- 3 targets for launch area, can be make from paper plates, printer paper, etc.
- Blue or masking tape to mark launch area
- Sticky notes or other landing markers
- ~5 Plastic spoons/forks
- ~10 wooden clothespins
- ~30 rubber bands, mixed sizes
- ~20 round toothpicks (flat toothpicks are not strong enough)
- ~5 lengths of flexible tubing cut into 6-9 inch lengths
- ~10 foam pieces
- ~ 6 oz. playdough or clay
- ~5 strips of netting or cloth, cut into 2 inch strips
- Have a mix of each of the following available for building:
    - ~15 sheets of various types of paper (e.g. cardstock, cardboard, index cards, printer paper)
    - ~30 pieces of vertical support structure material (e.g. tongue depressors, straws, tinker toys, pencils)
    - ~30 pieces of base support material (e.g. large tongue depressors, shoe boxes, large sturdy cups)
    - ~30 small containers to potentially hold ping-pong ball (e.g. sauce cups, various Dixie cups, cloth strips)
    - ~5 empty plastic bottles (e.g. empty shampoo bottles, soda bottles, water bottles)

Materials per group of students:
- 1 ping-pong ball
- 6 inches of masking tape
- 1-2 scissors

Optional materials (for 4th – 5th grades, we suggest providing less material/choices).
- ~6 pieces of string, cut into 1 ft. lengths
- ~3 springs of varied sizes
- ~10 magnets
- ~10 balloons
- ~3 hot glue guns
- ~4 quart zipper storage bags
- ~10 washers, mixed sizes

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Launch It! Set-Up
Set up the classroom with work areas for groups, a materials or supply table, and a launching area.

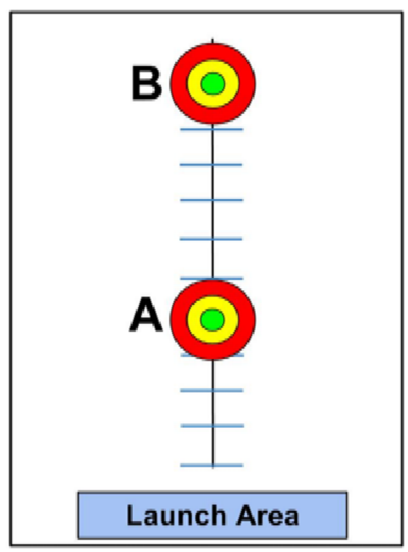
1. Have a whiteboard/chart paper/projector with following information about the challenge
   - Goal: Build and design a device to launch the ping pong ball
   - Design for:
     - Distance (How far did it travel?)
     - Accuracy (How close did the object travel to the target?)
     - Precision (Can you hit the same location 3 out of 5 times?)
   - Think about:
     - How you will record your data in your data table?
     - How will you measure accuracy?
     - How can you reduce the variables in your redesign to determine cause and effect?

Facilitator Notes:
Differentiation for launch
- For 6th-8th graders:
  - Include two additional targets: Place one additional target 1 meter left of the left of the center line at the 2-meter mark. Place an additional target 1 meter to the right of the center line at the 3-meter mark, off centered from the linear line by 1 meter to the right at the 3 meter mark.
- For 7th-8th graders:
  - Consider having two different objects with different masses for students to compare the effect mass has on performance. You can also challenge students to launch a small aircraft (at least 4 inches in length)
  - To test for repeatability, increase the number of run trials to 5-10 times instead of 3 times.

2. Materials:
   - Sort different materials into different bins and arrange them along the area for easy student access.
   - Instruct students to only take what they need and to return any unused material for other teams to use.

3. Work areas:
   - Have an area to design/build prototype for each group of students. Each table should have a set of the supplies listed under "Materials per group of students" on the previous page.
   - Students can design in groups of 2-4 students.
   - Consider moving chairs out of the way to encourage student movement.

4. Launch Area:
   - If possible have this area off to the side (away from Design and Materials tables).
   - Set up launch platform(s) (such as 1-2 table, stacked text books) in front of the measured runway.
   - To set up your runway, using blue or masking tape, mark 5 meters in increments of ½ meter.
   - Place two large circular targets at locations of 2m and 5m from the start in a straight line. The target diameter should be appropriately 30cm. Either use poster paper and draw targets on them, or use paper plates.



5. Data Collection:
   - Have students all begin by aiming for the closer target (target A). If teams are successful and there is more time, challenge them to aim for the target that is farther away (target B).
   - After each launch, measure and log the distance and accuracy of the landing location.
   - Repeat the launch for a total of 3 trials
   - Record data for all of the launchers *("Launch It! Data Collection Table," Appendix C)*

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- See sample data collection table below:

<table>
<tr><th></th><th colspan="2">Trial #1</th><th colspan="2">Trial #2</th><th colspan="2">Trial #3</th></tr>
<tr><td rowspan="2">1st Prototype:
(Draw a sketch in this box)</td><td><u>Distance</u>
2.5 m</td><td><u>Accuracy</u>
0.5 m right of target</td><td><u>Distance</u>
2 m</td><td><u>Accuracy</u>
On center line</td><td><u>Distance</u>
1 m (launcher fell apart mid-launch!)</td><td><u>Accuracy</u>
On center line</td></tr>
<tr><td colspan="3">What part of the criteria and constraints does this prototype meet?
• Launched the ping pong ball
• All team members participated actively
• All team members contributed
• Device launched facing forward off table
• Met all constraints</td><td colspan="3">What part of the criteria and constraints does this prototype NOT meet?
• Launcher is not reusable – it broke during the third trial!
• Did not hit the target
• Did not come within ¼ meter on any trial</td></tr>
<tr><td colspan="7">Based on the data collected from your first prototype, what MODIFICATIONS will you make for your second prototype, and WHY? What results do you expect?
• We are going to reinforce the place where the launch arm attaches to the base because that's where it fell apart during the 3rd trial. We think that will help us meet the "reusable" criteria
• We are going to put more rubber bands on it because that is where the power comes from and our ball isn't going far enough. If we add more rubber bands it should launch farther and reach the target.</td></tr>
</table>

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III. Launch It! Lesson Guide

Guiding Question: How can we use engineering concepts and practices to build the optimal launcher for our aircraft?

A. Introduction (10-15 minutes)

1. Introduce the design challenge theme. Some information you might introduce includes:
   - In a natural disaster, such as an earthquake or hurricane, people are cut off from resources they need to survive. Necessities like food, clean water, and medical supplies can be very difficult to transport to the people who need them most.
   - Over the course of this unit, you will be developing some new ways to help transport supplies to families in remote villages who are difficult to reach.
   - There are many ways to launch an object into flight. Some methods are more powerful and can launch things very far, while others are very accurate.
   - A launcher is part of a system that includes an object to be launched (projectile), launcher and an operator (person who uses the launcher).
   - To make the launch system work you need to consider all parts of the system.
   - Your task will be to develop a launch system that is both powerful and accurate.
   - This project will also help us prepare for the culminating Tech Challenge 2016.

> **Facilitator Notes:**
> Introduction
> - Consider NOT providing examples or pictures of launchers. Allow students to create and develop their own ideas independently.

2. Introduce key engineering design vocabulary. Information and key vocabulary you might introduce include:
   - Since we are working on a system of complex parts, we need to talk like **systems engineers**.
   - We will encounter many engineering terms as we work through this project. To get us started, here are a few key terms we'll be using today:
     - **Constraints** – The limitations of a design problem which typically include budget and schedule limitations but may also include other limitations such as maximum size restrictions.
     - **Criteria** – The requirements or desired features of a design problem often describing the purpose and standards that a system or device must meet.
     - **Systems engineer** – An engineer who focuses on how to design and manage complex engineering systems, frequently working over multiple interdisciplinary fields.

> **Facilitator Notes:**
> Introducing and reinforcing vocabulary
> - Introduce only a few target vocabulary words at a time
> - Connect target vocabulary to context and to experiences to which students can relate.
> - Use target vocabulary often and encourage students to use them often.
> - When introduced, post target vocabulary in the room and refer back to them periodically.
> - With student, make up hand or body motions that can represent their meaning.

3. Lead a discussion that draws on student's prior knowledge about launch systems. Chart and post student ideas for reference later in the lesson. Sample questions might include:
   - What are some objects or living things that you have seen launch or take-off?
   - Do all things launch or take-off in the same way?
   - How do these different launch or take-off systems work?
   - Where do launch systems get the energy to launch?
   - Which launch systems are the most accurate? What evidence do you have?

> **Facilitator Notes:**
> *Launch and take-off systems*
> Students may identify launch and take-off systems including rocket and launch pad, airplane and runway, bird and tree, slingshot and rock, golf club and ball, catapult and rock, baseball bat, ball and tee, Nerf gun and dart, hang glider and cliff, helicopter and ground, etc.

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B. Move It! Design Challenge (30-45 minutes)

1. Connect to the previous discussion on the variety of ways things take-off and launch.
   - Your team of engineers has been asked to develop several possible ways to transport supplies from an airport to nearby cities and villages where people are in need. You need not develop an **optimal** solution now, just come up with as many solutions as possible.
   - Engineers often use **models** to help them understand how complicated systems work. Models can be diagrams, computer models or physical models.
   - How can we use simple materials to model some of the launch or take-off systems we identified earlier?

> **Facilitator Notes:**
> **Optimal** – the best result obtained under specific conditions

2. Discuss the role of brainstorming in the design process.
   - Brainstorming is way of generating a lot of ideas in a short period of time. This challenge is about finding many different solutions. Brainstorming can help your group do that within the time constraint.

> **Facilitator Notes:**
> Brainstorming
> - Students new to brainstorming for design process often benefit more from a whole-class brainstorm where the teacher models the rules.
> - Consider using rules, such as these to guide students' brainstorming session.
> - Possible brainstorming rules:
>   - Suspend Judgement
>   - Go for quantity
>   - Be concise!
>   - Capture all ideas
>   - Go for wild ideas
>   - Build on ideas of others
>   - Be visual, sketch
>   - Focus on the topic
>   - All ideas are valid

3. Introduce the design challenge:

   Design Problem:
   - Engineers are working on new methods to transport food and rescue equipment to disaster sites around the world. These sites can be extremely varied and require many different approaches to delivering supplies. As an engineer, you must research as many ways as you can think of to move a payload. This will help you design a supply delivery system to many different locations around the world.

   Criteria (Design Requirements/Desired Features):
   - Use all of the materials in at least one way to move the ping-pong ball.
   - You must test at least 6 different ways to move the ball.
   - All team members must contribute and be able to articulate what their contribution was.
   - Sketch all of the designs you tried and make notes on how they worked in your data table.

   Constraints (Design Limitations):
   - Use only one material at a time to move the ball.
   - You can only touch the ball with the materials, not your body.
   - You have 10 minutes to complete the challenge.

   Testing:
   - Each group works at their work area to test and record as many different ways as possible to move the ball across a flat surface.
   - Any mechanisms that involve projectile motion will be launched in the launch area, not at desks.

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4. Debrief the design challenge: _Help students compare their different solutions. Some questions you may use to guide the debrief include:
   - What went well in this challenge?
   - What was difficult? How did you work to overcome these difficulties?
   - With which objects was the ball easiest to move?
   - What made them easier? (What were the properties of these materials that made them easier to use?)
   - With which objects was the ball most difficult to move?
   - What made them more difficult to use? (What were the properties of these materials that made them more difficult to use?)
   - Which objects did you use to move the ball in multiple ways?
   - What properties of these objects made this possible?

Facilitator Notes:
Debrief – Possible student responses may include:
- Students may notice that some objects were easier to move the ball farther (rubber band, spoon) and some were more suited to precise movements of the ball (blowing through the straw, tapping with a pencil or stick).
- Students should notice that many of the materials were able to be used in multiple ways (spoon, stick/pencil, straw)
- Students may begin to notice that some tools sacrificed one area of use for another. For example, using a rubber band is good for making the ball go far and fast, but is not ideal for exact aiming at a specific target. In engineering, this is called a **trade-off**.

5. Apply the idea of a **failure point** to the challenge students just completed.
   - In your first experiment, let’s say you launched your ball with a spoon. But on the third try, the spoon broke. Does that mean your whole design was a failure and it does not work to launch a ball with a spoon?
     - *Possible response: No. The spoon launched the ball with great success 2 times! The design itself, I would consider a success.*
   - We call the part of a system that, if it fails, will cause the entire system to stop working, a **failure point**. What then was the failure point in that situation?
     - *Possible response: The design was successful. However the handle of the spoon was not strong enough. The whole design was not a failure; the failure point was the weak and brittle handle of the spoon. If the handle fails, the whole system can no longer work.*
   - Based on that data, how could you iterate that design to address the failure point?
     - *Possible response: We could reinforce the spoon handle with duct tape. Or, we could use a metal spoon instead of a plastic spoon.*
   - Think about comparing multiple solutions based on data, mechanisms, distance, precision, accuracy, and failure points as we move on to our next challenge.

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C. Content Learning (15-20minutes)

1. Conduct a whole-class discussion on the relationship between the structure and function of the designs from "Move It!" Possible discussions questions could include:
   - In design we look for crosscutting concepts. These are concepts that are important in all types of science and engineering. One crosscutting concept in design is "Structure and Function". Designs have specific substructures (parts) that determine the function of the design. These substructures are made from certain materials and have specific shape.
   - For example which substructure allowed you to move the ball in multiple ways? How did the shape and/or material of that substructure enable you to move the ball in multiple ways?

2. Work with students to list the objects, their structure (shape/materials) and their function. Fill in a table of materials together either on an overhead, whiteboard, or projector *("Structure and Function," appendix C)*
   - Throughout discussion, stress that structure determines function(s)
   - Possible student responses may include:

Object	**Structure** (shape & material)		**Function**
straw	hollow	flexible sideways, light in mass	you can blow air through it because it's hollow
straw	long, thin	lengthwise, rigid	you can use it as a stick because it is rigid.
spoon	long, flat, curved "bowl"	flexible	allows you to pull the spoon back and launch it

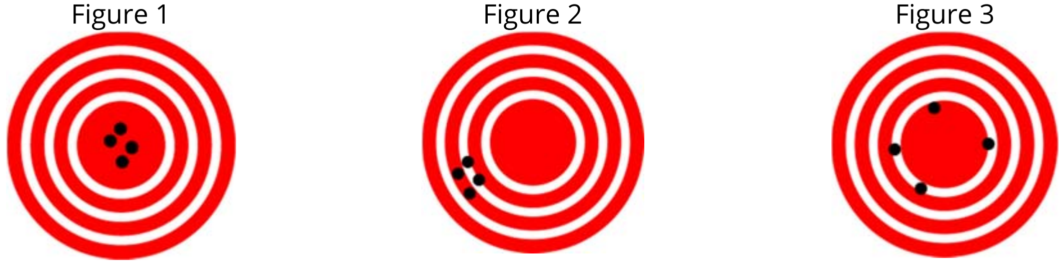
3. Define **data**, **distance**, **precision**, and **accuracy**. Review with the whole class the following vocabulary words.
   - Have students come up with the meaning, usage and examples of these vocabulary terms. In pairs, give students 2 minutes to come up with these on their own *(you may use "Vocabulary Write-Pair-Share," appendix C, if useful)*.
   - Call on groups to give their answers and combine answers as a whole class to create definitions and usage for each term. Ask probing questions. such as:
     - When/how would you use data?
     - When would it be important to have accuracy? Precision?
     - How would you distinguish between precision and accuracy?
     - How would distance change your plans or mechanisms?

Facilitator Notes:
Discussion – science vocabulary
- Teachers can take this opportunity to explain some science vocabulary that may come up as students discuss the function of their objects.
  - Bending back a spoon or using a rubber band makes use of the **elastic** properties of these objects. **Elasticity** is the tendency of an object to return to its original shape after it has been stretched or compressed.
  - In both the spoon and rubber band example as well, students are increasing **potential energy** (stored energy) until they release the ball, at which point it has **kinetic energy** (energy of motion)
  - Whatever way students move the ball, they are demonstrating **energy transfer** from one object to another, which is the process of passing energy from one device or system to another.
  - Students may use the stick or spoon as a **lever**, which is a simple machine in which a rigid object is used with a fulcrum (pivot point) to multiply the mechanical force that can be applied to another object.

Facilitator Notes:
Discussion
- It can be helpful for English Language Learner (ELL) students and struggling readers to provide sentence frames to support class discussions.
- For 6th-8th grade: To introduce trade-offs on speed (power) and accuracy ask students and write down their responses.
- Differentiation for grade levels: The standard for 3-5th grades expects students to compare multiple solutions. The standard for 6-8th grades expects students to optimize performance by making trade-offs.
- For more on the Crosscutting Concept of "Structure and Function" see 2015 Tech Museum "Engineering Takes Flight" lesson, where it is first introduced in the Aircraft Design Challenge portion of the lesson *(see here or Appendix B)*

4. Precision and accuracy are important concepts that are frequently mixed up, both by students and adults. Clarify the difference between the two concepts with the following exercise.
   - On the whiteboard or projector, display 3 blank targets, side by side *(sample target images can be found here and in appendix B)*
   - Place 4 marks in the center of the first target (figure 1). Ask students, if you threw 4 darts and they landed like this, how would you describe your accuracy? What about your precision?
   - Place 4 marks away from the center of the second target, but grouped together (figure 2). Ask students, if you threw 4 darts and they landed like this, how would you describe your accuracy? What about your precision?
   - Place 4 marks away from the center of the second target, and away from each other (figure 2). Ask students, if you threw 4 darts and they landed like this, how would you describe your accuracy? What about your precision?
   - Use these diagrams and students' answers to illustrate the differences between accuracy and precision.

Figure 1	Figure 2	Figure 3



High accuracy High precision	Low accuracy High precision	Low accuracy Low precision

5. Make sure that, as a class, you have come to the correct definitions of the vocabulary terms:
   - **Data** - are a collection of facts, such as numbers, words, measurements, observations or even just descriptions of things. Data are used to make conclusions.
     - *A method I have used to collect data in the past is ______.*
   - **Distance** - how far the object moves. It can be a data point.
     - *The greatest distance I think I could run without stopping is ____________.*
   - **Accuracy** – measures how close a measurement is to a known value or location, or to a target point.
     - *It is important for basketball players to be accurate shooters because _________.*
   - **Precision** – measures how reproducible measurements are. Precisely hitting a target means that all the marks are closely spaced, even if they are far from the center of the target.
     - *If I were shooting on a goal in a soccer game, having high precision would mean _______.*

6. [6-8th grade] Discuss and define **trade-offs**:
   - What trade-offs might a basketball player have to make when deciding where to shoot (or launch) the ball from?
   - Possible response: The player might have to consider the trade-off between distance and accuracy. She will have to decide: Is it more important to shoot the ball across a great distance (the 3 point line or half court) which will be more difficult to make, or shoot the ball from closer to the basket which will be more likely to make.
   - Definition of trade-off - Giving up one thing in return for another. An example of a trade-off might be larger cars tend to have more mass and can carry more people than smaller cars. Because of their mass, larger cars tend to be less aerodynamic and have poor gas economy.

D. Launch It! Design Challenge (60-90 minutes)

1. As an introduction to the Launch it! design challenge, teachers may choose to show and discuss 1 or more of the video(s) on the Nepal Earthquake. There are 3 short videos and a brief article *(see videos here or find link in appendix B).* Discussion questions might include:
   - What might be some effects of a major airport closing?
   - What affect might damaged runways have on air travel?
   - There are some helicopters flying and delivering aid to villagers. What are the pro/cons of delivering aid by helicopter vs airplane?

> **Facilitator Notes:**
> Introducing design challenge
> - Questions can be asked in whole class discussions and/or in small groups. Answers can also be recorded on chart paper.
> - Invite students to think of other real-life examples of where airplanes might need to be launched due to limited runway space. Or where it might be advantageous to have a short runway. Examples might be large cities with limited space. Navy aircraft carriers.

2. After watching the video(s) some possible discussion points include:
   - Earthquake-struck Nepal has been forced to close its international airport to large planes after its runway sustained damage from the April, 2015 earthquake (7.8 magnitude).
   - During this time there was a shortage of helicopters. In major disasters like this, disaster relief organizations often drop supplies from airplanes to help refugees.
   - The earthquake in Nepal and subsequent aftershocks were devastating. Over 8,000 were killed, villages were leveled leaving hundreds of thousands homeless in Nepal, India, China and Bangladesh.
   - Many people in remote areas have been unreachable by road and spread out over thousands of miles. How can we get the airplanes back into the air without long runways?

3. Introduce the Launch It! design challenge to the students
   - You have been asked to quickly design a small scale launcher that launches an aircraft with minimal runway length which will help the people of Nepal and other future disaster victims.
   - It's time to apply what you've learned about causing objects to move. Help Nepal launch their airplanes (in spite of its damaged runways)! What type of launcher can get the airplanes up in the air with both enough power to go the distance and enough accuracy to reach the remote villagers?

   Design Problem:
   - The airport runways have been damaged and there is a shortage of helicopters. Design a launcher that can launch an aircraft requiring minimal runway length. The goal is for the airplane to take off within a short distance and deliver supplies to remote villages.

   Criteria (Design Requirements/Desired Features):
   - The launcher must launch an aircraft (ping pong ball) with minimal launch area. (*Differentiation for grades 5-8: use two objects with different mass)
   - All team members must participate actively and be able to articulate the design decisions made and the rationale supporting these decisions.
   - All team members must contribute and must be able to articulate what their contribution was.
   - Device launches from table and must face forward (not sideways when aiming for one of the off-center targets).
   - The launcher must be reusable through multiple trials (robust)
   - Accuracy: Launched object hits the target 2 m from launch.
   - Precision: The launcher comes within ¼ meter of target in 3 out of 5 trials

> **Facilitator Notes:**
> Criteria and constraints
> - Before introducing the criteria of the challenge, you might ask students to discuss in small groups what some possible criteria might be for a launcher.
> - Additional constraints to scale up difficulty of this challenge could include limited budget and materials or a limited amount of time

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Constraints (Design Limitations):

- Use only materials on supply table
- 20 minutes to build and test your first launcher design
- Use only launch object provided (such as ping pong ball/duck)

Testing:

- Distance and Accuracy Test: A single person will launch the object five times from launch table at the same location to minimize launch variables. Object should be aimed at one of the designated targets. Repeat test 5 times and document your data. Two other team members will measure the distance traveled and accuracy (distance from the target to the object). Another member can make observations and record data.
- Observation: During tests, students should observe and document object's flight path.
- Students should document their data and design changes using the data collection tool or a science notebook *("Launch It! Data Collection Table," appendix C).*

4. While the students are designing their device, walk around and ask questions. Questions can be varied to cover the range of "depth of knowledge" levels. Refer here for website with depth of knowledge levels *(also see appendix B)*. For a more detailed list of questions refer to "Depth of Knowledge Questions for Discussion" in appendix A.2). Questions include:

Facilitator Notes:
Testing

- Students will likely need more time and may even need multiple class periods to work on their designs. That said, students tend to accomplish more when they feel some sense of urgency. We suggest giving students short work times of 20 minutes, which can be extended, if needed. Time permitting: you can extend the design challenge to the next day and give students an additional 10 minutes to obtain final data.
- Frequent testing is highly suggested. You might have the testing station open so that students can test a material by itself. Alternatively, or in addition, you might break up work times with whole class tests, so that groups can learn from each other and improve their designs.

Facilitator Notes:
Testing and student presentations

- Help students be aware of what works in their design. Many times students focus on what does not work. Instead of totally redesigning, help them focus on specifically what component is not working , the failure point *(for more detailed instruction about failure points see Appendix A2, Failure Point Background Information and Extension).*
- Change the criteria of the challenge for students who claim to be finished and have a large amount of time left. For example if they complete the challenge and hit the target at the 300 mark, challenge them to hit one of the side targets at a greater distance. Or, have them try to get more precise or more accurate data.

Level 1 Questions (Define/recall/list): • What materials did you use? • What data will you collect?	Sentence starters may include: • The materials we used were _____. • We will be collecting ____________.
Level 2 Questions (Collect and display/make observations/summarize): • What will your team look for/observe during the testing? Why? • What do you notice about how your launcher performs? • What do you notice in terms of accuracy? Precision?	Sentence starters may include: • During launching, we are going to look for ___________. • We notice that our launcher ___________. • We notice that in terms of accuracy/precision, our launcher __________.

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Level 3 Questions (Assess/compare/cite evidence):	Sentence starters may include:
• Using your data, explain why you chose to…? • Citing your data, what do you think would happen if…?	• Based on this data _____(cite data), we decided to change ____ in order to _____.
Level 4 Questions (evaluation or predict citing evidence/Analyze/ Prove/Connect). • Which design features could you change to improve _____________?	Sentence starters may include: • The changes I would make to improve _____ would be ____ because ___

5. Prior to testing as a whole class, go over the launch/safety procedures.
   - Have students stand along the perimeter of the launch area (so that the objects are not projected towards them), remind students to pay attention, stand behind a designated flight area so that they will not get hit and/or interfere with the motion of the object.
   - Groups will determine roles:
     - Who will launch the object?
     - Who will take measurements? (2 members)
     - Who will record data?
   - Agree on the launchers standing position, release point, angle and speed.
   - The launcher will yell, "Clear the launch pad", prior to each launch and will only launch when there are no people in the launch path.

6. After design time/individual testing is completed, give each group 10 minutes to prepare for their whole class design demonstration where they will demonstrate their launcher and address the following questions:
   - Explain how your launcher works (show it to the class)
   - Explain how your design changed from the 1st design to the current design by showing your design sketches or the pictures of your designs on the projector/laptop/etc.
   - Justify your design changes based on your data.
   - Explain some of the failure points/issues you experienced and how you overcame them.
   - [5-8th] Support your design with evidence of the trade-off between accuracy and precision.
   - Demonstrate your launcher (3 trials).
   - Possible differentiation for 5th -8th grades: students complete 5 trials.
   - All group members will participate in their presentation

7. To reinforce concepts from the lesson and design challenges, teachers may wish to follow up with vocabulary activities.
   - Word Bingo – in pairs or groups, have students pick any 4 words in a row (up, down, diagonally) and use the words in a discussion in their group (see "Word Bingo," appendix C)
   - Word Riddle Books - Students pick or are assigned 3-4 vocabulary word and create a small booklet by folding and cutting a sheet into 4ths. They then take each section and fold it into a booklet. The front cover is a riddle dealing with the concept. Inside pages might include (illustration, definition in their own words, examples, or when it is used in real life)

8. Teachers may assess students' understanding of concepts and vocabulary using the assessment rubric *("Launch It! Challenge Rubric," appendix C)*

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IV. Appendices

A. 1. Vocabulary and Background Information

The following is the start of a suggested list of words to discuss as you read and discuss with students.

accuracy	Describes ow close a measurement is to a known value or location. In the example of hitting a target, accuracy is how close your marks are to the center of the target, even if they are all on different sides of the target.
constraint	The limitations of a design problem which typically include budget and schedule limitations but may also include other limitations such as maximum size restrictions.
criteria	The requirements or desired features of a design problem often describing the purpose and standards that a system or device must meet.
data	A collection of facts you use to make conclusions. Data can be used as evidence to support a claim. For example, you made modifications to your design based on your data. The data can be observations, as well as measurements.
design feature	Characteristic of a design that has a purpose in the function of the device or system. For example a coffee cup has a handle (design feature) that enables a person to easily grasp it and not get burned (function)
distance	How far an object moves from the reference point.
elasticity	The tendency of an object to return to its original shape after it has been stretched or compressed.
energy transfer	The process of passing energy from one device or system to another.
failure point	The part of a system that, if it fails, will cause the entire system to stop working.
kinetic energy	Mechanical energy an object has by virtue of its motion
lever	A simple machine in which a rigid object is used with a fulcrum (pivot point) to multiply the mechanical force that can be applied to another object.
mechanism	A part on a device or machine that performs a function.

model	A representation of a design, system or structure, typically on a smaller scale than the original. Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations
optimize	A process in which solutions are systematically tested and refined and the final design is improved by trading off less important features for those that are more important.
potential energy	Mechanical energy an object has by virtue of its position; stored energy
systems engineer	An engineer who focuses on how to design and manage complex engineering systems, frequently working over multiple interdisciplinary fields
trade-off	A situation that involves losing one quality or aspect of something in return for gaining another quality or aspect. Trade-offs can occur for many reasons, including simple physics (into a given amount of space, you can fit many small objects or fewer large objects).
variable	Any factor, trait, or condition that can exist in differing amounts or types. An experiment usually has three kinds of variables: independent, dependent, and controlled. The independent variable is the one that is changed by the scientist.

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A. 2. Failure Point Background Information and Extension

More information to support the discussion of failure points during *C. Content Learning*:

1. Discuss **failure points** and redesigning based on data with students.
   - Our next challenge is going to be more complicated than our first challenge. It will be important for us to identify **failure points** and iterate our designs based on data.
   - Show the video on the Columbia disaster *(here or in appendix B)*
     - February, 2003, the Space Shuttle Columbia disaster occurred. As you watch the video think about what the failure point might be (what caused the accident). Some of you might already know.
     - Ask students: What do you think caused the shuttle to explode?
     - *The pieces of the shuttle that were recovered showed that a small breach left when a piece of foam insulation fell during take-off from the spacecraft's external fuel tank caused a crack in the heat-resistant tiles on the wing. During re-entry into earth's atmosphere, super-heated gases forced their way into the airframe through the hole, destabilizing the shuttle and causing the disaster.*
   - Display the diagram at the section labeled "Launch and Ascent Foam Strike" from Space.com *(here or in appendix B)* and read/explain that section to them. You can also scroll down past the diagram and read the section that explains the cause.
   - Once they have identified the cause- Introduce the term "failure point." We call the part that failed the failure point.
     - **Failure point -** a single point of failure is part of a system. If it fails, it will stop the entire system from working.
   - After reading/discussing ask students what the failure point was in the Space Shuttle Columbia accident. (add to word wall/student journal)
   - Connect the cause to the failure point. Also briefly discuss, how one part of a system can fail. Point out that there are many things that work on the shuttle and once they identified the failure point and fix it, the Shuttles were able to fly again.

2. Time permitting (optional), continue the conversation with information on the Challenger accident.
   - Show the video on the Challenger disaster *(here or in appendix B)*
     - January 28, 1986, another Space Shuttle exploded - the Space Shuttle Challenger. As you watch the video think about what the failure point might be (what caused the accident). Some of you might already know.
     - Ask them: If they know what caused the Space Shuttle Challenger to explode? If not then what do you think caused the explosion?
     - *The Challenger disaster occurred when an O-ring seal in the right solid rocket booster failed at liftoff. The O-ring failure caused a breach in the joint it sealed, allowing pressurized burning gas from within the motor to reach the outside and the external fuel tank. This led to the separation of the right-hand solid rocket booster attachment and the structural failure of the external tank.*
   - After a brief discussion read the section "Root Cause" from EngineeringFailures.com *(here or in appendix B)*
   - Connect the cause to the failure point. Also briefly discuss how one part of a system can fail. Point out that there are many things that work on the shuttle and once they identified the failure point and fix it, the Shuttles were able to fly again.

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A. 3. Depth of Knowledge Questions for Discussion

These can be varied to cover the range of “depth of knowledge” levels. Refer here for depth of knowledge levels.

Level 1 (Define/recall/list):

Questions:

- (For students having difficulty getting started) Think of a toy where it causes an object to move. How was the object moved? or Think of a sport that causes an object to move (or be propelled). How was the object moved?
- Where did you get your idea/inspiration from?
- What materials did you use and why?
- What data will you collect? Why?
- In the real world, what kinds of things are launched? How are things launched? Why are things launched?
- Can you explain your plan for design?
- How does your launcher work?

Sentence Starters:

- The materials we used were _____. We used them because _____.
- The launcher uses ____ to moves the ping-pong ball.
- We will be collecting ____________, because_______.

Level 2 (Collect and display/make observations/summarize)

Questions:

- What will your team look for/observe during the testing? Why?
- Can you explain what is working in your design?
- Can you summarize your plan of attack?
- Can you summarize what is working or not working?
- How are you going to collect and display your data?
- What were some of the trade-offs? (Cause and effect.. I notice that if i changed the tension of the rubber band, my ball went further but it was not very accurate).
- How might you improve your accuracy? Distance? What could you change?
- What materials did you use and why?
- What data will you collect? Why?

Sentence Starters:

- We noticed that __________ by looking at ____
- To improve the _____, we plan on changing ____ because_____
- We noticed that changing the ____ results in _____. This was based on _________(cite data).

<u>Level 3 (Assess/compare/cite evidence</u>

Questions:

- Why did you choose to _______? what was the result (cite evidence)
- What is the function of _______? How do you know this?
- What are some of the structures in your design that are working? How do you know? cite evidence
- Based on your data: In what other way could you solve this problem?
- What could it be about the structure of your device that caused it to fail? How you plan on redesigning this part?
- Using your data, explain why you choose to _____?
- Citing your data, what do you think would happen if increased/decreased ______?
- How does your data support your design changes?
- How did some of the features of your design help to optimize distance? Accuracy?
- What structures could you change to get the ping pong to go farther/be more accurate? Based on what data?

Sentence Starters:

- Based on this data _____(cite data), we decided to change ____ in order to _____.
- We determined a failure point by _______________.
- This ___ worked in our design because____.

<u>Level 4 (Evaluate or predict citing evidence/ Analyze/ Prove/Connect):</u>

Questions:

- Considering all the designs you have observed, what key features/structures/functions could you incorporate into your next design? Why?
- What changes would you make to solve _________________?
- Can you predict the outcome if __________ (e.g. the aircraft had more mass, had to fly over a mountain?)

Sentence Starters:

- The changes I would make to solve ________ would be _________, because _________.
- The structure I would add to my redesign would be _________ because _________. (expected outcome and justification).

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B. References

- "Target Clip Art." Public Domain Vectors. Web. 9 Oct. 2015. http://publicdomainvectors.org/en/target-clip-art-bullseye
- "Design Challenge 2 Depth of Knowledge Questions." *Google Docs*. Web. 30 July 2015. https://docs.google.com/document/d/1GC-hpP516OKcSG8jviasnzG-6U_eeqyxdX2XC-3qlV4/edit?usp=sharing
- "Design Challenge Learning." Design Challenge Learning. Web. 30 July 2015. http://www.thetech.org/educators/design-challenge-learning
- "Effective Strategies for Teaching Science Vocabulary." *Effective Strategies for Teaching Science Vocabulary*. Web. 30 July 2015. http://www.learnnc.org/lp/pages/7079?ref=search
- "Engineering Failures." » *Challenger*. Web. 30 July 2015. http://engineeringfailures.org/?p=85
- "Engineering Failures." » *Space Shuttle Columbia*. Web. 30 July 2015. http://engineeringfailures.org/?p=198
- "Nepal Earthquake: Kathmandu Airport Closes Damaged Runway to Big Planes." *NBC News*. Web. 30 July 2015. http://www.nbcnews.com/storyline/nepal-earthquake/nepal-earthquake-kathmandu-airport-closes-damaged-runway-big-planes-n352781
- "Red Bull Flugtag 2013: Chicken Whisperers Record of 258ft." *YouTube*. YouTube. Web. 30 July 2015. https://www.youtube.com/watch?v=XM9nL1h-L4M or https://www.youtube.com/watch?v=X8Y2F1320QI
- "Rules for Brainstorming." *Dschool*. Web. 30 July 2015. http://dschool.stanford.edu/blog/2009/10/12/rules-for-brainstorming/
- "Space Shuttle Challenger Explosion (GRAPHIC)." *YouTube*. YouTube, 3 Apr. 2013. Web. 15 Oct. 2015. https://www.youtube.com/watch?v=WDRxK6cevqw
- Tate, Karl. "Columbia Space Shuttle Disaster Explained (Infographic) | Space.com." Web. 30 July 2015. http://www.space.com/19526-columbia-shuttle-disaster-explained-infographic.html
- "The Tech Challenge 2016 Lessons." The Tech. The Tech Museum of Innovation, 6 Oct. 2015. Web. 3 Nov. 2015. http://www.thetech.org/tech-challenge-presented-emc/resources/tech-challenge-2016-lessons
- "What Caused the Space Shuttle Columbia Disaster?" BBC. 30 Jan. 2015. Web. 15 Oct. 2015. http://www.bbc.com/future/story/20150130-what-caused-the-columbia-disaster

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- "Watch a US Navy Aircraft Carrier Launch All Its F-18 Fighter Jets." *YouTube*. YouTube. Web. 30 July 2015. https://www.youtube.com/watch?v=c0vKjewofLU or https://www.youtube.com/watch?v=drMj7HP-IDI

- Webb, Norman L. and others. “Web Alignment Tool” 24 July 2005. Wisconsin Center of Educational Research. University of Wisconsin-Madison. 2 Feb. 2006. http://static.pdesas.org/content/documents/M1-Slide_19_DOK_Wheel_Slide.pdf

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C. Lesson Handouts

Name: ______________________________

Date: __________ Class: ______________

Move It! Data Collection Table

	Materials used and quantity	How did you get the object to move?	Observations on object's movement	Sketch/label design
Design 1				
Design 3				
Design 4				
Design 5				
Design 6				
Design 7				
Design 8				

Name: ______________________________

Date: ___________ Class: _______________

Structure and Function

Object	Structure		Function
	Shape	Material	

Name: ______________________________

Date: __________ Class: ______________

Vocabulary Write-Pair-Share

Term	Definition	Usage	Examples
Failure point			
Precision			
Accuracy			

Name: ______________________

Date: __________ Class: ______________

Launch It! Data Collection Table

1. Perform three separate trials with your launcher. For each trial record:
   - **DISTANCE** you were able to launch the ping-pong ball, straight along taped line.
   - **ACCURACY** of your launches: how far from the target the ball lands.
2. Describe which parts of the criteria and constraints your prototype met and which it did not.
3. Make ONE modification to your prototype to achieve greater distance or accuracy, and record the modification you made.
4. Repeat this process with your 2nd prototype.
5. Repeat again with your final prototype.

	Trial #1		**Trial #2**		**Trial #3**	
1st Prototype: *(Draw a sketch in this box)*	Distance	Accuracy	Distance	Accuracy	Distance	Accuracy
	What part of the criteria and constraints does this prototype meet?			**What part of the criteria and constraints does this prototype NOT meet?**		
Based on the data collected from your first prototype, what MODIFICATIONS will you make for your second prototype, and WHY? What results do you expect?						

Name: ______________________________

Date: __________ Class: ______________

	Trial #1		Trial #2		Trial #3	
2nd Prototype: *(Draw a sketch in this box)*	Distance	Accuracy	Distance	Accuracy	Distance	Accuracy
	What part of the criteria and constraints does this prototype meet?			**What part of the criteria and constraints does this prototype NOT meet?**		

Based on the data collected from your first prototype, what MODIFICATIONS will you make for your second prototype, and WHY? What results do you expect?

Name: ______________________________

Date: __________ Class: ______________

	Trial #1		Trial #2		Trial #3	
Final Prototype: *(Draw a sketch in this box)*	Distance	Accuracy	Distance	Accuracy	Distance	Accuracy
	What part of the criteria and constraints does this prototype meet?			**What part of the criteria and constraints does this prototype NOT meet?**		

1. **Describe one change you made to get to your final prototype and justify that change with evidence from your launches/data. Explain *why* you made that change using evidence.**

2. **Looking at your final prototype, describe the precision and accuracy of your launcher. Be specific!**

3. **Identify a failure point in one of your prototypes. How did you address this in your design changes?**

Name: ______________________________

Date: __________ Class: ______________

Launch It! Challenge Rubric

This rubric is designed to assess student explanations of their design process and solutions following the final reflection.

**Indicates differentiation. "Trade-off" is a concept explored in 6-8th grades. 4-5th grade teachers can skip these.*

	4	3	2	1
Academic Vocabulary	**All** of the target vocabulary words are used accurately in explanations: constraint, criteria, accuracy, failure point, *trade-off	**At least 5** of the target vocabulary words are used accurately in explanations: constraint, criteria, accuracy, failure point, *trade-off	**At least 3** of the target vocabulary are used accurately in explanations: constraint, criteria, accuracy, failure point, *trade-off	**2 or fewer** of the target vocabulary are used accurately in explanations: constraint, criteria, accuracy, failure point, *trade-off
Content Accuracy	**Clear and detailed** explanation is given of how **multiple** design decisions optimized precision and accuracy in the launching system.	**Clear and detailed** explanation is given of how **at least one** design decision optimized precision and accuracy in the launching system.	Explanation is given of how **at least one** design decision optimized precision and accuracy in the launching system.	Explanation **reports** on the performance of the launcher **without describing any design decisions** made.
Claims and Evidence	- Claims are **stated clearly**. - **Relevant evidence** is provided. - **Data** from prototype testing is provided. - Design decisions are **justified** with evidence and data.	- Claims are **stated**. - **Relevant evidence** is provided. - **Data** from prototype testing is provided.	- Claims are **weak or unclear**. - **Relevant evidence** is provided.	- Claims are **weak or unclear**. - **Evidence** is provided.
Engineering Process	- **More than three** iterations were **systematically** tested. - The final solution meets **all** criteria and constraints.	- **More than two** iterations were tested. - The final solution meets **most** criteria and constraints.	- At least **two** iterations were tested. - The final solution meets **few** of the criteria and constraints.	- At least **one** iteration was tested. - The final solution meets only **one** of the criteria and constraints.