Design your Dragon: A STEM Challenge thru Dimensional Analysis Inspired by " How to Train your Dragon" (6-8 Days)

Authors

KIM ALVIN DE LARA

JOSEPHINE MESINA

SUBJECT/GRADE LEVEL

Subject Area: Science, Math, ELA, Engineering

Grade Level: Middle School (5-8)/ Highschool (9-12)

Materials

Multimedia and Reading Materials

- **Video Clip:** Toothless and Hiccup's first flight scene from *How to Train Your Dragon* YouTube Link
- **Book Passage:** Chapters 9–11 from *How to Train Your Dragon* (printed copies or digital access), Amazon Book Link

Printables & Worksheets

- **Animal Data Cards or Chart:** Featuring mass, wingspan, and wing area of Bald Eagle, Bat, Pterosaur, Small Glider (Printable chart or data sheets for group investigation)
- **Scaling Law Worksheets:** Scaling Law Practice Worksheet
- **Dimensional Analysis Worksheet:** Mini-Investigation Worksheet
- **Engineering Design Journal Template:** Design a Flying Dragon Journal
- **Rubric and Self-Assessment:** Project Rubric & Reflection

Materials for Math and Conversions

- Calculators (for exponentiation and unit conversions)
- Rulers or meter sticks (if doing scaled drawing)
- Graph paper or digital drawing tools (e.g., Google Drawings, Tinkercad) for wing design and blueprint creation

Materials for Creative & Design Activities

- Drawing paper, pencils/pens/and colored markers

Notes on Purchasing or Sourcing Materials:

- **Calculators:** Any scientific calculator app or handheld calculator will work. Free apps like Desmos or Google Calculator are sufficient.
- **Drawing Tools:** Free web-based tools like Google Drawings or Canva can be used for digital design.
- **Books:** *How to Train Your Dragon* books can be purchased via Amazon or borrowed from school/public libraries.

Optional (Extension Activities)

- Access to the internet for additional research/videos on aircraft, gliders, and flight principles
- Model building kits (optional), lightweight materials like cardboard, foam board, or craft sticks, if constructing prototypes

STANDARDS

Next Generation Science Standards

Middle School (Grades 5-8)

- *MS-PS2-2: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.*
- *MS-PS3-1: Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.*
- *MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution.*
- *MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.*
- *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.*

High School (Grades 9-12)

- *HS-PS2-1: Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among net force, mass, and acceleration.*
- *HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles or energy stored in fields.*
- *HS-ETS1-3: Evaluate a solution to a complex problem based on prioritized criteria and trade-offs.*

Mathematics Standards | Common Core State Standards

Middle School

- *6.RP.A.3: Use ratio and rate reasoning to solve real-world and mathematical problems.*
- *7.RP.A.2: Recognize and represent proportional relationships between quantities.*
- *7.EE.B.4: Use variables to represent quantities in a real-world or mathematical problem and construct simple equations and inequalities to solve problems.*

High School

- *HSA-CED.A.2: Create equations in two or more variables to represent relationships between quantities.*
- *HSA-REI.B.3: Solve linear equations and inequalities in one variable, including equations with coefficients represented by letters.*
- *HSA-SSE.A.1: Interpret expressions that represent a quantity in terms of its context.*
- *HSF-LE.A.2: Construct linear and exponential functions, including arithmetic and geometric sequences.*
- *HSN-Q.A.1: Use units as a way to understand problems and guide solution strategies; choose and interpret units consistently in formulas.*

English Language Arts Standards | Common Core State

Middle School

- *CCSS.ELA-LITERACY.W.6.3: Write narratives to develop real or imagined experiences or events using effective techniques, relevant descriptive details, and clear event sequences.*
- *CCSS.ELA-LITERACY.SL.6.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, teacher-led) with diverse partners on grade 6 topics, texts, and issues, building on others' ideas and expressing their own clearly.*

High School

- *CCSS.ELA-LITERACY.W.9-10.3: Write narratives to develop real or imagined experiences or events using effective techniques, well-chosen details, and well-structured event sequences.*
- *CCSS.ELA-LITERACY.SL.9-10.1: Initiate and participate effectively in a range of collaborative discussions on grades 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.*

LESSON OBJECTIVE(S)

Science Objectives

1. **Explain** the physical forces (such as lift, gravity, and drag) acting on a flying object and how they affect the ability of a large creature like Toothless to fly.
2. **Apply** the square-cube scaling law to calculate the estimated wing area required for a dragon weighing approximately 1,000 kg to achieve flight.
3. **Compare** wing sizes and masses of various flying animals (bald eagle, bat, pterosaur, glider) and **analyze** which model best fits the flight requirements of Toothless.

Mathematics Objectives

4. **Use** ratios, proportions, and exponents to solve problems related to the scaling of wing area relative to body mass.
5. **Convert** measurements between square meters and square feet to relate scientific data to real-world units.

Engineering Objectives

6. **Design** a scientifically plausible wing blueprint for a flying dragon using the Engineering Design Process, incorporating wing size calculations and aerodynamic principles.
7. **Evaluate** and **revise** their dragon wing designs based on peer feedback and engineering criteria.

English Language Arts Objectives

8. **Analyze** a narrative passage describing flight from *How to Train Your Dragon* to identify descriptive language and emotional tone.

9. **Write** a journal entry from the perspective of Hiccup explaining, with scientific reasoning, how he would help Toothless fly again, using accurate math and engineering concepts integrated into a coherent narrative.
10. **Engage** effectively in paired and group discussions, articulating ideas clearly and building on peers' contributions related to flight challenges and design solutions.

Key Vocabulary: mass, weight, lift, drag, thrust, area, volume, scaling law, dimensional analysis

CAREER CONNECTION(S)

Mentor Background: Include the Army S&E mentor's name and bio.

Dr. Mark D. Ginsberg is a principal investigator in the Materials and Structures Branch, Facilities Division, United States Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) at Champaign, Illinois. He specializes in using control theory techniques to describe previously uncharacterized physical systems. His research relates to this lesson plan by incorporating some of the dimensional analysis he uses in his work.

STEM Careers: This should link to possible careers associated with this lesson/topic.

1. **Aerospace Engineer-** Designs and tests aircraft, spacecraft, and flying machines—applying principles of aerodynamics and structural engineering similar to designing realistic dragon wings.
2. **Mechanical Engineer-** Focuses on creating mechanical systems and prototypes, such as wing mechanisms and control surfaces, much like the engineering design process used to enable flight.
3. **Biologist (Zoologist or Comparative Anatomist)-** Studies the anatomy and physiology of flying animals (birds, bats, pterosaurs), providing essential data about wing structures and flight adaptations.
4. **Mathematician/Applied Mathematician**-Uses mathematical models and scaling laws to solve real-world problems like calculating wing area based on body mass.
5. **Science Educator or Curriculum Developer -**Creates and delivers engaging science lessons that integrate STEM concepts, inspiring students to explore engineering and scientific inquiry.

ENGAGEMENT

Brief Description: In this Engage Phase, introduce the essential question, *"Could a dragon really fly? How big would its wings need to be to carry its weight?"* Students will watch a short clip of Toothless and Hiccup's first flight from the *How to Train Your Dragon* Video Link. Following the clip and discussion, select one of the prompts based on students' abilities to guide deeper thinking.

Procedures: Day 1 (45-60 Mins)

Essential Question: *"Could a dragon really fly? How big would its wings need to be to carry its weight?"*

Hook: Begin by showing the video clip below-Toothless and Hiccup's iconic first flight from *How to Train Your Dragon*. Video: https://youtu.be/hFAg8F2GaZ0 After the clip, prompt students with this short discussion:

- *"If Toothless were real, would he actually be able to fly?"*
- *"What physical challenges would he face, like wing size, weight, wing shape?"*

After the discussion, do one of these prompts (A, B, or C) based on students' abilities:

A. Post-Video Discussion Prompt: (Group)

1. **Reality Check:** "Toothless looks so smooth and agile in the air. If he were real, what forces would be acting on him during flight?"
2. **Size Matters:** "Toothless is much bigger than a bird. How do you think his size affects his ability to

fly? What kind of wings would he need to lift himself?"

3. **Wing Mechanics:**" Take a close look at Toothless' wings. Do they remind you more of a bat's wings or a bird's wings? Explain what you notice and why this difference might be important."
4. **Engineering Link:** "What role did Hiccup's invention play in helping Toothless fly? What does that tell you about how engineers use design to solve problems?"
5. **Scientific Wondering:** "What questions do you have after watching the clip? Could we use math and science to figure out if a dragon could actually fly?"

B. Quick Pair-Share Prompt: (Partner)

"Turn to a partner and answer this: If you had to redesign Toothless' wings for real-world flight, what's the first thing you'd change and why?

C. Journal Prompt: (Individual)

Have students read Chapters 9–11 of *How to Train Your Dragon*, where Toothless takes Hiccup on his back and they soar through the air. Encourage students to pay close attention to Hiccup's reactions and how he describes the sensation of flight. This section captures Hiccup's first real flight with Toothless and provides a vivid look at their unique connection in the air.

After reading, have students respond to the following creative writing task: "Write a journal entry from Hiccup's point of view as he calculates what Toothless needs to fly again, using real math. Be sure to include:

- An estimated weight for Toothless
- Wing size requirements based on scaling laws
- Hiccup's engineering ideas to improve flight
- His emotional connection to Toothless and the challenge of helping him fly again

EXPLORATION

Brief Description: In this Explore Phase, students will engage in a Mini-Investigation: Dimensional Analysis in Nature. First, in small groups, students will conduct a math-based scientific investigation that connects real animal data to the fictional world of dragons like Toothless (Step 1). Next, the class will come together for a whole-group introduction to the Scaling Law (Step 2). Finally, students will complete practice exercises to estimate Toothless' wing area using four reference flyers: a bald eagle, a large bat, a pterosaur, and a small glider (Step 3). The class may opt to complete additional extension tasks, including:

- **Discussion Prompts:** Reflect on flight challenges and which animal model best fits Toothless
- **Creative Design Activity:** Draw or digitally design Toothless with realistically scaled wings.
- **Scaffolded Worksheet:** Use guided questions to apply the scaling formula and analyze results.

Procedures: Day 2(45-60 Mins)

Mini-Investigation: Dimensional Analysis in Nature. Students work in small groups to compare animal wing spans and masses (e.g., eagle, bat, pterosaur, and glider).

Step 1: Compare Real Flying Animals: Give each group data cards or a chart that includes the following:

Animal	Average Mass (kg)	Wingspan (m)	Estimated Wing Area (m²)
Bald Eagle	6	2.3	~0.7
Bat (Large)	1.5	1.5	~0.2
Pterosaur	250	10	~20
Small Glider	150	8	~15

Let students explore and compare how the wing area relates to body mass. Then answer the question on the worksheet: Mini-Investigation Worksheet

Step 2: Introduce the Scaling Law

a. Introduce the key concept of **allometric scaling** using this equation:

$$\text{Wing Area} \propto \text{Body Mass}^{2/3}$$

b. Explain or watch the **square-cube law:**

- As animals get **heavier**, their **wing area** must increase, but **not linearly**.
- It increases by the **2/3 power** of their body mass.
- Why? Because **mass (volume)** increases with the cube of size, while **wing area (surface)** increases with the square. This happens because an animal's mass (or volume) increases with the cube of its size, while its wing area (or surface area) only increases with the square of its size.
- Explain to students that this idea, known as the square-cube law, demonstrates why it is more difficult for larger animals to fly.

YouTube: Link: The Square Cube Laws Link: Small is Mighty Square Cube Law

Step 3: Apply to Toothless (Estimation Task): Introduce or review this formula to students

$$\text{Wing Area}_{\text{Toothless}} = \text{Wing Area}_{\text{Reference Animal}} \times \left(\frac{\text{Mass}_{\text{Toothless}}}{\text{Mass}_{\text{Reference Animal}}} \right)^{2/3}$$

Example Calculation (Do this first with guidance, teacher demo, or step by step with students)

Bald Eagle

- **Mass**: 6 kg
- **Wing area**: 0.7 m²
- **Toothless' mass**: 1,000 kg

1. Fill in the scaling law:

$$\text{Toothless Wing Area} = 0.7 \times \left(\frac{1000}{6}\right)^{2/3}$$

2. Calculate the ratio inside the parentheses:

$$\frac{1000}{6} = _____$$

3. Raise the ratio to the power of 2/3 (use calculator):

$$\left(\frac{1000}{6}\right)^{2/3} = _____$$

4. Multiply by 0.7/.: Toothless Wing Area _____m²

   Answer 21.17 m²

Instructions on how to use a calculator to solve this problem: Using a Calculator for Scaling Wing Area

Do more practice of the Scaling Law by doing this worksheet: Students will practice applying the Scaling Law further by completing the worksheet on the link. Scaling Law Practice Worksheet

Extension: (Optional): The class may opt to complete additional tasks to deepen understanding and learning. Link: Discussion Prompts After Calculation

- Discussion Prompts: Reflect on flight challenges and which animal model best fits Toothless
- Creative Design: Draw or digitally design Toothless with realistically scaled wings.
- Scaffolded Worksheet: Guided questions help students apply the scaling formula and compare results.

EXPLANATION

Brief Description: During the Explanation Stage, students will go through the scientific and

mathematical principles behind flight and scaling using real-world and fantasy examples. This also reinforced key concepts introduced during the Explore phase. Students will explain and use Unit Conversion (m² to ft²), apply and connect dimensional analysis to real-world applications by comparing Toothless' estimated wing size (in both m² and ft²) to real aircraft wings.

Procedures: Day 3 (45-60 mins)

A. Unit Conversion (m² to ft²)

- Teach students how to convert square meters to square feet.

- Use the conversion: $$1\ \text{m}^2 = 10.764\ \text{ft}^2$$

- Do a guided example together.
  E.g., if Toothless' wing area = 80 m², what is that in ft²?

Step-by-Step Instruction: Show the formula:

$$\text{Area in ft}^2 = \text{Area in m}^2 \times 10.764$$

Do a few examples together as a class: Example 1: If Toothless' wings are 80 m², how many ft² is that?

$$80 \times 10.764 = 861.12\ \text{ft}^2$$

Answer: 861.12 ft²

Example 2: If a bat's wing area is 0.2 m², what is it in ft²?

$$0.2 \times 10.764 = 2.15\ \text{ft}^2$$

Answer: 2.15 ft²

Example 3: If a pterosaur's wings are 20 m², what is that in ft²?

$$20 \times 10.764 = 215.28\ \text{ft}^2$$

Answer: 215.28 ft²

Example 4: If a glider has a wing area of 15 m², convert it to ft².

$$15 \times 10.764 = 161.46\,\text{ft}^2$$

Answer: 161.46 ft²

B. Review of the scaling law and apply the conversion and dimensional analysis to estimate Toothless's necessary wing size.

Step 1: Review the Scaling Law by guiding students through calculating Toothless' wing area (in m²) using the reference animal of your choice. Example using a bald eagle:

$$\text{Wing Area}_{\text{Toothless}} = 0.7 \times \left(\frac{1000}{6}\right)^{2/3} \approx 21.6\,\text{m}^2$$

Step 2: Convert Toothless' Wing Area to ft²: Use the conversion:

$$1\,\text{m}^2 = 10.764\,\text{ft}^2$$

$$21.6 \times 10.764 \approx 232.5\,\text{ft}^2$$

Step 3: Provide Aircraft Wing Data for Comparison: Give students a chart like this (fill in or let students research):

Aircraft/Glider	Wing Area (ft²)	Wingspan (m)	Mass (kg)
Cessna 172 (small plane)	174 ft²	11 m	~1100
Glider (ASK 21)	178 ft²	17 m	~360
Peregrine Falcon	4 ft²	1.2 m	~1
Drone (DJI Mavic)	1.1 ft²	0.5 m	~1.6
Toothless (calculated)	232.5 ft²	~8.5–9 m(~estimated)	1000

Note: **Estimated Wingspan for Toothless: 8.5–9 meters.** To estimate **Toothless's wingspan (in**

meters) based on the **calculated wing area of 232.5 ft²** (which is about **21.6 m²**), we can use the following approximation:

Assumption: For many birds, bats, and aircraft:

$$\text{Wing Area} \approx \text{Wingspan} \times \text{Average Wing Chord (width of one wing)}$$

Let's assume Toothless has **bat-like wings** with a relatively **narrow, elongated shape**, where the **average chord** (wing width) is about **2.4 to 2.7 meters**, typical for large flying animals with gliding adaptations.

Wingspan Estimate Formula

$$\text{Wingspan} = \frac{\text{Wing Area}}{\text{Average Chord}}$$

Using the wing area in m²:

Example using chord = 2.5 m:

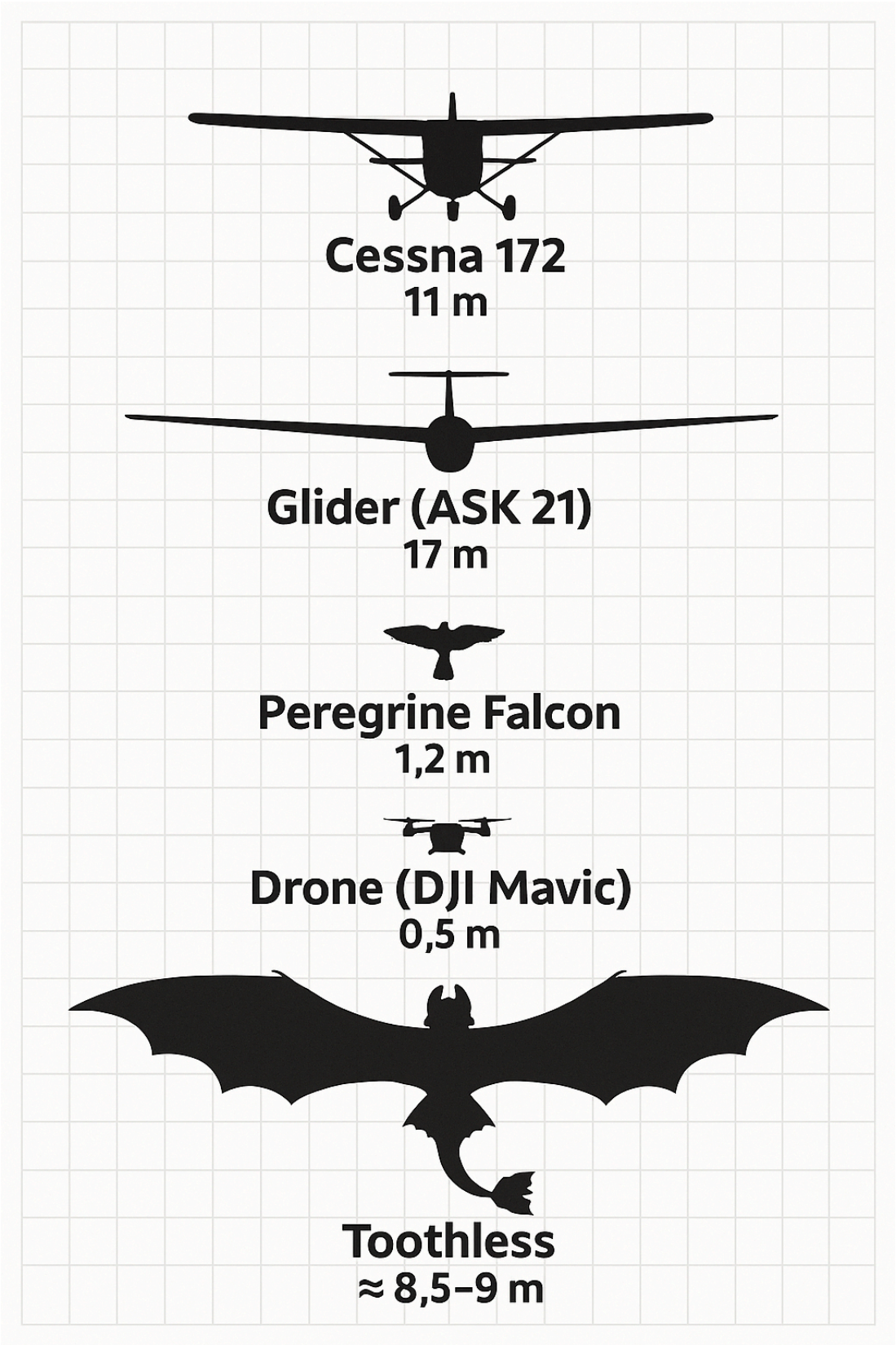
$$\text{Wingspan} = \frac{21.6}{2.5} = 8.64\,\text{m}$$

The Estimated Wingspan for Toothless is 8.5–9 meters

This fits within the range of large extinct flying reptiles like **Quetzalcoatlus** (wingspan ~10–11 m), making the estimate biologically plausible.

Step 4: Create a Student drawing or poster: Have students build their own version of this table with:

- Estimated Toothless wing area in both m² and ft²
- Comparison to at least two flying machines



Note: Example of poster/ drawing of comparison (Source: ChatGPT OpenAI)

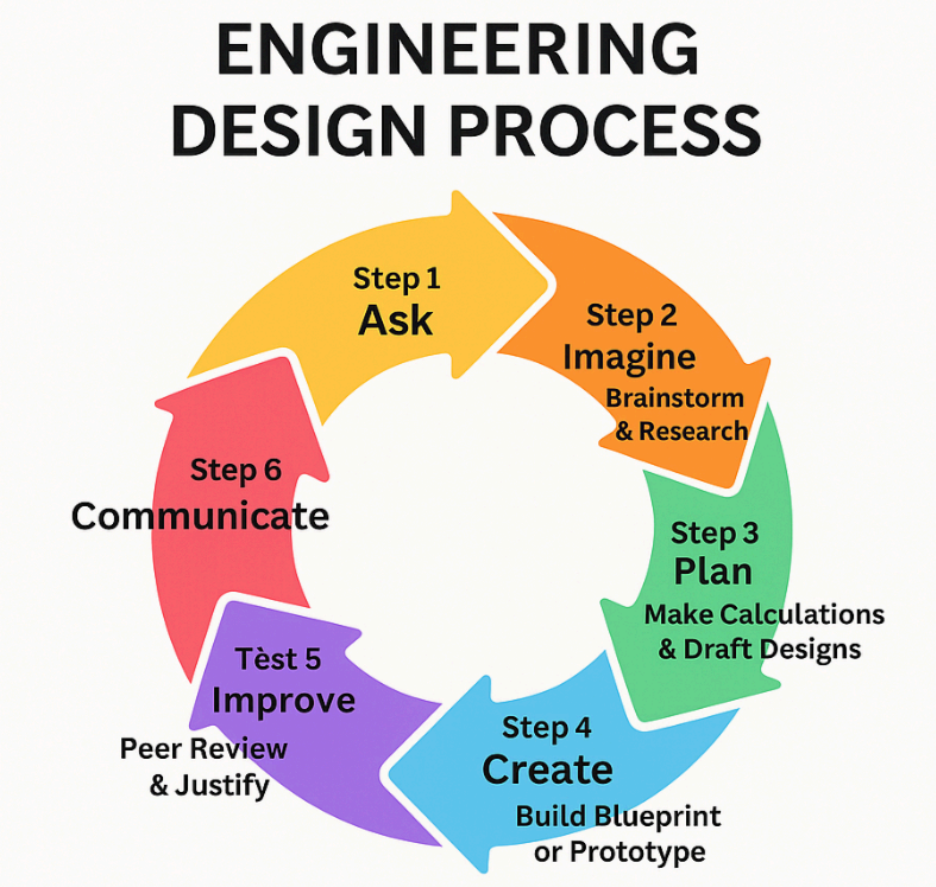
Additional explanation using videos for students: Visual Engagement: Videos & Images: Show Visuals of Gliders and Light Planes:

- ASK 21 Glider NASA Beginner's Guide to Aeronautics
- Cessna 172 (light aircraft) Cessna 172 flight video
- Hang gliders or ultralight aircraft: Glider takeoff video

ELABORATE

Brief Description: In this stage, the lesson embeds the Engineering Design Process (EDP) into the Elaborate phase through the "Design a Flying Dragon" STEM Challenge. This version structures the student project using the authentic steps of the EDP, making it both a rigorous STEM task and a creative, high-engagement experience. Students use the provided Engineering Design Journal template to document their thinking, calculations, designs, and revisions as they move through each phase of the process.

Procedures Day 4 and 5 (45-60 Mins): Students will apply the Engineering Design Process (EDP) to create a scientifically plausible, flight-capable dragon. Using the scaling law, unit conversion, and aerodynamic principles, students will develop and defend a blueprint for their dragon's wings and flight system.



"Design a Flying Dragon" STEM Challenge. Use the Journal- Template Design a Flying Dragon Journal

Step 1: Ask – Define the Problem Students identify the challenge: "How can we design a flying dragon whose wing size and mechanics are scientifically realistic for its body mass?"

Step 2: Imagine – Brainstorm & Research: Students brainstorm ideas and research:

- Real flying animals and aircraft for inspiration
- Wing shapes (bird, bat, glider)
- Control systems (tail fins, rudders, prosthetics)
- Materials (membrane, feathers, metals, lightweight composites)

3. Plan – Make Calculations & Draft Designs: Students use the scaling law to calculate wing area and then convert m^2 to ft^2:

4. Create – Build Blueprint or Prototype: Students produce a visual or digital blueprint of their dragon.

5. Test & Improve – Peer Review & Justify: Students present their dragons and receive peer feedback. Then, students revise their blueprints or explanations based on feedback.

6. Communicate – Final Presentation: Students present their designs with a short engineering pitch:

Formats:

- Gallery walk or science fair-style showcase
- Flipgrid or video pitch
- Group oral presentation with visual aid

EVALUATION

Brief Description: In this culminating activity, students apply what they have learned about flight, scaling laws, and engineering by designing a scientifically realistic flying dragon. Using the Engineering Design Process (EDP), they calculate wing dimensions based on a selected dragon weight, then create a visual or digital blueprint of their dragon. Simultaneously, students complete an Engineering Design Journal to document each step of their design journey, including calculations, planning, and peer feedback. This project bridges STEM content knowledge with creativity and hands-on problem-solving. Students may also opt to complete the optional.

Procedures: Day 6 (45-60 Mins) Students complete each step of the Engineering Design Journal, documenting calculations, design choices, and reflections. Participate in peer and teacher evaluations using the project rubric as a guide. To deepen understanding, students may choose to respond to optional Student Self-Assessment Questions that promote reflection on their learning process, design decisions, and areas for improvement.

Project Rubric & Reflection

REFERENCES

- **Cowell, C.** (2010). *How to Train Your Dragon*. Little, Brown Books for Young Readers.
- **DreamWorks Animation.** (2010). *How to Train Your Dragon* (Film clip). YouTube link: https://youtu.be/hFAg8F2GaZ0
- **Next Generation Science Standards (NGSS).** (n.d.). Retrieved from https://www.nextgenscience.org
- **Common Core State Standards Initiative.** (n.d.). *Mathematics Standards* and *English Language Arts Standards*. Retrieved from http://www.corestandards.org
- **NASA Glenn Research Center.** (n.d.). *Beginner's Guide to Aeronautics*. Retrieved from https://www.grc.nasa.gov/www/k-12/airplane/
- **Veritasium.** (2011). *Square-Cube Law Explained* (YouTube video). YouTube link: https://youtu.be/ATNQCEMGfRs
- **De Lara, K. A.** (2025). *Design a Flying Dragon: Engineering Design Journal Template*, *Scaling Law Practice Worksheet & Dimensional Analysis Resources*. Google Docs:
    - Scaling Law Worksheet
    - Animal Flight Data Worksheet
    - *Design a Flying Dragon: Engineering Design Journal Template*
- **Google Drawings & Canva.** https://docs.google.com/drawings, https://www.canva.com
- **ChatGPT (OpenAI).** (2025). *AI-generated images and diagrams for lesson visuals*, including: Engineering Design Process (EDP) diagram, Dragon wing scaling illustrations, Comparative wing size visuals (e.g., Toothless vs. pterosaur vs. glider). Generated via OpenAI's ChatGPT image generation tool. https://chat.openai.com
- **Federal Aviation Administration (FAA).** Aircraft specifications and performance data. https://www.faa.gov
- **Getty Images.** (n.d.). *Photos of Toothless* https://www.gettyimages.com
- **Ginsberg, M. D., Buckingham, R. L., & Libman, M.** (2005, August 4). *Dimensional Analysis: A relief for scholastic guilt. Lessons in an alternate physics. Suitable for reading on the road!*