Introduction to Engineering Design Process

Engaging students in the STEM disciplines requires students to gain an understanding of the primary focus of each core subject. Science is focused on conducting controlled experiments to gain further insight into a phenomenon. Engineering on the other hand centers on developing ways to integrate scientific processes into mainstream society. As such engineers and technicians focus on improving processes and application of science. The engineering design process is a series of steps that guides engineering teams as we solve problems. The design process is iterative, meaning that we repeat the steps as many times as needed, making improvements along the way as we learn from failure and uncover new design possibilities to arrive at great solutions.

Overarching themes of the engineering design process are teamwork and design. Strengthen your students' understanding of open-ended design as you encourage them to work together to brainstorm new ideas, apply science and math concepts, test prototypes and analyze data—and aim for creativity and practicality in their solutions. Project-based learning engages learners of all ages—and fosters STEM literacy.

This fits in with the key components of the Hardware Store Science program being lessons that include basic making skills, integration of all components of STEM (Science, Technology, Engineering, Math), and providing real world applications in manufacturing, construction, motorsports, and the skilled trades as a means of encouraging student engagement. In order to address the wide variety of topics as part of a one-year introductory physical science, intro to engineering, intro to manufacturing, or engineering technology course these making activities require certain types of material and specific equipment found in what has become known as Maker Spaces. While many of these items may be purchased using traditional funding models, other specialized equipment and materials will need to be purchased through nontraditional means. This could be through school/program sponsors or partners. The business content relates directly to the programs second goal of engaging students with the STEM disciplines by encouraging students to become active participants in their education.

Prototyping, building, testing, and producing usable products is a major job description of engineers and technicians today. The Engineering Design lessons were developed to provide students with first-hand experience with the design process, and the fundamental career tasks of an engineer. Each lesson will focus on one particular aspect of the engineer career field, culminating in the development of a usable model for conducting scientific investigations throughout the remainder of the Go-Kart Science Technology & Entrepreneur program.

The Physical Science & Technology STEM centered lessons and activities provide students and educators with hands-on build projects, basic making skills, integration of all components of STEM (Science, Technology, Engineering, Math), and the application of content to an authentic collaborative design process based platform, similar to what engineers and technicians use in their everyday careers and occupations.

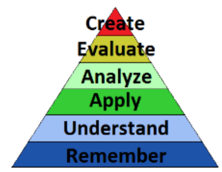
Purpose and Learning Objectives

Statement of Purpose

This is an extended set of lessons that will take approximately 5 days to complete. Students will be introduced to tolerances and dimensioning from the perspective of an engineer. These are key concepts when building or constructing moveable parts. Students will learn the use of calipers in obtaining dimensions of small objects, requiring precise measurements. Students will be introduced to the Micro-Kart Challenge, companion program to the evGrand Prix, RC Kart, and Autonomous RC Car Competitions that are the focus of this curriculum program. Students will begin to create design ideas and component information relating to the Micro-Kart Challenge. The measurements and tolerances of associated component pieces will help ensure accuracy in later 3D printing. Finally, students will use a design checklist to evaluate the final functional requirements of a rapid prototype chassis, including proposed improvements to sketch accuracy and prototyping effectiveness in meeting design requirements.

Guiding Question

How are functionality and ease of assembly ensured by accuracy of dimensions and tolerances?



Learning Objectives (SWBAT)

- Define the importance of engineering tolerances and dimensions in the engineering design process using specific examples
- Use measuring tools to add 1:1 scale engineering tolerances and dimensions to describe MSTEM Accel Car addon components
- Repeat the 5 phases of the engineering design process as they are applied to the development of the MSTEM Accel Car Chassis
- Identify aspects of the 5 phases of the engineering design process that contribute to the rapid prototype design model
- Provide constructive feedback during a critique rapidly prototyped models based on the 5 phases of the engineering design process.

Deliverables

Gummi Bear Tolerances & Dimensions
MSTEM Accel Car Component Dimensions
Rapid Prototype Models
MSTEM Accel Car Design Checklist

Topics Covered

Science	Technology	Engineering	Math	Polytechnic Skills
– Units – Variables – Scientific Method	– Hand tools – Modeling Software – Prototyping Materials	– Design Process – Question Storming – SCAMPER Acronym	– Measurement – Tolerance	– Idea Documentation – Collaboration – Resources Management

Lesson Timeframe

Traditional Classroom – 5 Days (45-55 minutes)

Key Concepts

- Measurements and dimensions
- Tolerance within product dimensions

- Caliper Use
- Rapid Prototyping
- Engineering Design Process

Global/Local Issue

In this lesson students will engage in activities and topics related to the grand engineering challenge of improving product development, manufacturing, and functional use. Students will learn about the importance of tolerancing and accurate dimensions throughout the design process, from conception to product production. Student teams will begin the process of designing a chassis for a miniature electric car as they examine the role of the engineering design process in guiding the work of design teams, and individual engineers. This lesson can help set the foundation for further studies and investigations using student developed testing models, and the focused development of an evGrand Prix competition go-kart, remote controlled cadet go-kart, or a 1/10th scale autonomous RC electric car.

Students throughout this lesson will learn critical skills related to engineering design and manufacturing. These skills will benefit students in many fields within technology and engineering and will apply to broader career and occupational pathways such as: Manufacturing, UX design, Electrical Engineering, and Computer Engineering, Mechanical Engineering. Indiana-based employers with career opportunities utilizing the skills taught in this lesson include: Subaru, Echo Engineering & Production Supplies Inc, and Fort Wayne Metals.

Enduring Understanding

Students will understand that Variation exists in manufactured parts and must be accounted for by applying tolerances when setting manufacturing dimensions and specifications. Students will be able to identify the use and application of the engineering design process for taking a creative idea from conception to production. Students will be aware of the fact that early decision-making processes play an important role in final design completion, and that cultivating positive, constructive feedback early in the process will improve chances of product success. Students will acknowledge that submitting ideas for review by peers allows one to refine an idea and gain insights that improves the design process. Students will understand that creative ideas do not always move quickly through the design process if the product is required to meet stringent guidelines, tolerances, and safety requirements.

Required Prior Knowledge & Skills

- Basic computer skills (typing, using Internet search engines, etc.)
- Some experience media presentations (using camera, video equipment, public speaking, etc.)
- Basic sketching skills - use of rulers, protractors, etc.
- Understanding of fractions and basic mathematics
- Familiarity with calipers and how to use them

Assessment

- ***Engineering Design Process***, to assess student learning and understanding of tolerance, dimensions, and the 5 phases of the engineering design process.

Instructional Sequence and Duration – 5 Days *(Classroom duration assumed to be 45-55 minutes in length)*

Purchase materials needed for 3D printing of student chassis designs.

Engage: Students will learn the use of calipers for making accurate measurements of small objects, by measuring specific dimensions associated with the size of Gummi Bear candy. Students will then compare the dimensions from a total of 10 gummi bear candies to develop an appreciation for creating objects within a small dimensional tolerance. This will be reinforced throughout the curricular program, helping students gain an intuitive feel for the need to ensure accuracy in measurements. Students will apply the lesson learned to both the design process and experimental data collection. (*Classroom Duration: 45-55 minutes*) ***(ESPS.2, 5, PS.6, IED-6.10,** STEM-T.2, 5**)***

Lead In: 10 – 15 minutes

1. **Objective -** Define the importance of engineering tolerances and dimensions in the engineering design process using specific examples. *(This should be written in a prominent location within the classroom and easily identifiable by students.)* Provide students with a copy of the ***Lesson Log*** as they enter the classroom.
2. **Bell Assignment/Affirmations/Good News/Objectives** *(7-10 minutes)*
   - **Warm Up -** *(4-5 minutes)*
     - Display an image of an everyday object. Ask students to use the Warm-up/Do Now section of their daily lesson log, their engineering notebook, or their science journal/notebook to describe the object - in detail - as if they were talking to a blind person
     - Have students answer the following questions in the Warm-up/Do Now section of their daily lesson log, their engineering notebook, or their science journal/notebook.
       1. What made it difficult to describe this object? *(Answers vary but may include things like complexity of object, no physical means of using other sense besides vision)*
       2. How might you improve your description if the object was physically in front of you? *(Answers vary, may include such things as - object could be touched, lifted, felt)*
3. **Agenda/Activities –** Point out the objective and have students record this in their Lesson Log/Notes. Point out key activities that directly relate to the stated objective. Connect student prior knowledge with the day's objective and build upon student background knowledge. Explain what students will need to complete, and turn in, by the end of the class period.

Activity: 30 – 35 minutes

4. **Classroom Activity, Gummi Bear Tolerances & Dimensions,** Divide students into pairs (or up to 3 students depending on the resources available). Each student pair will receive a small package of Albanese gummi bear, calipers, and a *Gummi Bear Tolerances & Dimensions Student Activity Sheet 2.3a*. Explain that every product that is manufactured goes through what is called quality control. In quality control it is up to the employees in that department to make sure that each product matches up to specifications. In this activity, students get to participate in a sort of quality control experiment for the Albanese Confectionery gummi bear. Explain to students that they will use the handout as a guide in measuring the dimensions of the gummi bear. Pictures are shown for how and where to measure on the individual gummi bear. Explain that students will need to be as precise as they possibly can be in measuring the gummi bear. Students will record their measurements on the handout.

   Give students approximately 15-20 minutes to accomplish this activity. Those students who finish early can help other students.

   After all the student pairs have completed the activity, gather the students back as a class. have each group determine an average for each of the dimensions they measured: total height, total width, depth of head, width of head by ears, height of "A". Assess whether student pairs found dimensions relatively close to those of the peers and the teacher key. This can be done through a voting system (i.e., "By the raise of hand, how many of you got ___ for the width of the head?") or by having student pairs each report on a specific dimension and comparing that with other student answers (i.e., "[Student names], what did you get for the gummi bear's head width?" They respond.

"Who else got that? Anyone get a different dimension?"). Take approximately 7 minutes for this activity.

Once completed, ask the students the following question: "If these gummi bears are all produced using the same materials in the same factory, why are there subtle variations in their dimensions?" Have students include their response in their worksheet, classroom activity section of their lesson log, engineering notebook, or science journal/notebook. *(Answers vary, check for concept understanding rather than a specific answer)*

Explain that it is impossible to manufacture two products that are absolutely identical. There will always be very slight variations in each product. This is something that is accounted for when designing and manufacturing products. **Ask** "How can slight variation be accounted for when designing and manufacturing a product?" Have students include their response in their worksheet, classroom activity section of their lesson log, engineering notebook, or science journal/notebook. *(Answers vary, Check for concept understanding rather than a specific answer)*

Wrap-up: 5 – 8 minutes

5. **Close and Launch –** Direct student attention to the daily objective. Ask for a student volunteer to read the day's objective and discuss how they were able to meet the day's objective. *(Take a moment to review the day's activities and how they relate to the stated objective)*
   - **Assignment – Gummi Bear Tolerances & Dimensions,** Have students write a 25 word summary of what they learned from comparing the dimensions of individual gummi bears. Inform students that they will need to use the words *dimension*, *tolerance*, *sample*, and *variation* within their summary.
   - **Exit Ticket/Assessment –** Have students answer the following questions in the Exit Ticket section of their Daily Log, their engineering notebook, or their science journal/notebook.
     1. Compare and contrast dimensions and tolerances? *(dimensions are set values describing the size and shape of an object. Tolerance is the permissible limit or limits of variation in a physical dimension)*
     2. When do you think tolerances don't matter? *(Answers vary based on student understanding. all manufactured items have some sort of tolerancing associated with it, the larger the item the larger the tolerance)*
     3. What types of things would you think have very small tolerances? *(students should be able to list specific items like gears, objects that fit together, objects with threads (nuts and bolts), etc.)*
   - **Collect – Lesson Log,** This should contain the questions from the warmup activity, Lesson Objective, Notes taken during classroom discussion, Classroom Activity, and answers to the Exit Ticket. *(End each lesson with a positive and encouraging statement for students to remember as they leave the classroom)*

Explore: Students will use their knowledge of variation within a sample to understand that engineering tolerances are accounted for in design and manufacturing. Students will then take a deeper look at variation within a sample as they learn about tolerances; in measurements, dimensions, and design development. Students then apply principles of tolerance to parts that fit together. Finally, students apply their learning to the development of acceptable tolerances to be utilized during the upcoming MSTEM Accel Car design project. *(Classroom Duration: 45-55 minutes)* ***(ESPS.2, 5, PS.6, IED-1.5, 6.10,*** *STEM-T.2, 5)*

Lead In: 10 – 15 minutes

1. **Objective -** Use measuring tools to add 1:1 scale engineering tolerances and dimensions to MSTEM Accel Car adon components. *(This should be written in a prominent location within the classroom and easily identifiable by students.)* Provide students with a copy of the ***Lesson Log*** as they enter the classroom.
2. **Bell Assignment/Affirmations/Good News/Objectives** *(7-10 minutes)*
   - **Warm Up -** *(4-5 minutes) (See Module 1 Warm-up Activities and Exit Tickets)*
     - Have students answer the following questions in the Warm-up/Do No section of their daily lesson log, their engineering notebook, or their science journal/notebook.
       1. Define variation? *(Answers vary, The range of a sample, as in the difference between the largest and smallest value)*
       2. How do manufactured parts end up with a variety of sizes? *(Answers vary, should include such things as: old and worn out molds or equipment, lack of operator attention, etc.)*
       3. How can manufacturers limit the variety of sizes that end up in their manufactured parts? *(Answers vary, ensure students list specific things like - maintaining equipment, new tools, proper training of equipment operators, etc.)*
3. **Agenda/Activities –** Point out the objective and have students record this in their Lesson Log/Notes. Point out key activities that directly relate to the stated objective. Connect student prior knowledge with the day's objective and build upon student background knowledge. Explain what students will need to complete, and turn in, by the end of the class period.

Activity: 30 – 35 minutes

4. **Classroom Discussion, Engineering Tolerances,** Use the *Engineering Tolerances Slideshow 2.3b* to guide the discussion and classroom activity that follows. This slideshow covers how engineering tolerances are accounted for in design and manufacturing. The discussion begins with a review of variation within a sample, as discussion during the gummi bear candy activity. Students are then taught about tolerances; in measurements, dimensions, and design development. Students then apply principles of tolerance to parts that fit together. Finally, students are introduced to the MSTEM Accel Car design project *(see classroom activity below)*.
5. **Classroom Activity, MSTEM Accel Car Component Dimensions,** Organize students into teams of 2-3 depending upon class size. Distribute Student Activity Sheet 2.3c. Discuss with students the question for analysis, key concepts, and use of calipers and tape measure. Help students identify critical dimensions and decide upon an appropriate tolerance for each component. This can be done by having the design teams share their measured dimensions and determining a tolerance based on the variation with measurements.

Wrap-up: 5 – 8 minutes

6. **Close and Launch –** Direct student attention to the daily objective. Ask for a student volunteer to read the day's objective and discuss how they were able to meet the day's objective. *(Take a moment to review the day's activities and how they relate to the stated objective)*
   - **Assignment - MSTEM Accel Car Component Dimensions,** Assign any unfinished measurements as homework.
   - **Exit Ticket/Assessment –** Have students answer the following questions in the Exit Ticket section of their Daily Log, their engineering notebook, or their science journal/notebook.
     1. What is one thing you learned today? *(Answers vary. Look for specific details of learning taking place)*
     2. Why is this information important? *(Answers vary, look for specific details that relate to*

tolerances and dimensions)

3. How will this information improve my ability to create successful model designs? *(Answers vary, look for specific details that relate to tolerances and dimensions)*

- **Collect – Gummi Bear Tolerances & Dimensions, Lesson Log,** This should contain the questions from the warmup activity, Lesson Objective, Notes taken during classroom discussion, Classroom Activity, and answers to the Exit Ticket. *(End each lesson with a positive and encouraging statement for students to remember as they leave the classroom)*

Explain: Students will relate the 5 phases of the engineering design process to a design challenge. Students will begin by learning the value of question storming and how it contrasts to brainstorming. Then students will participate in a brainstorming activity with the aid of the SCAMPER acronym guiding their thinking. Students will apply this understanding to the development of a first iteration chassis design for the MSTEM Accel Car project. Finally, students will learn the value of rapid prototyping prior to being provided an opportunity to construct their own prototype of an accel car chassis. Students will summarize their learning throughout the learning process. *(Classroom Duration: 45-55 minutes)* ***(ESPS.3, IED-1.5, 6.10,** STEM-T.2, 5**)***

Lead In: 10 – 12 minutes

1. **Objective -** Repeat the 5 phases of the engineering design process as they are applied to the development of the MSTEM Accel Car Chassis. *(This should be written in a prominent location within the classroom and easily identifiable by students.)* Provide students with a copy of the ***Lesson Log*** as they enter the classroom.
2. **Bell Assignment/Affirmations/Good News/Objectives** *(7-10 minutes)*
   - **Warm Up -** *(4-5 minutes)*
     - Distribute a copy of the **ABC Vocabulary Reading Strategy** and have students complete the chart for the term Engineering.
3. **Agenda/Activities –** Point out the objective and have students record this in their Lesson Log/Notes. Point out key activities that directly relate to the stated objective. Connect student prior knowledge with the day's objective and build upon student background knowledge. Explain what students will need to complete, and turn in, by the end of the class period.

Activity: 30 – 35 minutes

4. **Classroom Discussion, Engineering Design Process,** Use the *Engineering Design Process Slideshow 2.3d* to guide the discussion for the class period. Organize students into groups of 2 or 3 and distribute the MSTEM Accel Car Chassis Challenge student activity sheet 2.3e. The slideshow details the engineering design process. Students will see the engineering design process applied to an everyday object (a chair) and then apply the principles to the development of a 2D drawing of their idea for the MSTEM Accel Car chassis. Students will proceed through each of the following aspects of the engineering design process, with this lesson utilizing slides 1 thru 21 and the remainder being utilized during the Engineer section of the module. Depending on student understanding, this transition may take place during this class session or be postponed until the next class session.

   The five phases of the process discussed are *Ask, Imagine, Plan, Create*, and *Improve*.

   - **Ask**: During the ask phase, students will use a design tool called "question storming" (described in the slide deck). In Question storming students will write down a list of questions they have regarding the *Micro Kart*.
   - **Imagine:** Students will use a tool named SCAMPER (described in the slide deck) to help them generate potential chassis designs. Hand out the *SCAMPER Student/Teacher reference sheet* as needed for the activity.

- **Plan:** Based on a given list of supplies, students will sketch and plan out their final design for the *Micro Kart* chassis.
- **Create:** Students will sketch their final design of a *Micro Kart* chassis on graph paper. Students will then take that design and trace it onto white printer paper and cut it out to use as a working prototype.
- **Improve:** Students will evaluate their final designs by using their cutout white paper prototype and compare it against a checklist of final functional requirements (see *MSTEM Accel Car Design Checklist Student Activity Sheet 2.5c*). As part of the worksheet, there is a teacher signoff where student teams are required to hand over the prototype to the teacher who will sign off on whether it meets the desired requirements. Any prototypes that do not meet all the requirements should be redesigned.

Wrap-up: 5 – 8 minutes

5. **Close and Launch –** Direct student attention to the daily objective. Ask for a student volunteer to read the day's objective and discuss how they were able to meet the day's objective. *(Take a moment to review the day's activities and how they relate to the stated objective)*
   - **Assignment -** Assign students to complete needed preparation for next days in-class work on rapid prototyping. This may include having students collect objects that can be used during a prototyping session.
   - **Exit Ticket/Assessment –** Have students answer the following questions in the Exit Ticket section of their Daily Log, their engineering notebook, or their science journal/notebook.
     1. What are the 5 phases of the engineering design process? *(ask, imagine, plan, create, and improve)*
     2. How does the term SCAMPER assist with the generation of ideas? *(Answers vary, but should center around the idea of providing a process for brainstorming ideas)*
     3. What does each letter in SCAMPER stand for? *(Not required to memorize, just used as a reference - **S**ubstitute, **C**ombine, **A**dapt/**A**lter, **M**agnify/**M**inimize, **P**ut to other use, **E**liminate, **R**earrange/**R**everse)*
   - **Collect – MSTEM Accel Car Component Dimensions, Lesson Log,** This should contain the questions from the warmup activity, Lesson Objective, Notes taken during classroom discussion, Classroom Activity, and answers to the Exit Ticket. *(End each lesson with a positive and encouraging statement for students to remember as they leave the classroom)*

Engineer: Design teams will develop an accel car prototype chassis using a tape measure, miter saw, plywood, screw spacers/straw, and a EUDAX 82pcs Gear Set with Wheels and Axles. Students will apply the measurements and tolerances from their *MSTEM Accel Car Component Dimensions Student Activity Sheet* to guide their prototype construction. Students will then evaluate their prototype based on the 5 phases of the engineering design process and their use of the acronym SCAMPER. The model built will be utilized during the evaluate lesson of this learning module. *(Classroom Duration: 45-55 minutes)* ***(ESPS.3, PS.7, 8, IED-1.5, 6.10,*** *STEM-T.2, 5)*

Ensure teams have resources and tools for completing the rapid prototyping activity - 1/4 x 2.24 x 7 plywood, #6 Screw Spacers or Straws, EUDAX 82pcs Wheel and Axle kit. It is important to ensure that each group has access to the equipment, tools, and supplies to complete the activity. This does not mean each group has all equipment and tools, as these items may be shared.

Lead In: 10 – 12 minutes

1. **Objectives -** Identify aspects of the 5 phases of the engineering design process that contribute to the rapid prototype design model. *(This should be written in a prominent location within the*

classroom and easily identifiable by students.) Provide students with a copy of the ***Lesson Log*** as they enter the classroom.

2. **Bell Assignment/Affirmations/Good News/Objectives** *(7-10 minutes)*
   - **Warm Up -** *(4-5 minutes)*
     - Distribute a copy of the **Venn Diagram Graphic Organizer,** Have students complete the Venn diagram for question storming and brainstorming. It may be helpful to remind students how to complete a Venn diagram by giving them one entry for each section of the diagram.
3. **Agenda/Activities –** Point out the objective and have students record this in their Lesson Log/Notes. Point out key activities that directly relate to the stated objective. Connect student prior knowledge with the day's objective and build upon student background knowledge. Explain what students will need to complete, and turn in, by the end of the class period.

Activity: 30 – 35 minutes

4. ***Classroom Activity,* Rapid Prototyping,** Use the *Engineering Design Process Slideshow 2.3d* to guide the discussion for the class period. Associated activities are described in the slide notes in more detail, but are briefly discussed here. Students should be paired with a partner. This portion of the lesson will utilize slides 22 thru slide 25.

   Divide students into their design teams. Ensure each student team a copy of the *SCAMPER Reference Sheet 2.5b*. Students will use the handout as a guide for the prototyping activity. Using a tape measure, miter saw, plywood, screw spacers/straw, and a EUDAX 82pcs Gear Set with Wheels and Axles students will rapidly prototype an accel car chassis. Students should account for the component dimensions from the *MSTEM Accel Car Component Dimensions Student Activity Sheet 2.3c*. Their models should be 1:1 scale for referencing in their CAD drawing during an upcoming lesson.

   Students will utilize the *MSTEM Accel Car Design Checklist Student Activity Sheet 2.5c* to evaluate their prototype in the upcoming Evaluate lesson.

Wrap-up: 5 – 8 minutes

5. **Close and Launch –** Direct student attention to the daily objective. Ask for a student volunteer to read the day's objective and discuss how they were able to meet the day's objective. *(Take a moment to review the day's activities and how they relate to the stated objective)*
   - **Assignment -** You may choose to assign a summary of their experience with rapid prototyping. Student groups could also create presentations of their models, including steps of development, to share with the class.
   - **Exit Ticket/Assessment –** Have students answer the following questions in the Exit Ticket section of their Daily Log, their engineering notebook, or their science journal/notebook.
     1. What is one thing you learned today? *(Answers vary. Look for specific details of learning taking place)*
     2. What aspect of rapid prototyping did you find difficult? *(Answers vary, look for specific details)*
     3. How does prototyping help determine the final model design? *(Answers vary, look for specific details like tolerances and dimensions)*
   - **Collect – Rapid Prototype Models, Lesson Log,** This should contain the questions from the warmup activity, Lesson Objective, Notes taken during classroom discussion, Classroom Activity, and answers to the Exit Ticket. *(End each lesson with a positive and encouraging statement for students to remember as they leave the classroom)*

Evaluate: Student groups will utilize the *MSTEM Accel Car Design Checklist Student Activity Sheet to conduct a personal evaluation of their rapidly prototyped accel car chassis, prior to conducting a peer evaluation. Students will judge models based on requirements for the final MSTEM Accel Car 3D printed chassis, in an effort to inspire further design modifications and improvements. Finally, design teams will share their critiques of other models and provide positive, constructive feedback to other design teams (Classroom Duration: 45-55 minutes)* ***(ESPS.3, POE-5.3,*** *STEM-T.2, 5****)***

Lead In: 10 – 12 minutes

1. **Objectives -** Provide constructive feedback during a critique rapidly prototyped models based on the 5 phases of the engineering design process. *(This should be written in a prominent location within the classroom and easily identifiable by students.)* Provide students with a copy of the ***Lesson Log*** as they enter the classroom.
2. **Bell Assignment/Affirmations/Good News/Objectives** *(7-10 minutes)*
    - **Warm Up -** *(4-5 minutes)*
        - Have students answer the following questions in the Warm-up/Do Now section of their daily lesson log, their engineering notebook, or their science journal/notebook.
            1. When do you think tolerances don't matter? *(Answers vary based on student understanding. all manufactured items have some sort of tolerancing associated with it, the larger the item the larger the tolerance)*
            2. Why is an understanding of dimensions and tolerances important? *(Answers vary, look for specific details that relate to tolerances and dimensions)*
            3. What does each letter in SCAMPER stand for? *(Not required to memorize, just used as a reference - **S**ubstitute, **C**ombine, **A**dapt/**A**lter, **M**agnify/**M**inimize, **P**ut to other use, **E**liminate, **R**earrange/**R**everse)*
3. **Agenda/Activities –** Point out the objective and have students record this in their Lesson Log/Notes. Point out key activities that directly relate to the stated objective. Connect student prior knowledge with the day's objective and build upon student background knowledge. Explain what students will need to complete, and turn in, by the end of the class period.

Activity: 30 – 35 minutes

4. **Peer Evaluation, Prototyping Design Checklist,** Students will evaluate their final designs by using their cutout cardboard prototype and compare it against a checklist of final functional requirements (see *MSTEM Accel Car Design Checklist Student Activity Sheet 2.5c*). As part of the worksheet, there is a teacher signoff where student teams are required to hand over the prototype to the teacher who will sign off on whether it meets the desired requirements. Any prototypes that do not meet all the requirements should be redesigned.
5. **Classroom Activity, Gallery Walk,** It is recommended that after all student teams have finished printing their respective chassis, that students present their final designs to the class. Explain that the students are going to perform what is commonly called a "gallery walk." As if they were in an art gallery walking from painting to painting, the students will walk around the classroom and look at each of the paper designs made by the other student teams. As students do this, they are to observe the range of variation in the designs compared to their own.

    Written on the chalkboard/whiteboard are the following questions (these can be written up before class):

    - How are the other MSTEM Accel Car designs different from my own?
    - How are they the same?

- What advantages or disadvantages are there to having differences in these designs?

Have students consider the answers to these questions as they walk around the room and consider other MSTEM Accel Car chassis designs. This activity will take approximately 7-10 minutes. After students have viewed the other designs, they should return to their original seats. Lead a discussion based on the previous questions written on the board. Students should summarize their discussion in the Classroom Activity section of their Daily Log, Engineering Notebook, or Science Journal/Notebook.

lead a discussion to compare the group's thoughts about the rapid prototypes of their peers. **Ask** "were all the models similar? Why?" **Ask** "What aspects of the models were different?" Discuss students' opinions about the prototyping process by developing questions about their build process.

6. **Assessment, Engineering Design Process Practice Quiz,** This quiz is 7 questions long and covers information presented in the Engineering Tolerances and Engineering Design Process slideshows.

Wrap-up: 5 – 8 minutes

7. **Close and Launch –** Direct student attention to the daily objective. Ask for a student volunteer to read the day's objective and discuss how they were able to meet the day's objective. *(Take a moment to review the day's activities and how they relate to the stated objective)*
    - **Assignment –** Ensure students with specific tasks of reaching out to potential sponsors understand requirements and due dates.
    - **Exit Ticket/Assessment –** Have students answer the following questions in the Exit Ticket section of their Daily Log, their engineering notebook, or their science journal/notebook.
        1. What design elements did the groups have in common? *(Answers vary)*
        2. What design elements were unique? *(Answers vary)*
        3. How will feedback on your model help with developing a better model? *(Answers vary)*
    - **Collect – Engineering Design Process Practice Quiz, MSTEM Accel Car Design Checklist, Lesson Log,** This should contain the questions from the warmup activity, Lesson Objective, Notes taken during classroom discussion, Classroom Activity, and answers to the Exit Ticket. *(End each lesson with a positive and encouraging statement for students to remember as they leave the classroom)*

Tools / Materials / Equipment: *Required tools, materials, and equipment to fully utilize the lesson plan.*

- Blackboard or Overhead Projector
- Computers with Internet access
- Calipers (for student pairs or groups of up to 3)
- Albanese Gummi Bears
- 1/4 plywood (2-1/4 inches wide) (1/4" x 2 x 2 ACX Handi-Panel, $5.19 @ Menards)
- 4 – (1/4 x 3/4) #6 Screw Spacer (Midwest Fastener® #6 x ¼" x ¾" Aluminum Spacer for $0.79 @ Menards)
- EUDAX 82 pcs Plastic Gear Set with Wheels and Axles ($8.99 @ https://www.amazon.com/EUDAX-Plastic-Assortment-accessories-Bushings/dp/B0776ZPP7V?ref_=ast_sto_dp) *This set will be used for future investigations into gears, and during the Chemistry and Electricity Modules*
- Hand Saw with Miter Box base (MasterForce® 14" Hand Back Saw with Miter Box, $7.98 @ Menards)
- Tape measure (Performax 12 foot, $4.99 @ Menards)

- Optional Materials
  - 3-D Printed M-STEM Accel Car Body (STL file found at hardwarestorescience.org This file will open using Ultimaker Cura software, a free software download. The File can also be found at Tinkercad.com by searching M-STEM Accel Car Body)
  - 3-D Printed M-STEM Wheels (STL file found at hardwarestorescience.org This file will open using Ultimaker Cura software, a free software download. The File can also be found at Tinkercad.com by searching M-STEM Wheels)
  - Wire Clothes hanger (10 pack, $1.44 @ Walmart)
  - #20 O-Ring (1-3/16" O.D. x 1" I.D., $0.79 @ Menards) (Qty – 4)

Resources (Student, Teacher, & Assessment): *List of assessment tools, worksheets, or other teacher resources needed to assess the work done by students.*

- Documents
  - Daily Lesson Log
  - ABC Vocabulary Reading Strategy
  - Venn Diagram Graphic Organizer
  - Gummi Bear Tolerances & Dimensions Student Activity Sheet 2.3a
  - MSTEM Accel Car Component Dimensions Student Activity Sheet 2.3c
  - MSTEM Accel Car Chassis Challenge Student Activity Sheet 2.3e
  - Practice Problems Answer Key 2.5a
  - Scamper Reference Sheet Student Activity Sheet 2.5b
  - MSTEM Accel Car Design Checklist Student Activity Sheet 2.5c
- Slideshow Presentations
  - Engineering Tolerances 2.3b
  - Engineering Design Process 2.3d
- Additional Resources
  - MSTEM Accel Car Body STL file - (The File can also be found at Tinkercad.com by searching M-STEM Accel Car Body)
  - MSTEM Accel Car Topper STL file - (The File can also be found at Tinkercad.com by searching M-STEM Accel Car Body)

Vocabulary: *List of necessary, and unique, vocabulary for this lesson.*

- **Caliper** - a device used to measure the distance between two opposite sides of an object
- **Dimensions** - a numerical value expressed in appropriate units of measurement and used to define the size, location, orientation, form or other geometric characteristics of a part
- **Engineering Design Process** - a series of steps that engineers follow to come up with a solution to a problem
- **Engineering Tolerances** - an allowable amount of variation of a specified quantity, especially in the dimensions of a machine or part
- **Measurement** - the determination of the size or magnitude of something
- **Prototype** - the act of organizing people to accomplish the desired goals and objectives

Indiana Academic Standards

- Science and Engineering Process Standards:
  - SEPS.2 Developing and using models and tools
  - SEPS.3 Constructing and performing investigations

  - SEPS.5 Using mathematics and computational thinking
- Math Process Standards
  - PS.6 Attend to precision – Communicate precisely, use terms and symbols appropriately, specify units of measure, and calculate accurately and efficiently
  - PS.7 Look for and make use of structure - Explain patterns and structures, know and explain properties that apply *(cumulative, for example)*
  - PS.8 Look for and express regularity and repeated reasoning - Look for repetition in problems, explore and find short cuts, take repetitions and generalize into new situations using newfound shortcuts, check answers for reasonableness
- Introduction to Engineering Design Standards
  - IED-1.5 Students perform the steps of the design process to develop and analyze products and systems – Describe the steps in the design process, apply the steps of the design process as they are used to solve the problem, describe the iterative nature of the design loop, assess and refine original design solutions based upon reflection, critique, practice, and research.
  - IED-6.10 Students create designs using a variety of modeling techniques to communicate information – Formulate methods of communicating designs using various forms of modeling such as conceptual, graphical, mathematical, physical, or computer modeling.
- Principles of Engineering non-PLTW Standards
  - POE-5.3 Students apply the laws of motion as they apply to principles of engineering – Explain how gravity impacts motion.
- ***Technology Standards related to STEM Careers***
  - ***STEM-T.2*** Students use a variety of technologies within a design process to identify and solve problems by creating new, useful or imaginative solutions.
  - ***STEM-T.5*** Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.

Additional Resources: Go Kart Science & Technology Entrepreneur Program Introduction

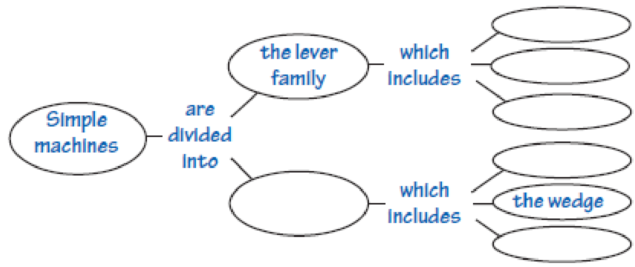
Reading Strategies

These reading tools will help students learn the material in this unit: Science Terms, Mathematical Language, and Concept maps.

Vocabulary Terms, Many words used in business and marketing are familiar words from everyday speech. However, their meanings are often different from or are more precise than the everyday meanings. As students pay attention to the definitions of these words their correct use of them in business and marketing contexts will improve. Have students set up a table in their scientific/engineering notebooks with three columns as seen below. As students are introduced to vocabulary, have them complete the table for the new term.

Word	Everyday Meaning	Scientific Meaning
speed	The act of moving fast	The distance an object travels divided by the time interval over which the motion occurs
velocity	speed	
acceleration	An increase in speed	

Concept Maps, A concept map is a diagram that helps you see relationships between the key ideas and categories of a topic. To construct a concept map, do the following: Select a main concept for the map. List all of the other related concepts. Build the map by arranging the concepts according to their importance under the main concept. Add linking words to give meaning to the arrangement of concepts.



Printable Resources

The following resources are found in the additional teacher resources file shared with this module.

Daily Lesson Log

Online Resources

The following resources are found online, and can be accessed through their individual websites or in a word document version at the Hardware Store Science website. One advantage of using the word document version of this article is that educators are able to download and edit the document with questions, writing prompts or other student suggestions.

