Solar Cars Apprenticeship

The Solar Cars apprenticeship prepares Citizen Schools' students to design, build and race a solar car. Students build math and science skills as they identify the benefits of solar energy, learn about engineering methods, and create their own solar car. Ideal Citizen Teachers include engineers, science teachers, scientists, professors, and all others interested in model building and/or solar energy.

WOW! Plan: Solar Cars

**WOW! Description**: The final project, or WOW!, for the Solar Cars apprenticeship could be a “solar car” “derby,” in which students test their solar cars against those that others have built. Races could take place between Citizen Schools’ classes, between campuses, within a city, or even in a region, with students competing against other middle school students (possibly through a Junior Solar Sprint competition). In addition to “fastest solar car,” awards could be given for “best engineering design” and “best looking.” Awards may be given to individual campus winners for each category, as well as to the overall competition winners.
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<td>▪ Apprentices will define friction and determine how it applies to building an effective solar car.</td>
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<td>- Apprentices will apply the steps of the engineering method to the challenges they face with their cars</td>
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<td>Transmission and Construction of the Solar Car</td>
<td>Apprentices will identify the challenges involved in building a transmission system</td>
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<td>Apprentices will explore how precision (measurement) is important for building a functioning car</td>
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<td>Structure and Support of the Solar Car</td>
<td>Apprentices will develop strategies for approaching the challenges involved in supporting the solar panel</td>
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<td>Apprentices will develop strategies for building a chassis that is not only stiff and strong, but also light.</td>
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<td><strong>Design Plans</strong></td>
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| Practice Scaffold 6 | Feedback to Improve the Solar Car | Apprentices will develop skills of construction.  
Apprentices will develop skills to give and receive constructive feedback in order to improve their product.  
Apprentices will discover that engineering is a process of trial and error. | 21st Century Skills:  
- Teamwork  
- Oral Communication  
MA Curriculum Frameworks:  
ELA:  
- 22.7 |
| Practice Coach 7 | Testing and Reflection | Apprentices will develop skills of construction  
What will identify the differences between testing their cars inside and racing them outside | 21st Century Skills:  
- Teamwork  
- Oral Communication  
MA Curriculum Frameworks:  
ELA:  
- 22.7  
Technology/Engineering:  
- 2.2 |
| Practice Coach 8 | Optimizing Vehicles: Aerodynamics and Improvements | Apprentices will identify how change of car shape causes change in the car’s aerodynamic nature.  
Apprentices will discover that engineering is a process of trial and error. | 21st Century Skills:  
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| Preparing to Race 9 | | Apprentices will discover that engineering is a | 21st Century Skills:  
- Opening puzzle: JSS logistics and  
- Opening puzzle: Circuits  
- Building  
- Team feedback and group problem-solving |

Citizen Schools  
Solar Cars Curriculum
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Lesson 1: The Introduction to Solar Cars

21st Century Skills:
- Teamwork
- Oral Communication

Snapshot Agenda:
10 minutes: Citizen Teacher introduction
15 minutes: Apprentice introductions and game
15 minutes: Agenda setting and expectations
20 minutes: Introduction to space science
5 minutes: Galileo’s Law demonstration
20 minutes: Gravity and reaction time
5 minutes: Teachback

Learning Objectives:
1. Apprentices will define the following basic vocabulary and concepts relating to solar cars.
2. Apprentices will develop an understanding of the basics of the scientific method through creative questioning.

Massachusetts Curriculum Frameworks:
ELA:
1. **22.7**-Use additional knowledge of correct mechanics (apostrophes, quotation marks, comma use in compound sentences, paragraph indentations), correct sentence structure (elimination of fragments and run-ons), and correct standard English spelling (commonly used homophones) when writing, revising, and editing.
2. **23.8**-Organize information about a topic into a coherent paragraph with a topic sentence, sufficient supporting detail, and a concluding sentence.

Math:
1. **5.P.6**- Interpret graphs that represent the relationship between two variables in everyday situations.

Opening Ritual:
Procedure: Puzzle Pieces:
- To create these puzzles, cut up pictures of four different solar cars
- Give one “puzzle” to each group
- Instruct groups to work together to complete the puzzle as quickly as they can by putting the pieces in order and taping their re-assembled pictures to their sheet of paper.
- After each group is finished, ask a representative from each group to tape the puzzle at the front of the room.

Brainstorm/Discussion:
- Look at the puzzles that have been taped up.
- Ask:
  - What do you notice about the cars?
  - Are there parts that they don’t recognize?
  - Make a list of observations on chart paper.

- Explain:
  By the end of 10 weeks, apprentices will be able to explain all about these cars and their various parts.

Required visuals for posting: 21st Century Skills list, agenda, ground rules and expectations chart.
**Introduction and Agenda:**

**Getting to Know Each Other**

- Getting to know the Citizen Teacher
  - The Citizen Teacher should introduce herself/himself
    - Where are you from? Where do you work? Etc
  - Tell the apprentices why you are so excited about the apprenticeship!
  - What about your background brought you to choose to participate in this apprenticeship?
  - Why do you think it is so important learn about solar cars?
  - What is the apprenticeship all about?
  - What can apprenticeships expect?

**Building an apprenticeship community**

- Split the group up into pairs. Give them a few minutes to interview each other and then have them introduce one another to the group.
  - Each Apprentice should ask their partner the following questions: Name? Grade? Teacher in School? Favorite subject? Favorite activity after school? Why did you pick this apprenticeship topic?

**Apprenticeship Outlook**

- Explain:
  - Building a solar car is a big project that will require hard work from them.
  - Apprentices will be working together in teams, and that the goal for the apprenticeship is for each team to create a working solar car by the end of 10 weeks.
  - Since this is a long-term goal, it will be important to break it down into smaller pieces so that they can keep track of their progress.
  - Take a look at the upcoming challenges and goals on the Roadmap to the Junior Solar Sprint, and give a few details on what the JSS actually entails.
  - Explain to apprentices that they will be using the Roadmap to track their progress throughout the semester.
  - Show apprentices car cutouts, which they can move along on the Roadmap as they complete steps in the design and building process.
  - Explain:
    - Different design teams may progress at different speeds, and that each team will have an opportunity to share and mark their progress during closing each week.

**Snapshot Agenda:**

1. **Opening Ritual: Pieces of the Puzzle**  
   10 Minutes
2. **Review Agenda and Set Context:**  
   10 Minutes
3. **Activity: Teambuilding and Community Contract**  
   25 Minutes
4. **Activity: Why Solar?**  
   15 Minutes
5. **Activity: Getting Started?**  
   15 Minutes
6. **Teach Back**  
   10 Minutes
7. **Clean up**  
   5 Minutes

**Activity 1: Teambuilding and Community Contract:**

**Materials and Setup:**

- Copy of the Group Contract
- Pen
- Visuals: car contract visual
- Roadmap to the Junior Solar Sprint (large visual, mounted on foam core, outlining the steps that
students will complete in the design and building process as they prepare for their race)

- Thumbtacks and car cutouts (one for each design team, to track progress on the Roadmap)
- Teamwork Tracker Document
- Playground Ball
- Set up circle of chairs

**Procedure:**
**Group Juggle Teamwork Game**
1. Explain Directions to “Group Juggle”
   - Directions:
     - One person will start with the ball and will pass to another apprentice, announcing his or her name and the name of the person he or she is passing to. (“_____ is passing to _____.”)
     - The person who receives the ball will then thank the person who passed it, using his or her name (“Thank you, _____”), and then pass it on to another team member.
     - Continue in this way until every apprentice has received the ball and it has returned to its starting point.
2. After one round, introduce the timer as an added challenge. Explain to the team that you are going to time how long it takes them to pass the ball through the group, following the same order as before.
3. Play one or two more rounds, encouraging apprentices to work together to beat their previous time.

**Group Contract**

**Brainstorm/Discussion:**
1. Brainstorm with the group to come up with professional expectations that will help the group to have a safe, fun, and positive experience as solar car engineers.
2. Inside of the car diagram write down positive behaviors, and outside of the car write down negative behaviors that the group promises to avoid.
3. Ask apprentices to sign the contract as a commitment to uphold these expectations.

**Teamwork Tracker:**
1. Explain
   - That teamwork is a skill that they will be developing and practicing each week in the solar car apprenticeship
   - Teamwork skills can improve throughout the 10 weeks.
   - Emphasize that apprentices are not expected to agree on everything all the time; instead, the goal is to work together to solve problems and overcome disagreements.
   - Remind apprentices that they may not be able to demonstrate excellent teamwork this early in the semester, but the goal is that they will be able to by the end.
   - The Teamwork Tracker will allow apprentices to see their progress in developing teamwork skills
   - At end of each session (and in the middle of some of the sessions), apprentices will have a chance to self-evaluate the group’s teamwork using a “Fist of Five,” (a quick activity that checks how each apprentice feels).
   - For the “Fist of Five,” apprentices, on the count of three, will rate their teamwork on a scale of 1 (really struggling) to 5 (really shining) by holding up the corresponding number of fingers.

**Activity 2: Fossil Fuels:**
Materials:

- Map of United States
- Chart of United States fuel consumption

Procedure:

1. Ask:
   - What do you think about when you hear the word renewable/?
   - Does anyone know a definition of the word?
   - Point out the prefix re- see if apprentices can deduct the answer by knowing the prefix

2. Explain:
   - Renewable energy sources are ones that can be used again and again because they are replaced as they’re used so that they don’t run out.
   - Solar power, which comes from the sun, is an example of a renewable energy source.

3. Ask:
   - What do you think a non-renewable energy source means? (One that cannot be replaced as it’s used, so it will eventually run out over a long period of time. Example: fossil fuels)
   - What are the pros of the use of fossil fuels as sources of energy? What are the cons of the use of fossil fuels as sources of energy?

4. Show apprentices a map of the world and compare the size of the United States to other countries in the world.

5. Show apprentices the following graphs/charts to engage visual learners (use this opportunity for a flawless math tie-in:
   - A map of the world to give apprentices a sense of the size of the United States in comparison to the rest of the world
   - A graph to represent the population of the United States vs. the population of the world
   - The point is to clarify those Solar Cars is not only a fun... This work is actually really important. The challenges that we’ll face this semester are directly relevant to real-world problems and solutions, and a major challenge that is currently facing

Activity 3: Notebooks and Writing:

Materials:

- Binders
- Notebooks
- Pen/Pencils
- Large piece of paper/Blackboard for list

Procedure:

1. Divide apprentices into temporary design teams.
2. Pass out binders and notebooks:
   - The notebooks are for individuals, and the binder is for the team. The point of both the notebook and binder is to keep a record/log as they progress through the apprenticeship. This log will enable apprentices to remember their work and showcase it for their friends and families at the end of the semester. Apprentices will be able to take their notebooks home once the apprenticeship is over.

3. Explain:
   - The notebooks will also serve as a place to keep their ideas as well as a place to work on the specific writing skills of organization and writing conventions/mechanics.
   - Throughout the apprenticeship, they will practice writing well-organized paragraphs about the work they complete and the decisions they make. Let apprentices know that they will receive regular feedback and suggestions in order to help improve their writing.
• Emphasize to apprentices that if they put effort into their engineering notebooks, it will help them build the skills that they learn in ELA.

4. Use a prepared sample notebook and a large visual to model the different sections of their notebooks.

5. Leave the sample at the front of the room and the visual on the wall for apprentices to use as references as they assemble their own notebooks and create labels for the following parts:
   - Vocabulary and Concepts
   - Activities and Investigations
   - Reflections and Challenges
   - Design Sketches
   - Teach backs

6. Review the vocabulary words and ask apprentice to write the words on the board. Instruct apprentices to write down the words and definitions in the vocabulary section of their notebooks
   - Engineer – a person who uses scientific knowledge to solve practical problems and produce goods for society
   - Fossil fuels – an energy source such as oil, gas, or coal, which is formed from ancient plant fossils. We are running out of fossil fuels.
   - Renewable resources – a resource that can be replaced as we use it, so it won’t run out
   - Solar – relating to the sun.

7. Give apprentices a handout about the JSS rules and guidelines and ask them to spend 5 minutes brainstorming and writing their 3 major goals in designing their solar car

8. Reinforce ELA concepts by asking apprentices to use complete sentences when they write their goals. After several minutes, allow a few groups to share their goals.

Teach Back:

Procedure:

1. Review the expectations and systems that will be in place for them to reflect on each apprenticeship session. Let them know that each session will close with an opportunity for them to practice communicating, either verbally or in writing, what they have learned that day.

2. Model weak public speaking skills (mumbling, talking too fast or too quietly, looking down at your feet) as you explain to apprentices that this apprenticeship will focus on oral communication. Over-exaggerate your performance so that apprentices are able to easily identify what you are doing wrong.

3. Once apprentices have pointed out the things you are doing “wrong,” shift and demonstrate strong public speaking skills as you outline what those skills are. Explain to apprentices that each time they come together as a group during the apprenticeship, it will be an opportunity for them to practice their oral communication and work on developing the following public speaking skills:
   - The ability to speak loudly, slowly, and clearly enough for the audience to understand
   - The ability to present information using eye contact and good body posture.

4. Tell apprentices that they will be receiving feedback on their oral communication throughout the apprenticeship so that by the end, they will be able to speak comfortably and confidently about the work they have been doing.

5. Ask apprentices to rate the group’s teamwork using the “Fist of Five” method. Allow several apprentices (high and low ratings) to share their reasons. Ask apprentices to share specific things they would like to work on in terms of teamwork next week, keeping in mind the characteristics of strong oral communication that we just identified.

6. Ask one apprentice from each team move their team car on the Roadmap.

Clean Up:
The following roles will be designated to different apprentices to build team accountability. Roles will rotate each week.

- Tabletop captains (clean off tables)
- Material organizers (use the checklist to make sure the team’s materials are all accounted for)
- Chair police (make sure all chairs are up on the tables)
- Visual captains (take down and store visuals)
Lesson 2: Friction and Structure

21st Century Skills:
- Teamwork
- Oral Communication

Snapshot Agenda:
1. Opening Ritual: Pieces of the Puzzle 10 Minutes
2. Review Agenda and Set Context 5 Minutes
3. Activity: Friction Conviction 15 Minutes
4. Activity: Safety Guidelines 10 Minutes
5. Activity Beginning to Build 40 Minutes
6. Closing, Questions, and Teach Back 5 Minutes
7. Clean up 5 Minutes

Learning Objectives:
1. Apprentices will define friction and determine how it applies to building an effective solar car
2. Apprentices will gain an understanding of the concepts of stiffness and strength-to-weight ratio and how to apply them to building a solar car.
3. Apprentices will define the steps of the engineering design process
4. Apprentices will discover that engineering is a process of trial and error.

Massachusetts Curriculum Frameworks:
Technology/Engineering:
1. 1.3-Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sander, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design.
2. 2.1-Identify and explain the steps of the engineering design process; i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign. (2.1)

ELA:
1. 22.7-Use additional knowledge of correct mechanics (apostrophes, quotation marks, comma use in compound sentences, paragraph indentations), correct sentence structure (elimination of fragments and run-ons), and correct Standard English spelling (commonly used homophones) when writing, revising, and editing.

Materials:
Initial Preparation and Space Set up:
- There should be several stations set up throughout the room.
  - “Pit stop” station: Equipped with puzzles and blocks
  - Classroom Management Note-Students who abuse any of these stations should be asked to go to the “pit stop” station. After the second instance of inappropriate behavior, the individual will be banned from using that particular station for the remainder of the day.
  - “Reference” station: Provides examples of different kinds of cars and transmissions.
  - “Cutting” station: All cutting takes place at the cutting station.
  - Classroom Management Note: Knives are not to be removed. All cutting must occur on top of cardboard, with the object lying flat. Blades must be retracted when finished.
  - “Sawing” station
  - Classroom Management/Safety Note-Students will wear safety goggles when sawing. The clamp must be used at all times. Students who abuse this station will be asked to go to the “pit stop” station.
  - “Gluing” station
  - “Pliers and Rulers”
  - “Bearings and Wheels”
- **Chassis Materials**
  - Potentially dangerous stations need signs posted to remind students of the relevant safety measures.
- **Post Agenda**
  - Post Roadmap to the Junior Solar Sprint (large visual, mounted on foam core, outlining the steps that students will complete in the design and building process as they prepare for their race)
- **Thumbtacks and car cutouts** (one for each design team, to track progress on the Roadmap)
- **Post Vocabulary:**
  - Axle – a thin rod connecting the wheels
  - Chassis – the structural frame or body of the car
  - Bearing – a rotating support placed between moving parts to allow them to move easily
  - Tradeoffs – gaining one benefit often means losing another. You can’t have everything!
  - Friction – the resistance to motion between two surfaces in contact
  - Force – the ability to change an object’s state of rest or motion
  - Hypothesis – a tentative proposal made to explain certain observations or facts, which requires further investigation to be verified
  - Payload – the cargo… What the vehicle carries (in this case, an aluminum can)

**Opening Ritual:**

**Procedure:**

1. Divide apprentices into two groups.
2. Give each apprentice in one group 1-2 slips of paper (which name one step of the scientific method)
3. Give each apprentice in one group 1-2 slips of paper (which name one step of the engineering design process)
4. Ask students to without speaking, arrange the papers in what they think is the correct order of the scientific method
5. Once the group has determined their order have each group present the order they have picked.
6. Reveal the correct order and briefly discuss why the order is set such a way.
7. Post Sign Outlining the Steps of the Engineering Design Process:
   - Steps of the Engineering Design Process:
     1. Identify the need or problem
     2. Research the need or problem
     3. Develop possible solution(s)
     4. Select the best possible solution(s)
     5. Construct a prototype
     6. Test and evaluate the solution(s)
     7. Communicate the solution(s)
     8. Redesign
8. Post Sign Outlining the Steps of the Engineering Design Process:
   - Steps of the Engineering Design Process:
     9. Identify the need or problem
     10. Research the need or problem
     11. Develop possible solution(s)
     12. Select the best possible solution(s)
     13. Construct a prototype
     14. Test and evaluate the solution(s)
     15. Communicate the solution(s)
     16. Redesign
     17. Lead a brief discussion regarding how the two lists are similar and different and note that they work in tandem to one another.
18. Have students record the steps of the design process in the Vocabulary and Concepts section of their notebooks. *(Use an example to illuminate steps for students)*

### Activity 1: Friction Conviction:

**Materials:**
- Chart paper
- Eraser
- Pennies
- Ramp
- Binders, pencils, markers, rulers

**Procedure:**
1. Assign/Reassign “design teams”
2. Give each design team one penny and one flat eraser
3. Write the following questions on the board
   1. *Which item slid faster?*
4. Ask students to slide both items across the table and to record their observations in their engineering notebooks.
5. Ask apprentices to with their group, hypothesize the reasons for their findings.
6. Remind students that a hypothesis is an educated guess and is a good thing to make before creating an experiment.
7. Show the class the different sample cars (use cars that are about the same size and shape as each other, but with different levels of friction in the bearings).
8. Ask students to test the cars by sliding them down the ramp.
9. Once all of the cars have been tested, have students write down physical observations of the cars that they think might have made a difference in how far each car coasted through the answering of the following questions:
10. Where do you hear rubbing that might cause the slowing down of the cars?
11. Where is the smooth movement?
12. Explain: When you are building cars you must think about the bearings and how to use them to reduce friction.
13. Have students write the definition of friction in their notebooks.
14. Give each group 2 different bearings
15. Ask students to within their groups look at different bearings and discuss the differences and similarities.
16. Have each team report out to the large group.

### Activity 2: Safety Session:

**Materials:**
- Sample Cars
- Checklist for Materials
- Chart Paper
- Car supplies
  - Foam core
  - Cardboard
  - Axles
  - Bearings
  - Wheels
  - Tires
- Engineering notebooks and design binders
- Ramp
- Pencils, rulers, Exacto knives, scissors
- Tape
- Hot glue guns
- Cardboard cutting surface
- Safety equipment:
  - Safety goggles
  - Cold water in case of burns
  - Band-Aids
  - Newspaper to protect gluing surfaces

**Procedure:**

1. Introduce the materials and tools that will be used in the creation of the solar cars.
2. Model safe and effective techniques as you introduce the materials and tools
   - For example
     - Be careful using the glue gun to ensure that you don’t burn yourself.
     - At the cutting station, show students how to measure and draw lines to guide their cutting to ensure not only a more accurate cut, but as a way to slow down and avoid accidents.
     - Model safe cutting technique using effective speed and pressure as you cut, and then show students the dangers of cutting too quickly or pushing too hard.
     - At the gluing station, emphasize the importance of using enough glue to make the pieces stick, but not so much glue that it clogs pieces and interferes with the car’s ability to function.
     - At the sawing station, show students how to place their material in the clamp so that it will be steady while they cut.
3. Emphasize that all materials must be kept at their stations.
4. After the presentation of materials is complete, guide the apprentices in developing safety rules through the creation of a class poster which will be posted not only during this lesson, but during the subsequent lessons.
   - Make sure to include:
     - Goggles must always be worn when using saws.
     - When cutting with exacto knives there must always be cardboard underneath.
     - All exacto knife blades must be closed when you are not using them.
     - Hot glue guns must be rested when they are not being used.
     - No running.
5. Introduce the “Pit Stop” station
   - Explain that any students who are misusing materials or not following expectations will be asked to take a break for 5 minutes. If students misuse materials again after taking a break, they will not be able to use that station for the rest of the session.
6. Introduce the check-in signal and system.
   - Explain to students that when they hear the whistle blow, they need to put down all materials, unplug the hot glue guns, and come to the front of the room. Students will be given a 10 second countdown after the whistle. Students who are not at the front of the room by the end of 10 seconds will have to sit out at the “Pit Stop” for the first five minutes of the next building session (either later that day or the next week).

**Activity 3: Beginning the Building Process:**

**Materials:**
- Car supplies
  - Foam core
  - Cardboard
  - Axles
  - Bearings
  - Wheels
  - Tires
- Engineering notebooks and design binders
- Cardboard cutting surface
- Ramp
- Pencils, rulers, Exacto knives, scissors
- Tape
- Hot glue guns
- Safety equipment:
  - Safety goggles
  - Cold water in case of burns
  - Band-Aids
  - Newspaper to protect gluing surfaces

**Procedure:**
1. Give each group one material (wheel, axle, bearing, and chassis) and have students report to the large group as to how the group thinks the material would be used in the creation of a solar car.
2. Using the labeled diagram of a car, introduce students to the vocabulary words that define different components (axles, bearings, chassis, and payload) of a solar car.
3. Ask students to write the definitions in their engineering notebook.
4. Instruct apprentices to each draw an outline of what they think their car design should look like.
5. When each apprentice is done, have apprentices present their design to the team.
6. The design team should then discuss what the car should look like.
7. Before students begin building, have each group assign roles (Tell apprentices that the roles will change each week, but that the roles will help the group stay organized and on task.
   - **Leader**
     - Clarifies task for the group
     - Helps keep group on task
     - Ensures all members have equal air space
     - Gets clarification
     - Participates as group member
   - **TIME-KEEPER**
     - Helps budget time and tasks
     - Informs facilitator of time constraints
     - Participates as a group member
   - **SPOKESPERSON**
     - Listens carefully so that they can portray GROUP concerns during report to the large group
     - Prepares report to fit the time limit
     - Participates as a group member
   - **SAFETY REMINDER**
     - Reminds team about safety rules
8. Ask students to begin building their car. Remind students that this is just a very basic practice. This may be the start of their solar car or they may do something completely different next week. The goal for each team is to create a car that will roll as fast as possible, while also traveling in as straight a line as possible.
9. After 30 minutes, blow the whistle to signal to students to come together as a group to test their cars on a ramp at the front of the room.
10. Run cars two at a time to see which one goes the farthest and straightest from the end of the ramp.
11. Recognize the winning team for outstanding work, and then analyze the reasons that each car performed the way it did.
12. Remind students that they will have an opportunity to improve their performance next week.

**Teachback:**

**Procedure:**

1. Ask students to take five minutes to record in their engineering notebooks the 3 things that they learned from today.
2. Go around and encourage students to improve/revise their writing making certain to give examples as to how to use proper writing mechanics.
3. Under each learned item have apprentices explain how they will apply those ideas to their final solar car model.
4. Ask apprentices to write any questions they have as you move forward.
5. Preview next week’s lesson plan.
6. Recognize individual students who have contributed above and beyond the expectations.
7. Ask students to rate the group’s teamwork using the “Fist of Five” method.
8. Allow several students (high and low ratings) to share their reasons.
9. Ask students to share specific things they would like to work on in terms of teamwork next week.
10. Allow students to move their team cars on the Roadmap.

**Cleanup:**
The following roles will be designated to different students to build team accountability. Roles will rotate each week:
- Tabletop captains (clean off tables)
- Material organizers (use the checklist to make sure the team’s materials are all accounted for)
- Chair police (make sure all chairs are up on the tables)
- Visual captains (take down and store visuals)
Lesson 3: Transmission and Gear Ratios

21st Century Skills:
- Teamwork
- Oral Communication

Snapshot Agenda:
1. Opening Ritual: Pieces of the Puzzle 15 Minutes
2. Review Agenda and Set Context 10 Minutes
3. Activity: Transmission 101 15 Minutes
4. Activity: Gear Ratio Investigation 25 Minutes
5. Activity: Design Plans 15 Minutes
6. Closing and Teach Back 5 Minutes
7. Clean up 5 Minutes

Learning Objectives:
1. Apprentices will identify factors that contribute to the effectiveness of the transmission of a car, specifically around optimal gear ratios.
2. Apprentices will apply the steps of the engineering method to the challenges they face with their cars.

Massachusetts Curriculum Frameworks:
Science and Technology/Engineering standard for Grades 6-8 in Engineering Design:
1. 2.2-Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multi-view drawings.

Math:
1. 6.N.4-Demonstrate an understanding of fractions as a ratio of whole numbers, as parts of unit wholes, as parts of a collection, and as locations on the number line

ELA:
1. 22.7-Use additional knowledge of correct mechanics (apostrophes, quotation marks, comma use in compound sentences, paragraph indentations), correct sentence structure (elimination of fragments and run-ons), and correct Standard English spelling (commonly used homophones) when writing, revising, and editing.

Apprentice Roles:
Timekeeper: Assign a timekeeper for the rocket building. The timekeeper should warn the class when there are only 10 minutes, and then 5 minutes left for the hands-on portion of the class.

Cleanup crew: Assign two people to serve as cleanup crew for the day.

Materials/Preparation:
- Three stations will be set up with different gear ratios.
- Post agenda, scientific method poster, engineering process poster, car contract visual
- Post Roadmap to the Junior Solar Sprint (large visual, mounted on foam core, outlining the steps that students will complete in the design and building process as they prepare for their race)
- Thumbtacks and car cutouts (one for each design team, to track progress on the Roadmap)

Opening Ritual:

Materials:
- Visuals
  - Agenda and objectives
- Vocabulary
- Car contract
- Pieces of puzzle copies

Procedure:
1. Hand out slips of paper with the following problem.
   - John and Maria decided to go on a bike ride around their hilly neighborhood one sunny afternoon. Both of them had 3-speed bikes, but John's bike had skinny, large wheels, while Maria's bike had thick, small wheels. Who do you think had to use more energy as they were pedaling? Why?
2. Ask students to write down their hypotheses
3. When the apprentices have written their hypotheses down, have students raise their hands to indicate who they think will be forced to exert more energy on their ride.
   - Math tie-in: Use this as an opportunity to review fractions/ratios- How many students thought John would have to exert more energy? How can we write that as a fraction/ratio? Etc...
4. Ask: How does friction apply to your answer? Could the two riders change the level of energy they need to exert by changing the bike speed?
5. Allude to the topic of the day as you write the definition of Mechanical Advantage on the board (maximizing the amount of distance or speed you get while minimizing the amount of power or effort you put in).
6. Have students write the definition in their engineering notebook.
7. Remind students of the ultimate goal is to construct an effective solar car which will require them to incorporate all the knowledge that they gain each week into their final model- so they need to make sure that they are keeping an organized and detailed engineering notebook.

Activity 1: Transmission 101:

Materials:
- Hand crank can opener
- Bicycle
- Ribbon to Mark wheel

Procedure:
1. Write the following guiding questions on the board: Can Opener Question- How is the power from a person’s hands being converted into mechanical energy? Bike Questions- How many times did the wheel go around per revolution of the pedal? What if you changed the gear of the bike?
2. Take the hand crank can opener and ask for a volunteer to demonstrate how it works.
3. Ask apprentices to take notes in their engineering notebooks on what they observe- Note the questions on the board as “jumping off” points (taking notes will not only keep them focused on the task at hand, but will help students simply practice note taking)
4. Discuss the answer to the can opener question
5. Take a multi-gear bicycle and flip it upside down.
6. Tell students what gear the bike is set on and mark one spoke with a ribbon.
7. Ask for a volunteer to flip the pedal around one time.
8. As a group count how many times the wheel goes around and have apprentices mark the answer in their engineering notebook
9. Flip the bike back over and change the gear.
10. Repeat Steps 7 and 8
11. Ask: How does the gear switch change the number of revolutions of the wheel per pedal revolution? Have students answer the question in their engineering notebook.
12. Discuss the answer and ask how does the gear change affect eh distance or the speed? Is it harder to
13. Refer back to the Puzzle question and have students discuss ways that Maria could go the same speed as John.

**Activity 2: Gear Ration Investigation:**

**Materials:**
- Gear experimentation materials: craft a direct drive, a belt drive, a friction drive
- Car kits for each team
- Engineering notebooks

**Procedure:**
1. Set up four areas around the room where students can experiment with different types of gear ratios (the different drives you have crafted).
2. Divide apprentices into their design teams.
3. Have each design team observe and record the differences in spool revolutions based on different size spools and different distances between spools. After four minutes have each group switch to another station.
4. As the apprentices observe the different gears write the following questions on the board:
   - What were the different kinds of pulley systems you observed?
   - What made each pulley system work?
   - Did some work better than others?
   - Why do you think this was so?
   - What were the different materials these pulley systems were made of?
   - What would be an advantage of using each pulley system for your groups’ car?
5. When each group is done, discuss the findings.

**Activity 3: Design Development:**

**Materials:**
- Large pieces of paper
- Binders, pencils, markers, rulers
- Engineering Notebooks

**Procedure:**
1. Provide each design team with a list of materials and large pieces of paper to redesign the model that they drew in the first week (in their note books).
2. Review goals
3. Have group work to review what their solar car will look like incorporating the gear ratio information they learned.

**Teachback:**

**Procedure:**
1. Ask students to take five minutes to record in their engineering notebooks the 3 things that they learned from today.
2. Under each learned item have apprentices explain how they will apply those ideas to their final solar car model.
3. Go around and encourage students to improve/revise their writing making certain to give examples as to how to use proper writing mechanics.
4. Ask apprentices to write any questions they have as you move forward.
5. Preview next week’s lesson plan and lastly,
6. Recognize individual students who have contributed above and beyond the expectations.
7. Ask students to rate the group’s teamwork using the “Fist of Five” method.
8. Allow several students (high and low ratings) to share their reasons.
9. Ask students to share specific things they would like to work on in terms of teamwork next week.
10. Allow students to move their team cars on the Roadmap.

**Cleanup:**
- Tabletop captains (clean off tables)
- Material organizers (use the checklist to make sure the team’s materials are all accounted for)
- Chair police (make sure all chairs are up on the tables)
- Visual captains (take down and store visuals)
Lesson 4: Transmission and Construction of the Solar Car

21st Century Skills:
- Teamwork
- Oral Communication

Snapshot Agenda:
1. Opening Ritual: Precision Puzzle 10 Minutes
2. Review Agenda and Set Context 10 Minutes
3. Activity: Building, Part I 25 Minutes
4. Activity: Mid-Session Check-in 5 Minutes
5. Activity: Building, Part II 20 Minutes
6. Closing and Teach Back 5 Minutes
7. Clean up 5 Minutes

Learning Objectives:
1. Apprentices will identify the challenges involved in building a transmission system
2. Apprentices will recognize that precision (measurement) is important for building a functioning car

Massachusetts Curriculum Frameworks:
ELA:
1. 22.7-Use additional knowledge of correct mechanics (apostrophes, quotation marks, comma use in compound sentences, paragraph indentations), correct sentence structure (elimination of fragments and run-ons), and correct Standard English spelling (commonly used homophones) when writing, revising, and editing.

Opening Ritual:

Materials:
- Paper/Pencil
- Ruler
- Stopwatch

Procedure:
1. Provide each apprentice with a piece of paper, a pencil and a ruler
2. Explain the challenge: When I say go you are going to draw the best square you can in 20 seconds.
3. After twenty-seconds is up have each apprentice share the square with the class
   Classroom Management Note- This may be a good time to model celebration of success and creating a positive group culture. Ask students to clap for each other and provide positive feedback.
4. After each person has presented have the apprentices flip their piece of paper over.
5. Explain the next challenge: When I say go you are going to draw the best square you can in 1 minute.
6. After the minute is completed have each apprentice share the square with the class.
7. As a group discuss which square is better and why?
8. Link this idea back to the creation of the solar car. Accuracy matters more than speed!

Materials and Set-up:
- There should be several stations set up throughout the room.
  - “Pit stop” station: Equipped with puzzles and blocks
- Classroom Management Note: Students who abuse any of these stations should be asked to go to the “pit stop” station. After the second instance of inappropriate behavior, the individual will be banned from using that particular station for the remainder of the day.

- “Reference” station: Provides examples of different kinds of cars and transmissions.
- “Cutting” station: All cutting takes place at the cutting station.
  - Classroom Management Note: Knives are not to be removed. All cutting must occur on top of cardboard, with the object lying flat. Blades must be retracted when finished.
- “Sawing” station
  - Classroom Management/Safety Note: Students will wear safety goggles when sawing. The clamp must be used at all times. Students who abuse this station will be asked to go to the “pit stop” station.

- “Gluing” station
- “Fliers and Rulers”
- “Bearings and Wheels”
- Chassis Materials’
  - Potentially dangerous stations need signs posted to remind students of the relevant safety measures.
  - Post Agenda
  - Post Scientific Method and Process of the Engineering Method Posters
  - Post Roadmap to the Junior Solar Sprint (large visual, mounted on foam core, outlining the steps that students will complete in the design and building process as they prepare for their race)
  - Thumbtacks and car cutouts (one for each design team, to track progress on the Roadmap)

**Activity 1: Building Part I:**

**Materials:**
- Materials checklist
- Engineering notebooks
- Motors, wires, batteries, fake solar panels, payloads, gear kits, extra wheels, and axles
- Sample cars
- Cardboard for Cutting

**Procedure:**
1. Demonstrate how to place gears on the axles, making sure to explain how to do it carefully.
2. Remind students that if/when a team finishes early they should raise their hand to make sure it is ok to move on to the next step
3. Remind students that they should ask questions when they get confused as materials are not limitless.
4. Before students begin, remind them of the importance of teamwork.
5. Brainstorm ways in which a good teammate acts (speaks nicely, listens to others ideas etc).
6. Instruct students that during the building process they are going to run into challenges or trials— have students write in their notebook the challenges/trials (or even failures) that they experience.
7. Give the materials manager of each group a checklist as well as the team’s materials.
8. Have group use the checklist to ensure that they have each material.
9. When the checklist is complete groups may begin construction.

**Activity 2: Mid-point Check-in:**

**Materials:**
- Progress Chart
- Car Contract

**Procedure:**
1. Halfway through the building process bring all the apprentices together for a check-in
2. During the check-in have each group report out on their progress and speak about the successes/challenges they are facing
   - Classroom Management Note: This check-in will help refocus the group (if necessary) as well as provide a feeling of community as groups will hear that some of their challenges are the same ones faced by other groups.
3. Have the group review the community agreement.

**Activity 3: Building Part II:**

**Materials:**
- Materials checklist
- Engineering notebooks
- Motors, wires, batteries, fake solar panels, payloads, gear kits, extra wheels, and axles
- Sample cars
- Cardboard for Cutting

**Procedure:**
Ask Students return to their teams and continue building for the last 20 minutes, using the ideas and suggestions of other teams for direction.

**Teachback:**

**Procedure:**
1. Ask students to take five minutes to record in their engineering notebooks the 3 things that they learned from today.
2. Under each learned item have apprentices explain how they will apply those ideas to their final solar car model.
3. Go around and encourage students to improve/revise their writing making certain to give examples as to how to use proper writing mechanics.
4. Ask apprentices to write any questions they have as you move forward.
5. Preview next week’s lesson plan and lastly,
6. Recognize individual students who have contributed above and beyond the expectations.
7. Ask students to rate the group’s teamwork using the “Fist of Five” method.
8. Allow several students (high and low ratings) to share their reasons.
9. Ask students to share specific things they would like to work on in terms of teamwork next week.
10. Allow students to move their team cars on the Roadmap.

**Cleanup:**
- Tabletop captains (clean off tables)
- Material organizers (use the checklist to make sure the team’s materials are all accounted for)
- Chair police (make sure all chairs are up on the tables)
- Visual captains (take down and store visuals)
Lesson 5: Providing and Using Feedback

21st Century Skills:
- Teamwork
- Oral Presentation

Snapshot Agenda:
1. Opening Ritual: Pieces of the Puzzle (Structure Challenge) 15 Minutes
2. Review Agenda and Set Context 15 Minutes
3. Activity: Building 25 Minutes
4. Activity: Peer “Editing” 15 Minutes
5. Activity: Design Plans 10 Minutes
6. Closing and Teach Back 5 Minutes
7. Clean up 5 Minutes

Learning Objectives:
1. Apprentices will develop skills of construction.
2. Apprentices will develop skills to give and receive constructive feedback in order to improve their product.

Massachusetts Curriculum Frameworks:
ELA:
1. 22.7-Use additional knowledge of correct mechanics (apostrophes, quotation marks, comma use in compound sentences, paragraph indentations), correct sentence structure (elimination of fragments and run-ons), and correct Standard English spelling (commonly used homophones) when writing, revising, and editing.

Science and Technology/Engineering standard for Grades 6-8 in Engineering Design:
1. 2.2-Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multi-view drawings.

Materials and Setup:
- There should be several stations set up throughout the room.
  - “Pit stop” station: Equipped with puzzles and blocks
  - Classroom Management Note-Students who abuse any of these stations should be asked to go to the “pit stop” station. After the second instance of inappropriate behavior, the individual will be banned from using that particular station for the remainder of the day.
    - “Reference” station: Provides examples of different kinds of cars and transmissions.
    - “Cutting” station: All cutting takes place at the cutting station.
  - Classroom Management Note: Knives are not to be removed. All cutting must occur on top of cardboard, with the object lying flat. Blades must be retracted when finished.
  - “Sawing” station
  - Classroom Management/Safety Note-Students will wear safety goggles when sawing. The clamp must be used at all times. Students who abuse this station will be asked to go to the “pit stop” station.
    - “Gluing” station
    - “Pliers and Rulers”
    - “Bearings and Wheels”
    - Chassis Materials”
    - Rubber Bands, twisties, and other attaching materials.
    - Designated area for testing cars.
  - Potentially dangerous stations need signs posted to remind students of the relevant safety measures.
- Post Agenda
- Post Scientific Method and Process of the Engineering Method Posters
- Post vocabulary Poster
- Post Roadmap to the Junior Solar Sprint (large visual, mounted on foam core, outlining the steps that students will complete in the design and building process as they prepare for their race)
- Thumbtacks and car cutouts (one for each design team, to track progress on the Roadmap)

**Opening Ritual:**

**Materials and Setup:**
- Structure puzzle materials:
  - Bins (1 for each design team)
  - Rulers (2 for each design team)
  - Duct tape
  - Paper
  - Blocks or other weights (1 for each design team)
- Place a bin, open-side facing up, on the table. Place two rulers across the bin, leaving a little less than 11 inches of space between the rulers. Tape the rulers to the bin so that students cannot move them closer together.

**Procedure:**
1. Explain that the challenge is to build a bridge that spans from one ruler to the other and supports the block using the fewest number of sheets of paper as possible.
2. *Math Tie-In: Practice division by deciding how many pieces of paper should go to each group.*
3. Give each design team a bin with rulers attached, several pieces of paper and a block to use as a weight.
4. Tell students that they will have 5 minutes to work with their team to complete this challenge.
5. After 5 minutes, ask students to put down their materials to debrief the activity by having students write in their notebooks the answers to the following questions (write the questions on the board):
   - Did everyone come up with the same solution?
   - What strategies did people use to reduce the number of sheets of paper they needed?
   - What kinds of structures were the strongest? (For example, was a folded piece of paper stronger than an unfolded piece?)
   - What did you learn from the activity?
   - Why is it important knowledge for building their cars?
6. Allow a few representatives to share the experiences of their group.
7. Facilitate a discussion to help students recognize the following lessons about structure, creativity, and teamwork:
   - Less can be more. If you think about it, you can find ways to build a stronger chassis with less material. This is important because weight slows down cars.
   - There is more than one solution to each problem.
   - It is important to listen to each group member’s ideas and contributions.

**Activity 1: Building:**

**Set Context:**
- *As a vocabulary check have students look in their engineering notebook and go through each vocabulary term, having students write down any missing words*
  - Engineer – a person who uses scientific knowledge to solve practical problems and produce goods for society
  - Fossil fuels – an energy source such as oil, gas, or coal, which is formed from ancient plant fossils.
  - Renewable resources – a resource that can be replaced as we use it, so it won’t run out
- Solar – relating to the sun.
- Axle – a thin rod connecting the wheels
- Chassis – the structural frame or body of the car
- Bearing – a rotating support placed between moving parts to allow them to move easily
- Tradeoffs – gaining one benefit often means losing another. You can’t have everything!
- Friction – the resistance to motion between two surfaces in contact
- Force – the ability to change an object’s state of rest or motion
- Hypothesis – a tentative proposal made to explain certain observations or facts, which requires further investigation to be verified
- Payload – the cargo… what the vehicle carries (in this case, an aluminum can)
- Feedback – information or comments that can be used as the basis for improvement

Materials:
- Materials checklist
- Engineering notebooks
- Motors, wires, batteries, fake solar panels, payloads, gear kits, extra wheels, and axles
- Sample cars
- Cardboard for Cutting

Procedure:
1. Have the materials manager gather materials.
2. Ask each group to discuss which role each apprenticeship plays (to remind apprenticeships of the importance of roles)
3. Explain that today’s building goal is to attach the solar panel and payload in a removable fashion

Ask:
4. Why do you think it is important for the solar panel and payload to be removable?
5. Push students to think about why behind the rules of the race: Why does the Junior Solar Sprint require that solar panels and payloads be removable?
6. Ask students whether they think it is more challenging to build a car that has removable pieces. Why or why not?
7. Allow teams to work on their cars, checking in with them as they work to see what challenges they are facing.

Activity 2: Peer Editing:

Materials:
- Group Binders
- Pencil/Pen

Procedure:
1. Ask students to come back together (blowing a whistle)
2. Introduce the Peer Editing Activity:

Ask:
- What does it mean to peer editing?
- Have you heard this term before?
- Explain that the peer editing session will be similar to peer editing in schools.
- They will be providing feedback for other teams and will be able to ask questions, and provide suggestions.

3. Remind students that it is important to revise and have a critical eye.
4. During the activity design teams will rotate so that each team speaks with every other team.
5. Apprentices will have 15 minutes to discuss and analyze the design plans and cards of their partner groups and to record in that group’s binder their feedback.
6. Ask students what they think the benefits are of looking at another group’s design or having another group look at your design.
7. Illustrate what makes feedback effective by talking through several examples with the group
   - Ineffective feedback (“You’re design is stupid!”) and several examples of effective feedback
     (“You’re structure to hold the payload uses a lot of extra material that may weigh your car down.
     You should try to use fewer pieces of foam core so that your car will be lighter.”)
8. Emphasize that it is important for feedback to be as specific as possible, and that it is important to communicate ideas using respectful language.
9. Ask students whether they have any questions, and then allow them to begin.
10. Rotate around the room to check how students are doing with their feedback.

Activity 3: Response to Feedback:

Materials:
- Design plans
- Feedback
- Cars

Procedure:
1. After 15 minutes ask apprentices to return with their team.
2. Give students 5 minutes to read over the feedback they received from the other group, and then allow them to look at their design plans and begin thinking about the changes they would like to make to their designs, or the directions they would like to go in their future building.

Teachback:
1. Ask students to take five minutes to record in their engineering notebooks the 3 things that they learned from today.
2. Under each learned item have apprentices explain how they will apply those ideas to their final solar car model.
3. Go around and encourage students to improve/revise their writing making certain to give examples as to how to use proper writing mechanics.
4. Ask apprentices to write any questions they have as you move forward.
5. Preview next week’s lesson plan and lastly,
6. Recognize individual students who have contributed above and beyond the expectations.
7. Ask students to rate the group’s teamwork using the “Fist of Five” method.
8. Allow several students (high and low ratings) to share their reasons.
9. Ask students to share specific things they would like to work on in terms of teamwork next week.
10. Allow students to move their team cars on the Roadmap.
Lesson 6: Feedback to Improve the Solar Car

21st Century Skills:
- Teamwork
- Oral Presentation

Snapshot Agenda:
1. Opening Ritual: Pieces of the Puzzle (Circuits) 10 Minutes
2. Review Agenda and Set Context 5 Minutes
3. Activity: Building, Part I 25 Minutes
4. Activity: Mid-Session Check-In 10 Minutes
5. Activity: Building, Part II 25 Minutes
6. Closing and Teach Back 5 Minutes
7. Clean up 5 Minutes

Learning Objectives:
1. Apprentices will develop skills of construction.
2. Apprentices will develop skills to give and receive constructive feedback in order to improve their product.
3. Apprentices will discover that engineering is a process of trial and error.

Massachusetts Curriculum Frameworks:
ELA:
1. 22.7-Use additional knowledge of correct mechanics (apostrophes, quotation marks, comma use in compound sentences, paragraph indentations), correct sentence structure (elimination of fragments and run-ons), and correct Standard English spelling (commonly used homophones) when writing, revising, and editing.

Apprentice Roles:
Clean up crew- 3 people to help clean up after the experiments

Materials and Setup:
(see previous Material and Setup sections)

Opening Ritual:

Procedure:
1. Provide each design group with a motor, two wires and a battery pack.

Explain:
1. Challenge one requires each group to make its motor spin.
2. When the group has accomplished the spinning motor challenge, the second challenge is to make the motor spin in the opposite direction.
3. After each group has completed each challenge ask for a volunteer to Teach Back and tell the entire group how they went about reversing the motor.
4. Ask: How could you tell which direction the motor was spinning? How did you know which wires to attach in which places to make sure that the motor spun in the direction they wanted? Why is it important to know to attach the wires so that the motor spins forward? What will happen at the race if they attach the wires incorrectly?
5. Ask: Where does the energy come from? Was solar power used? (If apprentices are stuck, explain that in this example, the battery pack provides the energy and review the word solar).
6. Remind students that the battery will be used to replace the solar paneling if on the day of the competition it is cloudy.

**Activity 1: Group Work:**

**Materials:**
- Binders, pencils, markers, rulers, engineering notebooks
- Materials checklist
- Puzzles for the pit stop
- Motors, wires, battery packs (for the opening challenge and for building)
- Fake solar panels, payloads, gear kits, extra wheels and axles.
- Sample Cars
- Safety goggles
- Plastic bins for support
- Twisties and rubber bands
- Extension cords
- Drill and drill bits
- Masking tape
- Whistle for signal
- Cardboard for cutting

**Procedure:**
1. Material Managers gather needed equipment
2. Allow teams to continue working on their cars, checking in with them as they work to see what challenges they are facing.
3. Offer feedback on the teamwork of groups.
4. Ask students questions about how they are incorporating different team members’ ideas and monitor division of labor
5. Check-in with each group to promote their own monitoring of progress.

**Activity 2: Mid-Way Check-in:**

**Procedure:**
1. Halfway through the building process bring all the apprentices together for a check-in
2. During the check-in have each group report out on their progress and speak about the successes/challenges they are facing.
   Classroom Management Note- This check-in will help refocus the group (if necessary) as well as provide a feeling of community as groups will hear that some of their challenges are the same ones faced by other groups.
3. Remind students to show these sessions are great places to work on their public speaking skills by speaking loudly, slowly, and clearly so that their classmates can understand them, and by using eye contact and proper body posture as they express their thoughts.
4. Offer students feedback on their oral communication after they present. Model effective and ineffective ways to orally communicate.
5. Ask students to share feedback with each other, following the same guidelines they learned in lesson four about giving and receiving feedback.
6. Have the group review the community agreement.
7. Chart progress on the roadmap.

**Activity 3: Building III:**

**Procedure:**
1. Students will then return to their teams and continue building for the last 20 minutes, using the ideas and suggestions of other teams for direction.
2. Offer feedback on the teamwork of groups.
3. Ask students questions about how they are incorporating different team members’ ideas and monitor division of labor.
4. Check-in with each group to promote their own monitoring of progress.

**Teachback:**

**Procedure:**

1. Ask students to take five minutes to record in their engineering notebooks the 3 things that they learned from today.
2. Under each learned item have apprentices explain how they will apply those ideas to their final solar car model.
3. Go around and encourage students to improve/revise their writing making certain to give examples as to how to use proper writing mechanics.
4. Ask apprentices to write any questions they have as you move forward.
5. Preview next week’s lesson plan and lastly,
6. Recognize individual students who have contributed above and beyond the expectations.
7. Ask students to rate the group’s teamwork using the “Fist of Five” method.
8. Allow several students (high and low ratings) to share their reasons.
9. Ask students to share specific things they would like to work on in terms of teamwork next week.
10. Allow students to move their team cars on the Roadmap.

**Cleanup:**

- Tabletop captains (clean off tables)
- Material organizers (use the checklist to make sure the team’s materials are all accounted for)
- Chair police (make sure all chairs are up on the tables)
- Visual captains (take down and store visuals)
Lesson 7: Testing and Redesign

21st Century Skills:
- Teamwork
- Oral Communication

Snapshot Agenda:
10 minutes- Opening Ritual
5 minutes- Hot and Cold game
10 minutes- Is space hot or cold?
35 minutes- “UV Man” and Radiation
20 minutes- Protecting Astronauts: Experiment OR How Cold is Cold Part I- Dry Ice
5 minutes- Teachback
5 minutes- Clean up

Learning Objectives:
1. Apprentices will develop skills of construction.
2. What will identify the differences between testing their cars inside and racing them outside?

Massachusetts Curriculum Frameworks:
Science and Technology/Engineering standard for Grades 6-8 in Engineering Design:
1. 2.2-Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multi-view drawings.

ELA:
1. 22.7-Use additional knowledge of correct mechanics (apostrophes, quotation marks, comma use in compound sentences, paragraph indentations), correct sentence structure (elimination of fragments and run-ons), and correct Standard English spelling (commonly used homophones) when writing, revising, and editing.

Opening Ritual:

Materials:
- Guide wires
- Foam core

Procedure:
1. Provide each group with a piece of foam core with the guides attached.
2. The Challenge for the group is to attach this piece to the guide wire as smoothly and quickly as possible.
3. Allow students several minutes of practice.
4. Conduct a “race” to see who can attach their foam core to the guide wire the most quickly.

Ask:
5. How is this race similar to the race they will be competing in with their solar cars?
6. How is it different?

Activity 1: Outdoor Testing Activities:

Materials:
- Track materials
- Notebooks
- Solar Cars and materials

**Procedure:**
1. Prior to going outside explain the rules of the race course.
2. Each group is responsible for setting up their own race course.
3. Refer to the visual diagram of the race course set-up in order to demonstrate how students will set up their tracks.
4. Inform students that they are required to raise their hands once their tracks are set up so that the CT or TF/TL can inspect it.
5. If there are questions refer back to the track visual diagram of the race course to demonstrate how students will set up their tracks.

**Ask:**
6. Why do you think tracks are constructed like this? What is the purpose of the guide wire? What would happen if cars were not attached by the guide wire?
7. Explain the three roles involved in racing each car:
   - Car starter: attach the car to the guide wire and connect the wires.
   - Sun protector: hold a sheet above the car, blocking the light until it’s time to race.
   - Finish line protector-Stands at the finish line to catch the car and disconnect the wires so that it does not get damaged.
   - Note-taker takes observational notes
   *If more roles are needed:*
   - Time Keeper
   - Finish Line Judge
   - Results Recorder
8. Assign students to these roles.
10. When students are settled, tell students that they have 5 minutes to set up their courses.
11. When each course is set up announce the start of the race.
12. After the first race is completed, choose specific cars to observe.
13. Have the group gather around and watch the performance of each car.
14. Facilitate a discussion regarding the successes and challenges that each car is facing.
15. Ensure the use of teamwork, making sure that students are taking turns and listening to one another.
16. Remind the note-takers to record the comments in their design notebooks.
17. Once all cars have been examined, have students disassemble their tracks, gather all materials, and prepare to go back inside.
18. Transition back to the classroom for reflection and analysis.

**Activity 2: Reflection and Analysis:**

**Materials:**
- Notebooks
- Pencils
- Dictionary

**Procedure:**
1. Explain that it is important for students to remember their practice race so they can use their observations to improve their cars in the coming weeks.
2. Ask students to share their knowledge about writing a paragraph
3. What is a topic sentence? What does it mean to use proper grammar? What is a run on sentence? How can you check grammar?
4. Give students 5 minutes to write in their notebook a paragraph on the experience of racing outside.
5. Offer the following questions to guide students’ reflection:
   - Did your car perform as well as you had hoped? Why or why not?
   - What are some of the conditions outside that make it more difficult for your car to run? What are some things you can do to help your car perform well considering these challenges?
6. Ask students to read their reflections within their design teams.
7. Have teams share out some of their comments to the large group.

**Activity 3: Redesign:**

**Materials:**
- Large pieces of paper
- Pens/Pencils

**Procedure:**
1. Pass out large pieces of paper to each team.
2. Ask students to within their design teams create, based on their observations from their test-runs, sketches for the changes that they hope to make.

**Teachback:**

**Procedure:**
1. Choose one representative from each team to share out what was most exciting about the day.
2. Choose one different representative from each team to explain how the group is going to change the car to make it even more efficient.
3. Review oral communication and teamwork skills by having students give each other feedback on their public speaking skills (Pace, volume, clarity, body position, eye contact)

**Cleanup:**
- Tabletop captains (clean off tables)
- Chair police (make sure all chairs are up on the tables)
- Visual captains (take down and store visuals)
- Notebook collector
Lesson 8: Optimizing Car Performance

21st Century Skills:
- Teamwork
- Oral Communication

Snapshot Agenda
1. Opening Ritual: Aerodynamics Challenge 15 Minutes
2. Review Agenda and Set Context 5 Minutes
3. Activity: Building, Part I 25 Minutes
4. Activity: Mid-Session Check-In 10 Minutes
5. Activity: Revision and Improvement 20 Minutes
6. Closing and Teach Back 5 Minutes
7. Clean up 5 Minutes

Learning Objectives:
1. Apprentices will identify how change of car shape causes change in the car’s aerodynamic nature.
2. Apprentices will discover that engineering is a process of trial and error.

Materials and Setup:
(see previous Materials and Setup sections)

Opening Ritual:

Materials:
- Soda cans
- Dowels
- Scotch tape
- Paper
- Duct tape

Procedure:
1. Review the following vocabulary terms and ask students to write the terms on their vocabulary list
   - Aerodynamics – the properties of solid objects related to how the move through air in order to maximize efficiency
   - Creativity – using imagination or original ideas, especially to make something more artistic
   - Innovation – a new method or approach to a design challenge
2. Create a track on a table in the front of the room by placing two long wooden dowels several inches apart that a soda can is able to rest on top of them.
3. Ask for volunteer to use duct tape to attach the track to the table.
4. Place an empty soda can at one end of the track, with its top facing the open track.
5. Ask for a volunteer to come up in front of the group and try his or her hardest to blow the can across the track.
6. Use a piece of tape to mark on the table how far he or she blew the can.
7. After the first person has gone, repeat several times with other students, recording how far each person moves the can. In this part of the activity, some students will be able to blow the can farther than others, but no one should be able to blow the can all the way across the track.
8. After several students have tried the first can, introduce a can that has a paper cone on the end to make it more aerodynamic.
9. Ask for a few volunteers to try blowing this can, marking each person’s distance to demonstrate that the cone makes it possible for students to blow the can much farther than before.
10. Ask: What hypotheses do you have about why the cone worked?
11. Review the term aerodynamic and explain that the shape of cars affect how they move through the air.
12. Hold up two different sample cars and ask students to predict which one they think would be more aerodynamic (which one they think would cut through the air better) based on its shape.

Activity 1: Building IV:

Materials:
- Sample Cars
- Checklist for Materials
- Chart Paper
- Car supplies
- Safety equipment:
  - Safety goggles
  - Cold water in case of burns
  - Band-Aids
- Pencils, rulers, Exacto knives, scissors
- Tape
- Hot glue guns
- Cardboard cutting surface
- Newspaper to protect gluing surfaces
- Engineering notebooks and design binders

Procedure:
1. Allow teams to continue working on their cars, checking in with them as they work to see what challenges they are facing.
2. Ask questions to focus their attention on the shape of their cars, and on ways to make their cars more aerodynamic.
3. In addition to facilitating students’ progress in terms of building, offer feedback on the teamwork they are demonstrating.
4. Ask students questions about how they are incorporating different team members’ ideas in to their design, and how they are dividing the work so that everyone contributes.

Activity 2: Check-in:

Procedure:
1. Halfway through the building process bring all the apprentices together for a check-in
2. During the check-in introduce the four categories in which students’ cars will be judged (speed, creativity, innovation, and technical merit)
3. Redefine these terms and then provide examples by referring to specific students’ cars.
4. Ask several students to share one category in which they think their group’s car is strong, and one category that they think their group is struggling with.
5. To focus on oral communication, ask students to identify one public speaking skill that they would like to focus on doing well today before they begin speaking
6. After they finish speaking, offer them specific feedback on ways to improve that skill.

Activity 3: Revision and Improvement:

Procedure:
1. Ask students to continue building for the final 20 minutes,
2. As they work ask what category their team is focusing on to fix/revise.
3. If a team is “done” in terms of the structure and design, encourage the team to decorate their cars as a way to express their creativity and to have their car stand out at the competition.

Teachback:
Procedure:
1. Ask students to take five minutes to record in their engineering notebooks the 3 things that they learned from today.
2. Under each learned item have apprentices explain how they will apply those ideas to their final solar car model.
3. Go around and encourage students to improve/revise their writing making certain to give examples as to how to use proper writing mechanics.
4. Ask apprentices to write any questions they have as you move forward.
5. Preview next week’s lesson plan
6. Recognize individual students who have contributed above and beyond the expectations.
7. Ask students to rate the group’s teamwork using the “Fist of Five” method.
8. Allow several students (high and low ratings) to share their reasons.
9. Ask students to share specific things they would like to work on in terms of teamwork next week.

Cleanup:
- Tabletop captains (clean off tables)
- Material organizers (use the checklist to make sure the team’s materials are all accounted for)
- Chair police (make sure all chairs are up on the tables)
- Visual captains (take down and store visuals)
Lesson 9: Prepping for WOW!

Select 2 21st Century Skills:
- Teamwork
- Oral Communication

Snapshot Agenda:
1. Opening Ritual: 10 Minutes
2. Review Agenda and Set Context: 10 Minutes
3. Activity: Almost Done Building 30 Minutes
4. Activity: Check-In 10 Minutes
5. Activity: Final Building 20 Minutes
6. Teach Back: 5 Minutes
7. Clean up: 5 Minutes

Materials and Setup:
(see previous Materials and Setup sections)

Opening Ritual:

Materials:
- Local street/transportation maps (Optional-Use of computers to find maps)
- Markers

Procedure:
1. Each student will be given a map of the area around the race location, with nearby public transportation stations labeled.
2. Instruct students to color the public transportation labels yellow.
3. At the WOW! site students should draw a star
4. Students should draw a line from the nearest public transportation station to the race site in another color.
5. On a separate piece of paper students should write out directions explaining how to get from the public transportation station to the race site.
6. Ask for volunteers to share their directions with the class- tell students that they should use the oral communication skills that they have been learning as they discuss their directions.
7. Explain that because the Solar Cars WOW! Is off-campus, there are some important details and logistics that need to be noted.
8. Ask: What details do you think we need to think about for those coming to the event?
9. Distribute permission slips and explain that these forms describe several different transportation options for students and their families.
10. Call on students to read out loud specific parts of the permission slip, and ask students if they have any questions.
11. Remind students that in order to participate they need to return their forms to Citizen Schools.

Activity 1: Almost Done Building Session:

Materials:
- Sample Cars
- Checklist for Materials
- Chart Paper
- Car supplies
  - Foam core
  - Cardboard
  - Axles
  - Bearings
  - Wheels
  - Tires
- Engineering notebooks and design binders
- Ramp
- Pencils, rulers, Exacto knives, scissors
- Tape
- Hot glue guns
- Cardboard cutting surface
- Safety equipment:
  - Safety goggles
  - Cold water in case of burns
  - Band-Aids
  - Newspaper to protect gluing surfaces

**Procedure:**
1. Instruct Students that they should use this last building session to finish anything they have left on their cars.
2. Encourage students to use the test-track to make sure their cars are running well.
3. Give students frequent reminders to let them know how much time they have left.
4. Circulate around the room and check-in with groups to make sure everyone is on track, no one is frustrated, etc.
5. Remind students that one way to use teamwork in this final stretch is to divide the work up so that each person is responsible for completing a different task.
6. After 40 minutes, gather students for their check-in.

**Activity 2: Final Check-in:**

**Materials:**
- Checklists

**Procedure:**
1. Distribute check-lists with the specifications that cars must meet in order to be allowed to race.
2. Review any specifications that students are confused about.

**Activity 3: Final Building and Revision Section:**

**Procedure:**
1. Give students 10 minutes to check their cars against the specifications, and to make any last minute additions so that their cars are fully eligible to race.
2. Check with groups to make sure there are no major problems with any of the cars.

**Teachback:**

**Procedure:**
1. Have students use the “Fist of Five” method to rate how excited they are for the “dress rehearsal” race next week, and the final race at the WOW!
2. Ask several students (high and low) to share why they chose the number they chose.
3. Remind students to demonstrate the public speaking skills they have been building throughout the apprenticeship.

**Cleanup:**
- Tabletop captains (clean off tables)
- Material organizers (use the checklist to make sure the team’s materials are all accounted for)
- Chair police (make sure all chairs are up on the tables)
- Visual captains (take down and store visuals)
Lesson 10: WOW! Practice and Reflection

21st Century Skills:
- Teamwork
- Oral Communication

Snapshot Agenda:
1. Opening Ritual: 10 Minutes
2. Review Agenda and Set Context: 10 Minutes
3. Activity: Final Practice Races 30 Minutes
4. Activity: Reflection 15 Minutes
5. Activity: Shout Outs 15 Minutes
6. Teach Back: 5 Minutes
7. Clean up: 5 Minutes

1. Explain that they will be going outside today to do a final test-run of their cars, before coming inside to complete some apprenticeship wrap-up activities.
2. Review the set-up of the race course by asking a student to come up and draw a diagram on a blank piece of flip chart paper.
3. Remind students of the roles involved in racing their cars, and assign students to roles.
4. Make sure to assign students who will be at the WOW! to the roles that are directly involved in racing their cars.
5. Ask any students who will not be able to make it to the WOW! to be time keeper, line judge, and other indirect support roles.
6. Review the expectations for safety and appropriate behavior outside the school.
7. Explain that during this lesson instead of recording observations in notebooks, everyone will be writing down successes on index cards to exchange with each other as congratulations.

Learning Objectives:
1. Apprentices will reflect on their accomplishments in the apprenticeship
2. Apprentices will discover that engineering is a process of trial and error.

Massachusetts Curriculum Frameworks:
ELA:
1. 22.7-Use additional knowledge of correct mechanics (apostrophes, quotation marks, comma use in compound sentences, paragraph indentations), correct sentence structure (elimination of fragments and run-ons), and correct Standard English spelling (commonly used homophones) when writing, revising, and editing.
2. 23.8-Organize information about a topic into a coherent paragraph with a topic sentence, sufficient supporting detail, and a concluding sentence.

Opening Ritual:

Procedure:
1. Play a review game using the vocabulary that students have learned over the course of the apprenticeship
2. Collect final permission slips
3. Answer any remaining questions regarding the logistics of the final WOW!

Activity 1: Final Practice Runs:
Materials:

- Solar Cars

Procedure:

1. As a group, transition outdoors.
2. Have each team set up its race track.
3. Run the first heat of races.
4. During heat one each team should focus on watching their own car.
5. Following the race ask each person in the group to write down one thing that they are proud of about their car.
6. Repeat this process of rotating and reflecting until each team has raced each car.
7. Once each car has been raced is over, return inside.

Activity 2: Reflection:

Materials:

- Notebooks
- Pencils/pens

Procedure:

1. Pass out the engineering notebooks.
2. Make certain to congratulate students on their hard work and success and explain that they are going to now reflect.
3. Post the reflection visual in the front of the room.
4. Ask for volunteers to read each question.
   - What was your favorite part of this apprenticeship?
   - What was your least favorite part of the apprenticeship?
   - What was the most interesting thing you learned?
   - How can you use what you learned in this apprenticeship in your school life?
   - How can you use what you learned in the apprenticeship in your home life?
5. Instruct students to write 2-3 sentences per question in reflection. Remind students of their writing skills and the importance of writing focused, carefully edited sentences.
6. Ask for volunteers to share their answers.
7. Have students sign the last page of each other’s notebooks as a farewell page. Apprentices may keep their notebooks to remember what they’ve learned in the apprenticeship.

Activity 3: Shout Outs:

Materials:

- Shout Out cards
- Pencils/pens

Procedure:

1. Have students exchange their note cards from the race course.
2. Pass out individual Shout Out cards, with notes written for each student, from the Citizen Teacher and/or Team Leader
3. Then ask for several volunteers to give Shout Outs to other students in the class.