3

Playground Forces

NGSS EARLY IMPLEMENTERS

WestEd

A Collaboration of the K–12 Alliance @ WestEd,
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Introduction

The California K–8 NGSS Early Implementation Initiative was developed by the K–12 Alliance at WestEd with close collaborative input on its design and objectives from the California State Board of Education, the California Department of Education, and Achieve. This project was designed to build local education agency (LEA) capacity to fully implement the Next Generation Science Standards (NGSS) as a core subject in the elementary grades (K–5) and as the SBE's preferred integrated model in grades 6–8.

The six-year Initiative provided teachers and administrators with in-depth, content-rich professional development to build leadership capacity and teacher acumen to deliver high-quality 3-dimensional learning for K–8 students. In addition, through collaborations among the K–12 Alliance, Achieve, and others, the LEAs in the Collaborative had opportunities to pilot test new NGSS-aligned tools, processes, assessment item prototypes, and digital and other instructional materials. The LEAs continue to serve as resources for NGSS implementation across California, and in other NGSS-adopting states as well.

This resource presents the conceptual storyline for a unit of instruction at a specific grade level, then focuses on a portion of the storyline called a learning sequence. The learning sequence uses the three dimensions of the NGSS (disciplinary core ideas—DCI; science and engineering practices—SEP; and crosscutting concepts—CCC) to build and deepen student understanding of natural phenomena and design challenges.

Participants in the CA NGSS K–8 Early Implementation Initiative developed and field-tested the lessons in the learning sequence.

Overview

After completing this unit, students will never look at recess or physical education the same way again. The anchoring phenomenon for this unit is objects move in different ways during physical activities on the playground. This unit is the first half of the third grade Physical Science standards and addresses the first two Performance Expectations only. In this unit, students identify forces and that forces have strength and direction. While exploring the playground, students observe the action of contact forces by investigating how balanced and unbalanced forces cause motion as well as how speed and direction changes are caused by the strength and the direction of the force. Students also incorporate their observations of patterns to predict the future motion of objects when a force is applied. The students complete this unit by using their knowledge of force and motion on the playground to design a new playground structure or activity.

The Performance Expectations addressed in this unit are:

3-PS2-1 Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. *[Clarification Statement: Examples could include an unbalanced force on one side of a ball can make it start moving; and, balanced forces pushing on a box from both sides will not produce any motion at all.] [Assessment Boundary: Assessment is limited to one variable at a time: number, size, or direction of forces. Assessment does not include quantitative force size, only qualitative and relative. Assessment is limited to gravity being addressed as a force that pulls objects down.]*

3-PS2-2 Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion. *[Clarification Statement: Examples of motion with a predictable pattern could include a child swinging in a swing, a ball rolling back and forth in a bowl, and two children on a see-saw.] [Assessment Boundary: Assessment does not include technical terms such as period and frequency.]*

3-5-ETS1-1 Define a simple design problem reflecting a need or want that includes specified criteria for success and constraints on materials, time, or cost.

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

Learning Sequence Narrative

The Learning Sequence Narrative briefly describes what students do in each lesson and links the learning between the lessons as a conceptual storyline. At the end of each learning sequence, students make connections to their understanding of the investigative phenomenon and/or the identified problem (and to the anchoring phenomenon when appropriate).

The anchoring phenomenon for the learning sequence is objects move in different ways during physical activities on the playground.

Students figure out this phenomenon by:

Science and Engineering Practices (SEPs)

Asking Questions and Defining Problems

- Ask questions that can be investigated ~~and predict reasonable outcomes based on patterns such as cause and effect relationships~~.
- Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.

Developing and Using Models

- Collaboratively develop and/or revise a model based on evidence ~~that shows the relationships among variables for frequent and regular occurring events~~.
- Develop and/or use models to describe and/or predict phenomena.
- Develop a diagram or simple physical prototype to convey a proposed object, tool, or process.
- Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.

Planning and Carrying Out Investigations

- Evaluate appropriate methods and/or tools for collecting data.
- Make observations ~~and/or measurements~~ to produce data to serve as the basis for evidence for an explanation of a phenomenon or to test a design solution.
- Make predictions about what would happen if a variable changes.

Analyzing and Interpreting Data

- Represent data in tables and/or various graphical displays (bar graphs, pictographs and/or pie charts) to reveal patterns that indicate relationships.
- Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation.
- Analyze data to refine ~~a problem statement or~~ the design of a proposed object, tool, or process.

Constructing Explanations or Designing Solutions

- Construct an explanation of observed relationships.
- Use evidence (e.g., ~~measurement~~, observations, patterns) to construct or support an explanation or design a solution to a problem.
- Apply scientific ideas to solve design problems.
- Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.

Engaging in Argument from Evidence

- Construct and/or support an argument with evidence, data, and/or a model.

Obtaining, Evaluating, and Communicating Information

- Communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.

Disciplinary Core Ideas (DCIs)

PS2.A: Forces and Motion

- Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion.
- The patterns of an object's motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it.

PS2.B: Types of Interactions

- Objects in contact exert forces on each other.

ETS1.A: Defining and Delimiting Engineering Problems

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

ETS1.B: Developing Possible Solutions

- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.

Crosscutting Concepts (CCCs)

Patterns

- Similarities and differences in patterns can be used to sort, classify, communicate, ~~and analyze simple rates of change~~ for natural phenomena and designed products.
- Patterns of change can be used to make predictions.

Cause and Effect

- Cause and effect relationships are routinely identified, tested, and used to explain change.

Influence of Engineering, Technology, and Science on Society and the Natural World

- Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands.

Introduction

The following narrative is based on the conceptual flow found at the end of this section.

Lesson 1: Movement on the Playground

Identified Problem: A school can't reopen the playground until it receives a design for a new playground structure.

This lesson builds on students' observation that objects move on a playground (anchoring phenomenon) and introduces students to a real-world problem: the scenario of a playground that needs to be redesigned. Students discuss why playgrounds are important, make observations of movement on the current playground, and use those observations to determine initial criteria to meet the design challenge of creating a new playground. They also determine initial investigation questions to gather evidence to support their design. Students explore forces and motion with such questions as: What is the movement? What caused it to move? How does it apply to our identified problem?

Lesson 2: Forces Move Objects

Investigative Phenomenon: A basketball on the playground moves when it is thrown.

This lesson builds on students' prior knowledge shared in Lesson 1: Movement on the Playground. In this lesson, students explore the three questions from Lesson 1 as they investigate the cause and effect of various characteristics of forces using the playground game of basketball. Students use a model to show that forces have strength and direction. Students are also introduced to the force of gravity. They discuss cause-and-effect relationships to move a basketball and look for patterns in motion.

Lesson 3: Patterns in Motion

Investigative Phenomenon: A kicked soccer ball on the playground didn't make it all the way into the goal.

In Lesson 2: Forces Move Objects, students created models to show balanced and unbalanced forces based on the knowledge gained through basketball experiences. In this lesson, students build on these fundamental understandings of force and motion and apply them to a soccer ball. They continue to explore the three questions from Lesson 1: Movement on the Playground as they analyze and interpret data about how strength of the force impacts the distance the soccer ball moves. They apply the patterns of motion and cause-and-effect relationships to predict team players and their success for a new soccer game for the new playground.

Lesson 4: Balanced and Unbalanced Forces

Investigative Phenomenon: Small children on the playground win a tug-of-war challenge against a group of bigger children.

In Lesson 2: Forces Move Objects and Lesson 3: Patterns in Motion, students continued to build on the fundamental understandings of force and motion using balls. In this lesson, the students work with a non-ball example (tug-of-war) to continue to think about the cause and effect of balanced and unbalanced forces on an object as well as the strength and direction of the force. They also look for patterns in motion. They apply these understandings to the design of the playground.

Lesson 5: Playground Design

Identified Problem: A school can't reopen the playground until it receives a design for a new playground structure.

This lesson builds on the student data, knowledge, and explanations of force and motion gained in the prior lessons. This is the culminating lesson in the learning sequence. This lesson introduces the concepts of engineering design and the use of forces and motion to solve a problem. The previous lessons had students constructing explanations and models about the cause and effect of forces by observing patterns and collecting data from their investigations. Students will use this information to design and construct a new playground activity or piece of equipment to help solve the problem of replacing an old, unusable playground structure.

Learning Sequence 3-Dimensional Progressions

SEP PROGRESSION	
Asking Questions and Defining Problems	
Lesson 1	Students ask questions that can be investigated and are given a simple design problem that can be solved through the development of an activity or structure. They identify several initial criteria for success.
Lesson 5	Students continue to use this practice and add in constraints for materials and time.
Developing and Using Models	
Lesson 2	Students build on their K–2 knowledge of developing and using models to collaboratively produce a model as the basis for evidence of the force of gravity.
Lesson 4	Students continue to build their understanding of this practice to show relationships and connections between direction and strength of forces. Students continue to use this practice as they did in Lesson 2 with a focus on using their models as evidence for balanced and unbalanced forces.
Lesson 5	Students continue to use this practice and use their models to develop a prototype to describe and display their activity or structure. They also use their models to show the cause-and-effect relationships or interactions in their designed prototype.
Planning and Carrying Out Investigations	
Lesson 4	Students build on their K–2 knowledge of conducting an investigation to evaluate appropriate methods to collect data to serve as a basis for evidence for their explanation of the balanced and unbalanced forces in the tug-of-war activity. They also work collaboratively to make predictions about what might happen if the variable changes from number of students on each side to the size of the students.

Learning Sequence 3-Dimensional Progressions (continued)

SEP PROGRESSION (continued)	
Analyzing and Interpreting Data	
Lesson 3	Students build on their K–2 abilities to record information by comparing and contrasting data collected by different groups to discuss the patterns they noticed and if those patterns indicate a relationship between the strengths of a force and the distance traveled.
Constructing Explanations and Designing Solutions	
Lesson 4	Students apply scientific ideas to design solutions. They construct an explanation of the observed relationships and use evidence to support that explanation.
Lesson 5	Students apply the scientific ideas they have learned in these lessons to the design problem. They design their solution and compare other groups' solutions to the problem based on how well they meet the criteria and constraints of the designed solution.
Engaging in Argument from Evidence	
Lesson 2	Students construct and/or support an argument using evidence, data, and a model.
Lesson 5	Students apply the scientific ideas they have learned in these lessons to the design problem. They design their solution and construct an argument with data and a model. They compare other groups' solutions to the problem based on how well they meet the criteria and constraints of the designed solution.
Obtaining, Evaluating, and Communicating Information	
Lesson 5	Students communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.

DCI PROGRESSION	
Prior Learning	The intent is to use the 3-5-ETS1 Performance Expectations and its associated DCIs (ETS1.A, and ETS1.B), but if your students have no exposure/history with engineering design at this point, then refer to the K-2-ETS1 Performance Expectations for this initial challenge.
Lesson 1	Builds on Kindergarten (PS2.A) Each force acts on one particular object and has both strength and a direction. Objects in contact exert forces on each other. (PS2.A, PS2.B) The success of a designed solution is determined by considering the desired feature of a solution. (ETS1.A)

Learning Sequence 3-Dimensional Progressions (continued)

DCI PROGRESSION (continued)	
Lesson 2	Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on an object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion. Objects in contact exert forces on each other. (PS2.A, PS2.B) Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (ETS1.A) At whatever stage, communicating with peers about proposed solutions is an important part of the design process and shared ideas can lead to improved designs. (ETS1.B)
Lesson 3	Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on an object. Forces that do not sum to zero can cause changes in the object's distance ~~speed or direction~~ of motion. The patterns of an object's motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it. (PS2.A)
Lesson 4	An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion. The patterns of an object's motion in various situations can be observed ~~and measured~~; when that past motion exhibits a regular pattern, future motion can be predicted from it. (PS2.A)
Lesson 5	Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on an object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion. The patterns of an object's motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it. (PS2.A)

CCC PROGRESSION	
Patterns	
Lesson 2	Students identify patterns in their collected data and use these patterns to make predictions as evidence of the strength and direction of forces.
Lessons 3 and 4	Students identify patterns of change and use them to make predictions.
Cause and Effect	
Lesson 1	Students build on their understanding that events have causal relationships and use these relationships to identify changes in motion.
Lesson 2	Students identify causal relationships and use these relationships to explain the force of gravity.

Learning Sequence 3-Dimensional Progressions (continued)

CCC PROGRESSION (continued)	
Cause and Effect	
Lesson 3	Students identify causal relationships and use these relationships to explain strength and direction of force.
Lesson 4	Students identify causal relationships of balanced and unbalanced forces to explain the cause of motion.
Lesson 5	Students identify causal relationships as they design their playground equipment and use those relationships to explain force and motion.

Assessment

The Grade 3: Playground Forces unit provides multiple and ongoing strategies for teachers to assess student understanding as they progress toward mastery of Performance Expectations. These include:

- Possible assessment opportunities are marked with a red flag (▶). Throughout the lessons, these are often formative assessments. Sometimes the Evaluate phase might serve as a summative assessment.
- Rubrics are provided to assess student understanding in Lesson 2: Forces Move Objects, Lesson 3: Patterns in Motion, and Lesson 5: Playground Design.
- Science notebooks are used in each lesson. Students' responses in their science notebook allow you to informally assess student progress.
- Expected Student Responses (ESRs) are used throughout the unit to guide you in the types of responses students may provide. The actual student responses can be compared to the ESR as a formative assessment of student understanding at that point in time. Note: ESRs are not the only possible student responses, and you should not provide the ESRs to the students.
- The 5E instructional model provides an opportunity for you to assess students' prior knowledge in the Engage phase, to assess tentative explanations in the Explain phase, and to measure student understanding of the full lesson concept in the Evaluate phase.

References

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. DOI: https://doi.org/10.17226/13165. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K–12 Science Education Standards. National Academies Press, Washington, DC.

Grade 3 Playground Forces Conceptual Flow

Anchoring Phenomenon

Objects move in different ways during physical activities on the playground.

Balanced and unbalanced forces act on an object.

Investigative Phenomena or Identified Problem

A school can't reopen the playground until it receives a design for a new playground structure.	A basketball on the playground moves when it is thrown.	A kicked soccer ball on the playground didn't make it all the way into the goal.	Small children on the playground win a tug-of-war challenge against a group of bigger children.	A school can't reopen the playground until it receives a design for a new playground structure.
PS1.A, PS2.A	PS1.A, PS2.A	PS2.A	PS1.A, PS2.A	PS1.A, PS2.A
Playground games and equipment demonstrate the concepts of force and motion.	Forces (including gravity) have strength and direction. Objects have multiple forces acting on them.	An unbalanced force can cause changes in direction or distance. Patterns can be used to predict future motion.	Balanced and unbalanced forces act on an object with strength and direction. Objects in contact exert forces on each other.	Playground designs are based on force and motion concepts that meets criteria and constraints. Designs are compared and improved.
ETS1.A				ETS1.A, ETS1.B
Asking questions and defining problems	Developing and using models	Analyzing and interpreting data	Developing and using models	Constructing explanations and designing solutions
	Engaging in argument from evidence		Constructing explanations and designing solutions	Obtaining, evaluating, and communicating information
			Planning and carrying out investigations	Engaging in argument from evidence

Patterns

Cause and Effect

Movement on the Playground

3.1

Anchoring Phenomenon

Objects move in different ways during physical activities on the playground.

Lesson Concept

Students communicate information about observations of the motion of objects on a playground and what causes the objects to move in order to determine initial criteria for the solution to the problem.

Identified Problem

A school can't reopen the playground until it receives a design for a new playground structure.

Standards

Refer to Appendix 3.1 for NGSS, CCSS—ELA, and California ELD standards.

3.1 Movement on the Playground

Storyline Link

Lesson 1: Movement on the Playground begins with the scenario of a playground that needs to be redesigned. Students discuss why playgrounds are important, make observations of movement on the current playground, and use those observations to determine initial criteria to meet the design challenge of creating a new playground. They also determine initial investigation questions to gather evidence to support their design. Students explore forces and motion.

In Lesson 2: Forces Move Objects, students investigate the strength and direction of forces and resulting motion that happens in the process of a basketball game, specifically looking at what the movement was, how it happened, and how it can be applied to the problem.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena or solving a problem.

Time

135 minutes

Part I	15 minutes	Engage
Part II	60 minutes	Explore 1/Explain 1
Part III	60 minutes	Explore 2/Explain 2

Materials

Whole Class

- ❑ Chart paper
- ❑ Markers
- ❑ Playground areas (swings, tetherball, basketball hoops, four square, etc.)
- ❑ Playground balls
- ❑ 3.1.R1: Design a Playground
- ❑ 3.1.C1: Basketball
- ❑ 3.1.C2: Soccer
- ❑ 3.1.C3: Tug-of-war

Individual

- ❑ 3.1.H1: Motion Observation
- ❑ Science notebook

Teacher

- ❑ TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf)

Advance Preparation

1. Gather materials.
2. Assess playground(s) for activities (i.e. swings, slides, climbing structures, teeter-totter, horizontal bars, tetherball, playground balls or equipment, etc.) from which students will observe motion.
3. Review TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf) to determine when best to use this resource in student-to-student discourse.
4. Make copies of **3.1.H1: Motion Observation** recording sheet for each student.

Procedure

Part I

Engage (15 minutes)

Obtain and communicate information describing patterns of movement on the playground.

1. Present students with the design problem and the goal. Display **3.1.R1: Design a Playground**. Say, "Suppose we arrived at school today only to find that the playground area was closed because there is a plan to replace the playground with new playground structures and activities. The school cannot rebuild and open the playground until it receives a design for new equipment and games.

   The school wants you, the students, to design new playground structures and activities that use the concepts of force and motion. Your challenge will be to use the engineering process to design and build a model for a new playground structure or activity and write an argument with evidence about why this design is the best."

2. Ask students to turn to their neighbor and discuss why we have a playground. What can we do at recess that we can't do in the classroom? As students share, record their ideas on a classroom chart.

   Leading Questions:

   "Why do we have a playground? I think _____.

   What can we do at recess that we can't do in the classroom?"

   Expected Student Response:

   - *We have playgrounds so that we can move around and not have to sit all day.*
   - *We can run, play games, and move anywhere we want.*

   TEACHER NOTE

   Connect "why" students think recess is necessary to the question about what is their favorite activity in terms of movement.

3. Continue the partner discussion, asking students to name their favorite playground activity, the type of movement they can do, and why they like it. Ask students to record their ideas in their science notebook.

   Leading Question:

   "When on the playground, I like to _____ because _____."

   Expected Student Response:

   - *I like to play soccer because it's fun to run up and down the field.*

- *I like to skip rope because I get to hop and sing with my friends.*
- *I like to play four-square because I get to hit the ball to my friends.*

4. Ask a few to share with the whole group their favorite playground activity, the type of movement they can do, and why they like it. Chart only the activity.

> **TEACHER NOTE**
>
> Keep this chart for reference in Step 16. Review the chart of the types of activities students like. If students listed basketball, soccer, and tug-of-war, circle them on the chart. If not, add them to the chart, stating that these are the activities they will be investigating during the next few days.

Part II

Explore 1/Explore 1 (60 minutes)

Use observations to describe movement on the playground, noting what causes the movement.

5. Remind students that they are going to design a playground to provide opportunities for movement so they need to observe movement on the current playground.
6. Distribute **3.1.H1: Motion Observation** to each student. Preview **3.1.H1: Motion Observation** with students so they know what to record in each of the boxes. Explain that the class will now go outside to observe movement on the playground in small groups. Their job is to work with their group to observe an object before it moves and then as it moves. Students will record their observations in words and drawings on **3.1.H1: Motion Observation**. Discuss what they will write and draw depending on whether the object is moving or not.
7. Divide the class into groups of 4. Assign each group something on the playground to investigate in terms of movement, making sure one group observes a basketball court (e.g., one to the tetherball, one to jump ropes, four-square, etc.).

> **TEACHER NOTE**
>
> Depending on the situation, several groups could observe the same object.

8. Take students outside and allow them to investigate their assigned object. Remind students to record their observations on **3.1.H1: Motion Observation**. (Later this handout can be taped/glued in their science notebook.) Walk around and observe what students are recording. Pay attention to their prior knowledge of communicating observations related to forces and interactions of objects through cause and effects.

TEACHER NOTE

▶ Look at samples of **3.1.H1: Motion Observation** to formatively assess prior knowledge of students' ability to communicate their observations. Students may be sharing their observations using the kindergarten language of pushes, pulls rather than forces. If so, the term *force* is introduced in Step 11.

9. Return to the classroom. Have students discuss in their small groups their observations and drawings. Ask groups to focus on:
   - "What was the movement of the object?"
   - "What caused the object to move?"

   Have students tape/glue the **3.1.H1: Motion Observation** recording sheet in their science notebook.

10. Conduct a classroom discussion, having each "object" group share the movement of their object and what caused it to move. Record each group's answers on chart paper.

11. Ask students to record their responses to these three questions in their science notebook.

    Leading Question

    "How can you describe the motion of the objects that moved?"

    Expected Student Responses:
    - *Motion changed the position of an object because a force acted on it.*
    - *Motions moves something that was standing still to another place.*

    Leading Question

    "What similarities or patterns did you see in the movement or nonmovement of all of the objects?"

    Expected Student Responses:
    - *All of the moving objects moved from where they were to somewhere new.*
    - *All of the objects that were still didn't move at all.*

    Leading Question

    "What caused the objects to move?"

    Expected Student Response:
    - *Forces (pushes or pulls) caused the object to move.*

TEACHER NOTE

Students may be sharing their observations using the kindergarten language of *pushes* and *pulls*. If so, introduce the term *force* (any action that changes the shape or movement of an object). Explain that from now on they will be using this term to describe movement.

12. Lead students in a discussion of their explanations, noting cause and effect.

TEACHER NOTE

- Reference how when something happens because of something, the thing that makes the change occur is the cause, and the change is the effect.
- Briefly refer to language arts and other content areas where cause and effect is applicable.
- To clarify cause-and-effect relationships, use some of the students' sentences and highlight the cause and effect in each one.
- It is important for students to grasp the concept of events having causes and that these causal relationships sometimes form patterns that are observable and measurable. This will be introduced in Lesson 2: Forces Move Objects.

Part III

Explore 2/Explain 2 (60 minutes)

Identify initial criteria for a problem's solution based on observations of movement and its causes.

13. Remind students that they will design the new playground. How will the school administration decide which design to choose to build the playground? Explain that engineering design must meet certain criteria for the final product.
14. Ask students to identify the science information they learned in today's lesson regarding forces and motion that they will use as foundational to their design. Have them respond to these questions in their science notebook:
    - What was the movement?
    - What caused it to move?
    - How does it apply to our problem?

TEACHER NOTE

Lesson 2: Forces Move Objects, Lesson 3: Patterns of Motion, and Lesson 4: Balanced and Unbalanced Forces are built on answers to these 3 questions, and rubrics are found in Lesson 2: Forces Move Objects and Lesson 3: Patterns of Motion to formatively measure student understanding about force and motion.

15. Conduct a brainstorm of this question: “How can you use what you know about force and motion to create the criteria for the playground design?” Chart the list of criteria, which will be added to during each lesson.

TEACHER NOTE

Students should suggest the following for criteria: motion, motion changes direction and strength, pattern of predictability, and forces. The idea of balance and unbalanced forces will most likely not be mentioned in the list yet. They will learn more about this in Lesson 2: Forces Move Objects. It can be added to the criteria list then.

16. Connect the criteria list to the types of movement that students need to investigate to gather evidence to support their playground design. Review the chart with the types of movement on the playground. Ask: “Which activities could you investigate to gather evidence that will explain the science behind the criteria in your design? Why do you think this would be a good activity to investigate?” If students listed basketball, soccer, and/or tug-of-war, circle them as an affirmation that they already had thought about these activities. If not, explain that the school has requested a basketball court, a soccer field, and an area for games like tug-of-war. Tell students, “We will investigate basketball, soccer, and tug-of-war over the next several lessons. As you investigate basketball, soccer and tug-of-war, you will make designs for these three playground areas. Then you will put those designs together with designs for other playground equipment for their final playground design at the end of the unit.”

17. As a class, create three charts. Use **3.1.C1: Basketball**, **3.1.C2: Soccer** and **3.1.C3: Tug-of-war** as models. For each activity, have the class brainstorm the questions that can be investigated about movement and the evidence that can be gathered that will support a playground design. Record student ideas on the charts.

18. Review the three charts. Ask students if they have any other questions or wonderings to add to the charts.

TEACHER NOTE

Save each chart and add new learnings and wonderings to it after each lesson activity.

References

STEM Teaching Tools. (n.d.). Talk Science Printable. Retrieved from http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf

Toolbox Table of Contents

Basketball

What Questions Can We Investigate About Movement?	What Evidence Can We Gather That Will Support Our Design?

Soccer

What Questions Can We Investigate About Movement?	What Evidence Can We Gather That Will Support Our Design?

Tug-of-war

What Questions Can We Investigate About Movement?	What Evidence Can We Gather That Will Support Our Design?

Motion Observation

Draw and label a model of the playground object when it is not moving:	Draw and label a model of the playground object when it is moving:
What do you notice about how the object doesn't move?	What do you notice about how the object moves?
What do you think caused the object to not move?	What do you think caused the object to move?
What questions do you have about the movement of the object?	

Design a Playground

A demolition crew removed the playground structure and activity areas. The school wants the students to design a new playground structure and activity area that uses the concepts of force and motion.

Image via iStock.com/PhilAugustavo

Image via iStock.com/Spiderplay

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
3-PS2-1	Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. [Clarification Statement: Examples could include an unbalanced force on one side of a ball can make it start moving; and, balanced forces pushing on a box from both sides will not produce any motion at all.] [*Assessment Boundary: Assessment is limited to one variable at a time: number, size, or direction of forces. Assessment does not include quantitative force size, only qualitative and relative. Assessment is limited to gravity being addressed as a force that pulls objects down.*]

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)

Asking Questions and Defining Problems

- Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.
- Define (Given) a simple design problem that can be solved through the development of an object, tool, process, or system and includes (identify) several criteria for success.

DISCIPLINARY CORE IDEAS (DCI)

PS2.A: Forces and Motion

- Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion.

PS2.B: Types of Interaction

- Objects in contact exert forces on each other.

ETS1.A: Defining and Delimiting Engineering Problems

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

Appendix 3.1

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Students routinely identify and test causal relationships and use these relationships to explain change. They understand events that occur together with regularity might or might not signify a cause and effect relationship.

Common Core State Standards (CCSS)

CCSS ELA READING
CCSS.ELA-LITERACY.RI.3.3 Describe the relationship between a series of historical events, scientific ideas or concepts, or steps in technical procedures in a text, using language that pertains to time, sequence, and cause/effect.
CCSS ELA SPEAKING & LISTENING
CCSS.ELA-LITERACY.SL.3.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 3 topics and texts, building on others' ideas and expressing their own clearly.
CCSS.ELA-LITERACY.SL.3.4 Report on a topic or text, or recount an experience with appropriate facts and relevant, descriptive details, speaking clearly at an understandable level.

California English Language Development (ELD) Standards

CA ELD		
Part 1.3.1 Exchanging information and ideas.		
EMERGING	**EXPANDING**	**BRIDGING**
Contribute to conversations and express ideas by asking and answering *yes-no* and *wh-* questions and responding using short phrases.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, and adding relevant information.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, adding relevant information, building on responses, and providing useful feedback.
In addition to the standard above, you may find that you also touch on the following standard in this lesson as well: **P1.3.9** Plan and deliver brief oral presentations on a variety of topics and content areas.		

Forces Move Objects

3.2

Image via iStock.com/leolintang

Anchoring Phenomenon

Objects move in different ways during physical activities on the playground.

Lesson Concept

Develop a model showing how the strength and direction of a force can cause an object to move.

Investigative Phenomenon

A basketball on the playground moves when it is thrown.

Standards

Refer to Appendix 3.2 for NGSS, CCSS—ELA, and California ELD standards.

Storyline Link

This lesson builds on students' prior knowledge shared in Lesson 1: Movement on the Playground. In this lesson, students explore the cause and effect of various characteristics of forces using the game of basketball. Students create a model to show that forces have strength and direction. Students are also introduced to the force of gravity.

In the next lesson, students analyze data to determine patterns and predictability of motion and apply their analysis to their engineering challenge.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena.

TEACHER NOTE

The next 3 lessons will be working on three-dimensional learning. SEPs include models in Lesson 2: Forces Move Objects, and analyzing data/arguing from evidence in Lesson 3: Patterns of Motion, and models in Lesson 4: Balanced and Unbalanced Forces. CCCs include cause & effects throughout and building on patterns in Lesson 2: Forces Move Objects to predictability in Lesson 3: Patterns of Motion and Lesson 4: Balanced and Unbalanced Forces. The DCIs for force and motion include: strength and direction, patterns and prediction of movement, and balanced and unbalanced forces. Strength, direction, patterns, and predictability are emphasized in Lesson 2: Forces Move Objects and Lesson 3: Patterns of Motion; balanced and unbalanced forces are used in Lesson 2: Forces Move Objects and Lesson 3: Patterns of Motion culminate in Lesson 4: Balanced and Unbalanced Forces.

In Lesson 2: Forces Move Objects and Lesson 3: Patterns of Motion the focus is on using balls to experience the basic concepts of force and motion. In Lesson 4: Balanced and Unbalanced Forces, the understanding of these forces is applied to a non-ball activity, a tug-of-war. This physical experience of balanced and unbalanced forces resonates with third graders who think about balance as not falling down. In the tug-of-war, when students slide or fall, it physically represents the idea of unbalanced forces.

Using different experiences of motion (i.e. a ball that is thrown, a ball that is kicked, and tug-of-war) allows students multiple opportunities to gain an understanding of third-grade concepts of forces and motion.

Although there is a zero net force discussion in this lesson in terms of equal forces acting on an object, a deeper discussion of zero net force is a middle school disciplinary core idea.

Time

190–350 minutes: (4–6 lessons)

Part I	60–120 minutes	Engage
Part II	60–120 minutes	Explore/Explain 1
Part III	10–20 minutes	Explain 2
Part IV	30–60 minutes	Elaborate
Part V	30 minutes	Evaluate

Materials

Whole Class

- 4 to 6 basketballs (or 10-inch-diameter rubber balls)
- Chart paper or large whiteboard
- Marking pens (4–5 sets)
- 3.1.C1: Basketball (from Lesson 1: Movement on the Playground)
- 3.2.C1: Observable Features of Models
- Boys Outside Shooting Hoops video (https://www.youtube.com/watch?v=-3m202OMCsI) (Optional)

Partners

- Ping-pong ball (or another small ball)
- Small plastic cup with a 2-inch or 3-inch diameter

Individual

- Science notebook
- 3.1.H1: Motion Observation (from Lesson 1: Movement on the Playground)

Teacher

- TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf)
- 3.2.R1: Rubric

Optional

These activities/references can extend understanding of force and motion:

Computer Simulations

- ❑ Sid the Science Kid—Fun with Friction (https://www.youtube.com/watch?v=3Qs2W7gMxDk)
- ❑ PhET Simulation—Forces and Motion (https://goo.gl/vUQW4E)

Video

- ❑ Gravity, Force, and Work video (https://goo.gl/ix3fkD) [Notes: has directional force, but no strength]
- ❑ Force, Work, and Energy for Kids video (https://goo.gl/eYCCvp) [explains forces, has no arrows]
- ❑ For teacher: Use as a source of background information. What Forces Are Working On You video (https://goo.gl/WjZ27X)

Advance Preparation

1. Gather materials.
2. Make a large chart **3.2.C1: Observable Features of Models** or use a document camera.
3. Prepare two charts on with the title Models and one with the title Patterns.
4. Have available **3.1.C1: Basketball** from Lesson 1: Movement on the Playground. Decide which questions from **3.1.C1: Basketball** you will have investigated by outside work groups. (Select 5 or 6 questions that can be answered by simple investigations.)
5. Prepare posters to display vocabulary terms and their definitions:
   - *push:* a force that moves an object away from a participant
   - *pull:* a force that moves an object towards a participant
   - *force:* pulls and pushes
   - *gravity:* a force that pulls objects down

   Note: *Push* and *pull* are kindergarten vocabulary; *force* and *gravity* are used in third grade.
6. Review TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf) to determine when best to use this resource in student-to-student discourse.

Procedure

Part I

Engage (60–120 minutes)

Develop a model showing how the strength and direction of a force can cause an object to move.

1. Have students share their science notebook with **3.1.H1: Motion Observation** (from Lesson 1: Movement on the Playground) with a partner. Ask them to discuss what they observed about not moving and moving objects and how they showed that in their drawings.

> TEACHER NOTE
>
> Find an example from a science notebook that has arrows showing motion and possible forces acting on the basketball. You will use this sample, under the doc camera, to facilitate a discussion on what might be needed in a model to represent motion and possible forces acting on an object.

2. Have students look at the sample and ask: "What do you notice about this example that helps you understand what is happening in this drawing?"

   Leading Questions:

   "Is the object moving or not? How can you tell? How was this represented in this drawing?"

   "How are the arrows helping represent what this student observed?"

   "What is happening to the object?"

   "What caused it to move?"

   Expected Student Responses (ESRs):

   - *The object is moving because there are arrows showing the direction the object moves.*
   - *There was an explanation describing what was observed and why the object moved.*

3. Tell the class that they will be having more opportunities in this lesson to create models of their investigations, adding the details needed to represent their observations and explanations just like scientists.

> TEACHER NOTE
>
> Features of a model include identification and labeling of the parts, how the parts relate to one another, and how the model can be used to make a prediction or explanation. These features will be explored throughout the rest of the lesson using **3.2.C1: Observable Features of Models**.

4. Explain that in addition to explaining the things we can observe about movement, scientists often use models to help them think about and explain how movement works (cause and effect).

> **TEACHER NOTE**
>
> When thinking about force and motion, scientists use labels and arrows to show the direction of the force (cause) to an object and the strength of the force causing the object to remain in place or move (effect). They add supporting details to better explain what is happening.

5. Have the class look at the chart **3.1.C1: Basketball** from Lesson 1: Movement on the Playground. Explain that we can create a model of this basketball adding more details than we had on **3.1.H1: Motion Observation**.
6. Place a basketball in front of the class on a flat desk. Direct students not to touch the ball. Make sure it is stationary.
7. Direct students to observe the basketball, and in their science notebook make an initial model to describe what the ball is doing (not doing) and identify what they think might be causing it to do what it is doing (not doing).

> **TEACHER NOTE**
>
> Not all of the students were able to draw a basketball on **3.1.H1: Motion Observation**. This gives all students the opportunity to draw a model of a basketball. Encourage students who drew a basketball on **3.1.H1: Motion Observation** to transfer their model of the basketball from the ground onto a desk and label it.

8. Ask a few students to share their initial models and ideas with the class. "What detail or labels did you add to represent what you observed? What do you think is causing the basketball not to move?" *ESRs: I labeled the ball and the desk. The basketball is staying still on the desk. The basketball is not moving because no one is touching it.*

> **TEACHER NOTE**
>
> There will be many steps in the scaffolding of "creating a model" within this lesson. Students will be given multiple opportunities to revise and add to models throughout this lesson. Therefore, basic models without details representing or explaining cause-and-effect relationships are acceptable at this time.
>
> ▶ As students revise their models, notice how their thinking is changing both in terms of developing models (i.e., the observable features of models) and using models to describe the scientific concepts.

9. Explain that now they will make a model of the ball in motion. Ask a student to come to the front of the class and move the ball (without picking it up) across the desk until it falls off.

> **TEACHER NOTE**
>
> Encourage the student to push the ball so that it falls off the desk. This gives students the chance to add it falling in their model. At this time students might not mention gravity.

10. Direct students to observe the basketball and in their science notebook make an initial model to describe what the ball is doing (not doing) and identify what they think might be causing it to do what it is doing (not doing).

11. Look for sample models as students are drawing: look for samples where there is an arrow showing the ball being pushed; an arrow showing it traveling across the desk; an arrow pointing down when it falls off the desk; and notes of supporting details or explanations.

12. Have selected students present their models and have a class discussion about these models—asking if they think there are any more forces causing action on the ball. If they make suggestions, write them on the board.

> **TEACHER NOTE**
>
> Students should discuss *push* and *pull* which they learned in kindergarten. They may bring up the word *force*. If they do, you should discuss its meaning. If they don't bring up this word, you can use it in relation to their model by saying, "Do you know what a scientist calls a push or a pull? They are both called a *force*."
>
> Students are not expected to draw different size arrows to indicate the strength of the force at this time. Force/strength arrows will be added later in the lesson.

13. Call two students to the front of the classroom and ask them to extend one arm with their palm up. Place a basketball in each student's hand.

14. Ask the class to think about what forces are working on the basketball, based on what forces were evidenced acting on their basketball in their models:

    Leading Questions:

    "Is the basketball moving or not moving? Why?"

    "What forces might be causing the basketball to move or remain still?"

    "What can you say about the forces on each side of the basketball (top/bottom, side/side)?"

Expected Student Responses (ESRs):

- *The hand is sort of moving because the basketball is heavy, but the ball itself is not moving.*
- *Gravity is pulling on the basketball.*
- *His/Her hand is holding up the ball.*
- *There are no forces on the sides of the basketball.*

15. Challenge them to consider what is holding up the basketball and if there is anything pulling down on the basketball.

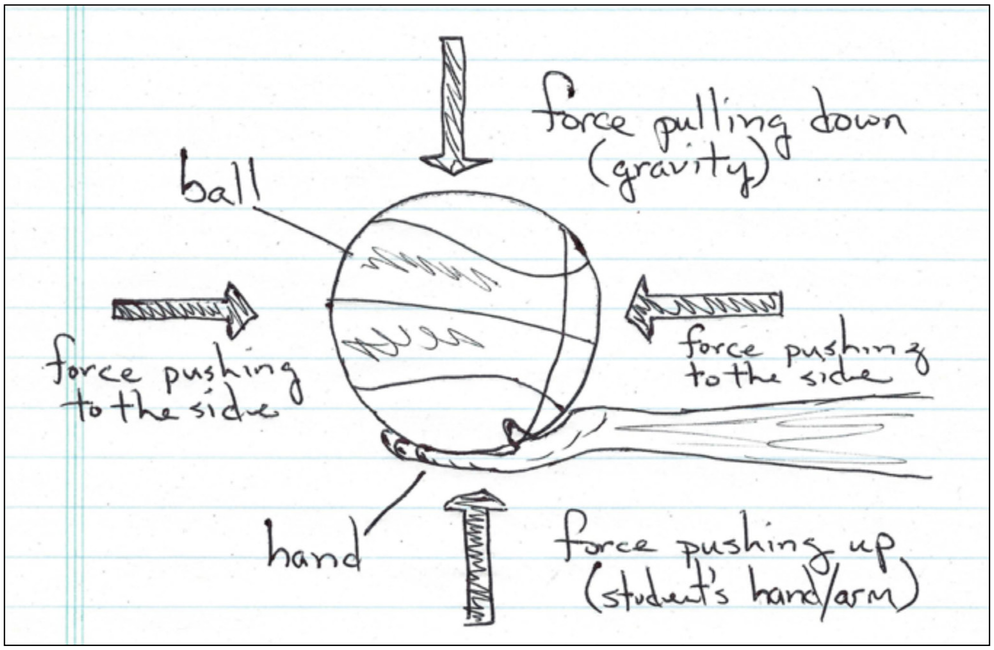
TEACHER NOTE

Students are not expected to be able to explain equal forces or gravity at this point, but it will be made explicit in the class model that follows. They may mention that a force is "pulling the ball down."

16. ▶ As a class, create a model of the forces acting on the basketball and write an explanation of what the forces are doing. Ask the class what should be included in the model. Chart their ideas on the Model chart you made in Advance Preparation and compare them to the characteristics that scientists use on **3.2.C1: Observable Features of Models**.

17. Based on their ideas, discuss the importance of making a drawing and labeling every part. They should label the ball and any forces acting on the ball.

Example of a Student Model



18. Discuss how they can indicate the relationships between the parts in their models. How did they show the upward force from their hand or downward force from gravity? What did they label to show the side forces? If these are not labeled, explain that models need to show invisible as well as visible components. How can they show that there are invisible sideway forces acting on the ball?

    Leading Questions:

    > “What forces might be causing the basketball to remain still? Is there only one force or many?”
    >
    > “What can you say about the forces on each side of the basketball (top/bottom, side/side)? Are they equal?”
    >
    > “How do these side/side forces relate to each other? Is one stronger or weaker than the other?”

    Expected Student Responses (ESRs):

    - *There are many forces acting on a ball when it is not moving*
    - *His/Her hand is holding the ball still.*
    - *His/Her hand is pushing up on the ball. Gravity is pulling down on the basketball so it is not moving.*
    - *There are the same forces on the sides of the basketball so it doesn’t move.*
    - *The forces on the sides are equal. They’re the same.*
    - *The forces are balanced all around.*

TEACHER NOTE

It is important for students to understand that an object at rest typically has multiple forces acting on it and that these forces are equal or balanced. Most likely students will use the word *equal*. If they do, introduce that equal forces are balanced. Use the leading questions above to facilitate this discussion.

19. Finally, discuss how the model could be used to explain their observations.
    Possible explanations include:

    - *Equal forces pushing up (arm) and pulling down (gravity) cause the forces on the ball to be balanced and the ball to stay still.*
    - *Equal forces pushing on the sides of the ball keep it balanced.*

20. Have students return to their model of the basketball on the desk. Explain that now, based on their class basketball model, they are to revise the model they made of the basketball 'at rest' on the desk. Have them consider what they can add (not erase) to their model focusing on explaining the cause and effect of the forces applied to the ball (upward force from the desk; pulling down force from gravity).

TEACHER NOTE

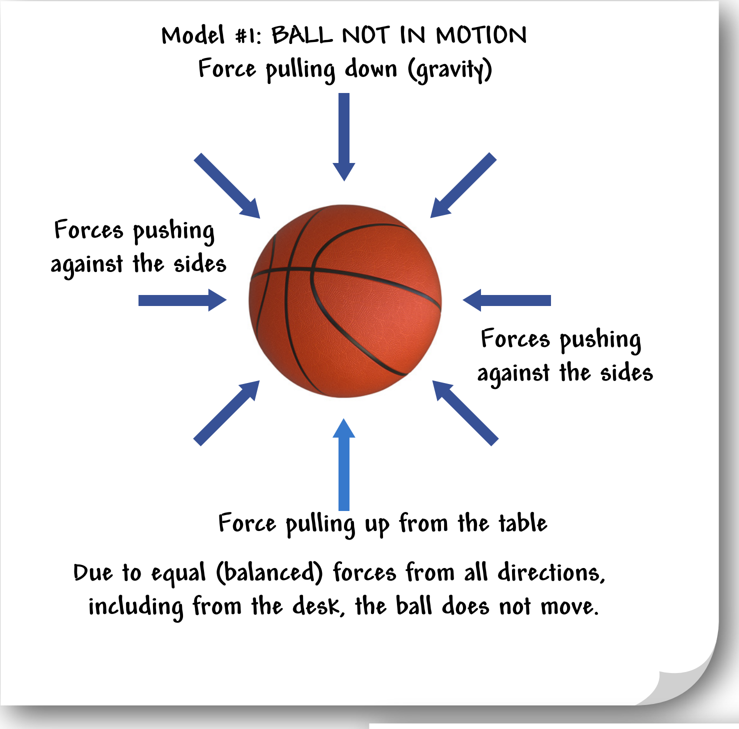
It is not necessary to explain gravity at this point (it will be explained at the middle school level). Only label it as the force that pulls down. Also, point out that it is a force that causes motion without contact.

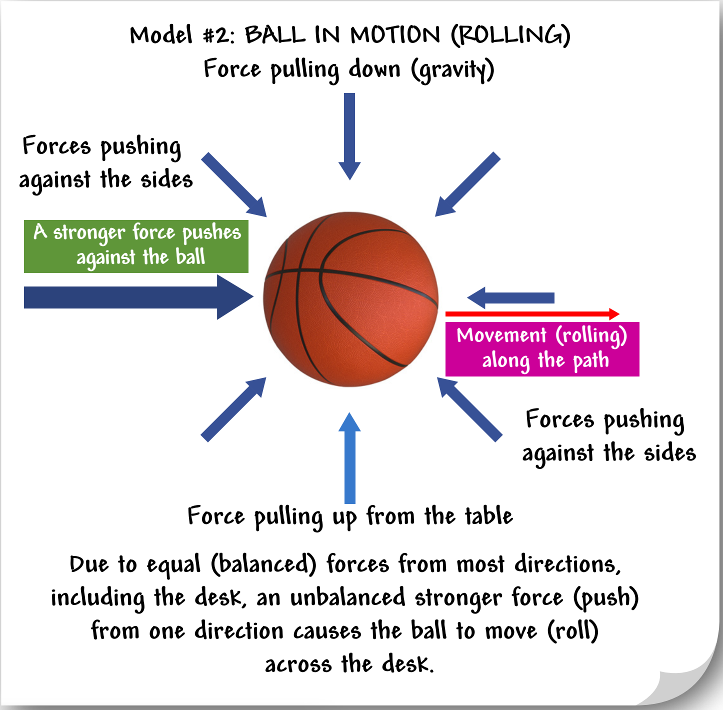
21. Explain that when the forces are equal the object is said to have a *net force of zero*, and there is no change in movement. Therefore, it is balanced.
22. Call two new students to the front of the classroom and ask them to extend one arm, with their palm up. Place a basketball in each student's hands.
23. Ask the class, "What will happen if the students drop their arms?" (*ESR: The basketball will fall*.) Have the students holding the balls drop their arms to demonstrate.

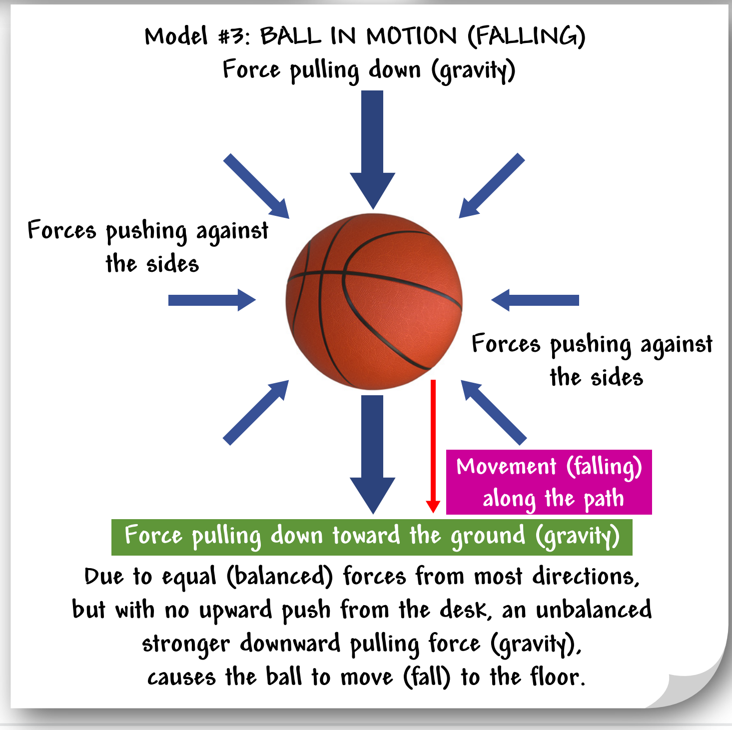
TEACHER NOTE

At this point label (or confirm) that the downward-pulling force is called gravity. Explain that this force pulls things down. Also, point out that gravity is a force that causes motion without contact.

24. Ask students to return to their earlier model about the basketball in motion (on the desk and falling off) and make revisions based on what they now understand about making a model that includes 'directional' and 'strength of a force' arrows. Suggest that students draw three models: model #1 is the basketball at rest; model #2 is the basketball moving across the desk, and model #3 is the basketball falling off the desk onto the floor.







25. Ask students to write an explanation of the changes in the motion of the basketball and the forces that caused those changes in the three models.

    Expected Student Responses (ESRs):

    - *In model #1 the ball is not moving because all of the forces (up and down; left and right) are balanced.*
    - *In model #2 the ball begins to move across the desk because of a student pushed it. The force from the left is stronger than the force from the right. This makes an unbalanced force that causes the ball to move to the right. So I put a strong arrow on the left of the ball to show the strength of the force moving it toward the right. I put another arrow to show the direction of the ball moving across the desk. The top and down forces are balanced, making the ball stay on the desk.*
    - *In model #3 the ball falls off the desk. I drew a directional arrow to show it falling off the desk. I also drew a strong down arrow and labeled it gravity. It is stronger than the upward force, which causes the forces to be unbalanced and the ball to fall down.*

26. Have several students share their models (on the doc camera). Discuss the models in terms of the drawing, labels, and explanations of the balanced and unbalanced forces that caused the movement.
27. Provide one more opportunity for students to revise their models based on the class discussion.
28. Ask students to self-assess their models using **3.2.C1: Observable Features of Models**. Did they include a drawing with labels? How did they indicate the relationship between the parts of the model? What were they able to explain about forces and motion using their model?
29. Have students think about the differences between the models they made of the basketball at rest and in motion. Discuss with a partner the relationship between cause and effect when the basketball doesn't move or moves in the models they made. Share a few comments.

Part II

Explore/Explain 1 (60–120 minutes)

Develop a model to describe movement on the playground, noting what causes the movement.

30. Remind students of their playground design challenge as they think about going outside to investigate how a basketball moves on the playground.
31. Have the class look at **3.1.C1: Basketball** from Lesson 1: Movement on the Playground. "Which questions can we investigate to gather evidence about force and motion? How can we use what we know from our models of basketball motion to apply to our new playground design?" Circle the questions the students want to investigate.

TEACHER NOTE

Make sure the circled questions support the students' understanding that the strength and direction of forces can cause a basketball to move and how balanced and unbalanced forces impact that motion. If the questions do not allow for this, add several of your own questions that do.

32. Divide the class into groups of 3–5 students. The groups will go to the basketball court to investigate one of the class questions. Give each group one question, and ask them to discuss what they will need to do outside to create a model that helps gather evidence to answer that question.
33. Have groups discuss what they will record on their individual model about the movement of the basketball (e.g., force of ball push, angle of ball travel). How does this help answer their question? Remind students that they will be using their observations to make a model of what they did to move the basketball. They will draw their model in their science notebook and write a description of the cause-and-effect relationship to change the ball from not moving to moving.
34. Take the class outside to the basketball court. Remind groups to take turns collecting evidence, making observations about the forces causing the movement of the basketball, and drawing individual models in their science notebook that they can contribute to their group model. The goal of this activity is to have students apply various amounts of force and direction to get the basketball into the basket and answer their question. *ESRs: Students make observations of the strength of the force applied to push the basketball towards the basket and that the basketball is pulled down.*

TEACHER NOTE

If your students are not ready to work independently, you may want to have one group model the activity while the other students record observations. Allow student teams to take turns with the activity.

TEACHER NOTE

If time, or lack of available playground equipment, does not allow for the class to participate with the basketball, you can show Boys Outside Shooting Hoops video instead. Stop the video at 20 seconds (repeat if necessary).

35. Allow groups 15 minutes on the playground to investigate the movement and create the models in their science notebook. Then return to the classroom.

36. Distribute chart paper or a whiteboard to each group and ask them to draw a group model of the evidence that supports their observations.
37. Remind students that their model must include:
    - arrows showing direction and strength
    - a written explanation of the basketball at rest
    - a written explanation of what caused the basketball to move
    - a written explanation and models showing the pattern of motion as evidence
    - the relationship of cause and effect related to the movement of the basketball
38. Conduct a science talk where each group presents its poster (one at a time) to the class. Encourage students to ask questions of the presenters about the models and the explanations.
39. In table groups, ask students to discuss what they noticed that was similar in all of the presentations about force and motion. Ask table groups to chart their ideas on Patterns chart you made in Advance Preparation. Look for the ideas that there were patterns in the movement; all involved balanced and unbalanced forces; forces have strength and direction; and the ball moves according to force strength and direction. If these ideas are not stated, add them to the chart.
40. Ask students to record these patterns about motion in their science notebook.

Part III

Explain 2 (10–20 minutes)

Obtain and communicate information describing characteristics of the cause and effects of force on motion.

41. Assign a reading from the Literacy Link list on page 3.2.16. Ask students to find sentences from the reading that add key details to their understanding of the characteristics of forces. Have students record these key details in their science notebook.

> **TEACHER NOTE**
>
> When selecting a book or reading passage from the recommended list:
>
> - choose one passage for all students OR
> - choose various 'leveled' passages based on student reading ability.

42. Have students share one of their sentences within their groups.

TEACHER NOTE

You may choose to have students share selected sentences with the whole class. Write them on sentence strips. Group similar sentence strips that support learning concepts on the wall as a visual summary of the reading. These can be referenced throughout subsequent lessons as needed.

Part IV

Elaborate (30–60 minutes)

Using the characteristics of forces and their effects on motion, design a solution for a new piece of playground equipment or activity.

43. Explain that students will now have an opportunity to apply what they know about basketball movement to their engineering design. Connect the patterns of motion that students wrote in their science notebook to the criteria list they created in Lesson 1: Movement on the Playground. Review design criteria (*must have motion; change in direction and strength of motion; pattern of predictability; balanced and unbalanced forces*).
44. Ask students to discuss with a partner, "How do we design activities or structures that are fun and allow for movement? How will the motion happen, and what patterns will I see in that motion? How can we use what we've learned about basketball to help explain our design?"
45. Tell the class that each set of partners will be given a paper cup and ping pong ball. They will have 15 minutes to create a smaller version of an activity or structure that would meet the criteria. They can only use one desktop as their "activity/structure" space. Students will be creating a model in their science notebook and sharing this model of their activity with another group. Remind students that models are used to help explain how movement works.

TEACHER NOTE

You may add any other constraints you want to this investigation.

46. After 15 minutes ask partners to trade their science notebook with another pair to provide feedback on their design models. Using sticky notes, students provide comments about student models and meeting criteria.

    Tell students, "With each science notebook you view, provide your classmate with feedback using a sticky note that uses one of these sentences":

    I agree with _____.

    I wonder _____.

    This makes me think _____.

    I disagree because _____.
47. Have students review feedback and make revisions to their model.

Part V

Evaluate (30 minutes)

Communicate information describing patterns of movement on the playground.

48. Assign students to write a paragraph stating why they agree and disagree with the statement, "An object always moves when a force acts on it." They must support their statement using evidence from the models they made in their investigations.

    If students need support, offer these sentence frames and word bank for those that need these supports:

    I agree that an object always moves when a force acts on it because ______.

    I disagree that an object always moves when a force acts on it because ______.

    Word Bank:

force	balanced or unbalanced
ball	equal
gravity	cause and effect

49. ▶ Collect paragraphs to evaluate student understanding. Use **3.2.R1: Rubric** to evaluate/assess how students applied their understanding of force and motion to answer the question.

    TEACHER NOTE

    The question is designed so that students who really understand force and motion would both agree and disagree with the statement based on balanced and unbalanced forces, and strength and direction of forces.

50. Close this lesson by referring the class back to **3.1.C1: Basketball** from Lesson 1: Movement on the Playground. Have students share any wonderings/questions that they had for which they now have explanations.

51. Ask the class to share any new wonderings they would like to add to the "Soccer" chart for their next investigation. Also add any questions that will help them gather evidence for their final design for the new playground or further their understanding of movement on the playground.

Literacy Links

- *Making Things Move: Force and Motion* by Adriana Frost
- *Give It a Push! Give It a Pull! A Look at Forces* by Jennifer Boothroyd
- *First Science: Motion* by Kay Manolis
- *Simply Science: Motion* by Melissa Stewart

ReadWorks (Online Passages available at www.readworks.org)

- *Will You Push or Pull?* (240L) (K level)
- *A Big Push* (320L) (K level)
- *What is Gravity?* (500L) (1st grade level)
- *Machines Can Move* (580L) (3rd grade level)
- *Famous Scientists Sir Isaac Newton* (560L) (3rd grade level)
- *The Motion of a Baseball* (900L) (5th grade level)
- *How Soccer Can Help Us Understand Physics* (1060L) (7th grade level)

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Toolbox Table of Contents

Observable Features of Models

- **Identification and labeling of the components (parts)**
- **How the components (parts) relate to one another**
- **How the model can be used to form an explanation or to make a prediction**

Rubric

An object always moves when a force acts on it.

	4	3	2	1
	agrees and disagrees with the statement	agrees or disagrees with the statement	agrees or disagrees with the statement	no response
Balanced and Unbalanced Forces	agrees because when the forces are unbalanced, the ball will move AND disagrees because if all the forces are balanced, the ball will not move	EITHER agrees because when the forces are unbalanced, the ball will move OR disagrees because if all the forces are balanced, the ball will not move	EITHER agrees because when if someone pushes it, the ball will move OR disagrees because if no one pushes the ball, it will not move	provides no “because” statement
Strength of Force	In my model if the unbalanced force is strong, the ball moves farther. AND In my model if the balanced forces are all equally strong, the ball won’t move.	EITHER In my model if the force is strong, the ball moves farther. OR In my model if the forces are all equally strong, the ball doesn’t move.	EITHER Strong pushes make the ball go far. OR Strong pushes on all sides will make the ball stay still and not move.	Hard goes far.
Cause and Effect (if the prompt was used, “because” should be addressed)	My models show that unbalanced forces cause the ball to move. AND My models show that balanced forces caused the ball not to move.	EITHER My models show that unbalanced forces cause the ball to move. OR My models show that balanced forces caused the ball not to move.	EITHER My models show that a push causes the ball to move. OR My models show that if no one gives the ball a push, the ball will not move.	My models show a push moves the ball and that no push makes the ball stay still and not move.

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
3-PS2-1	Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. [Clarification Statement: Examples could include an unbalanced force on one side of a ball can make it start moving; and, balanced forces pushing on a box from both sides will not produce any motion at all.] [*Assessment Boundary: Assessment is limited to one variable at a time: number, size, or direction of forces. Assessment does not include quantitative force size, only qualitative and relative. Assessment is limited to gravity being addressed as a force that pulls objects down.*]

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)
Developing and Using Models
• Collaboratively develop and/or revise a model based on evidence ~~that shows the relationships among variables for frequent and regular occurring events~~.
• Develop and/or use models to describe and/or predict phenomena.
Engaging in Argument from Evidence
• Construct an argument with evidence, data, and/or a model.

PS2.A FORCES AND MOTION
PS2.A: Forces and Motion
• Each force acts on one particular object and has both strength and a direction. ~~An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion~~.
PS2.B: Types of Interaction
• Objects in contact exert forces on each other.

Appendix 3.2

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Students routinely identify and test causal relationships and use these relationships to explain change. ~~They understand events that occur together with regularity might or might not signify a cause and effect relationship~~. (3–5 Progression)
Patterns
• Students identify similarities and differences in order to sort and classify natural objects and designed products.
• They identify patterns ~~related to time, including simple rates of change and cycles,~~ and to use these patterns to make predictions.

Common Core State Standards (CCSS)

CCSS ELA READING
CCSS.ELA-LITERACY.RI.3.1
~~Ask and~~ answer questions to demonstrate understanding of a text, referring explicitly to the text as the basis for the answers.
CCSS.ELA-LITERACY.RI.3.3
Describe the relationship between a series of historical events, scientific ideas or concepts, ~~or steps in technical procedures in a text,~~ using language that pertains to time, sequence, and cause/effect.
CCSS.ELA-LITERACY.RI.3.10
~~By the end of the year,~~ read and comprehend informational texts, including ~~history/social studies,~~ science, ~~and technical texts,~~ at the high end of the grades 2–3 text complexity band independently and proficiently.
CCSS ELA WRITING
CCSS.ELA-LITERACY.W.3.8
Recall information from experiences ~~or gather information from print and digital sources;~~ take brief notes on sources and sort evidence into provided categories.
CCSS ELA SPEAKING AND LISTENING
CCSS.ELA-LITERACY.SL.3.1
Engage effectively in a range of collaborative discussions ~~(one-on-one, in groups, and teacher-led)~~ with diverse partners on grade 3 topics and texts, building on others' ideas and expressing their own clearly.
CCSS.ELA-LITERACY.SL.3.4
Report on a topic or text, or recount an experience with appropriate facts and relevant, descriptive details, speaking clearly at an understandable level.

Appendix 3.2

California English Language Development (ELD) Standards

CA ELD		
Part 1.3.1 Exchanging information and ideas.		
EMERGING	**EXPANDING**	**BRIDGING**
Contribute to conversations and express ideas by asking and answering *yes-no* and *wh-* questions and responding using short phrases.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, and adding relevant information.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, adding relevant information, building on responses, and providing useful feedback.
In addition to the standard above, you may find that you also touch on the following standard in this lesson as well: **P1.3.9** Plan and deliver brief oral presentations on a variety of topics and content areas.		

Patterns in Motion

3.3

Image via iStock.com/franckreporter

Anchoring Phenomenon

Objects move in different ways during physical activities on the playground.

Lesson Concept

Analyze and interpret data to determine patterns and cause and effect to predict the motion of a soccer ball based on force strength and to apply the data to an engineering design.

Investigative Phenomenon

A kicked soccer ball on the playground didn't make it all the way into the goal.

Standards

Refer to Appendix 3.3 for NGSS, CCSS—ELA and Math, and California ELD standards.

Storyline Link

In Lesson 2: Forces Move Objects, students created models to show balanced and unbalanced forces based on knowledge gained through basketball experiences. Students investigated the effect of strength and direction on the speed and distance traveled by the basketball.

In this lesson, students build on these fundamental understandings of force and motion and apply them to a soccer ball. They analyze and interpret data about how the strength of the force impacts the distance the soccer ball moves. They apply the patterns of motion to predict team players and their success for a new soccer game for the new playground. In the next lesson, students continue to think about balanced and unbalanced forces as well as strength and direction as they complete a tug-of-war activity.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena or solving a problem.

Time

4 hours 45 minutes

Part I	30 minutes	Engage
Part II	45 minutes	Explore 1/Explain 1
Part IIIa	60 minutes	Explore 2/Explain 2
Part IIIb	45 minutes	Explore 3/Explain 3
Part IV	45 minutes	Explain 4
Part V	60 minutes	Elaborate/Evaluate

Materials

Whole Class

- ❑ Soccer ball(s) (or kickball)
- ❑ Soccer goal(s) (or two orange cones)
- ❑ 3.1.C2: Soccer (from Lesson 1: Movement on the Playground)
- ❑ 3.1.C3: Tug-of-war (from Lesson 1: Movement on the Playground)
- ❑ 3.3.C1: Class Data
- ❑ 3.3.C2: Even Chart

Groups (Groups of 3)

- ❑ Whiteboard and markers
- ❑ Poster board and markers
- ❑ Math counting manipulatives

Individual

- ❑ Science notebook
- ❑ 3.3.H1: Coach's Notes
- ❑ 3.3.H2: Data Table
- ❑ 3.3.H3: Even Table

Teacher

- ❑ 3.3.R1: Line Plot Example
- ❑ 3.3.R2: Possible Teams Combinations
- ❑ 3.3.R3: Evaluation Rubric
- ❑ TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf)
- ❑ Women's Soccer video (https://www.youtube.com/watch?v=rz1-SOk8PfE)
- ❑ Men's Soccer video (https://www.youtube.com/watch?v=OmKbGOARXao)

Advance Preparation

1. Gather materials and make a copy of **3.3.H1: Coach's Notes**, **3.3.H2: Data Table**, and **3.3.H3: Even Table** for each student.
2. Make large charts of **3.3.C1: Class Data** and **3.3.C2: Even Chart** or use them with a document camera.
3. Prepare a chart page with the title Soccer Ball Movement Prediction.
4. Have ready **3.1.C2: Soccer** and **3.1.C3: Tug-of-war** (from Lesson 1: Movement on the Playground).
5. Review TalkScience resource: (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf) to determine when best to use this resource in student-to-student discourse.

6 Review **3.3.R1: Line Plot Example**, **3.3.R2: Possible Teams Combinations**, and **3.3.R3: Evaluation Rubric**.

7. Review these videos to see an example of a 4-touch soccer goal: Women's Soccer video 0:17–0:27 or 1:54–2:04 and Men's Soccer video 0:48–0:55.

Procedure

Part I

Engage (30 minutes)

Communicate information about how unbalanced forces move a basketball and how the same cause and effect can predict movement in a soccer ball.

1. Have students work in pairs to review their evidence from their science notebook about why a basketball sitting on a person's hand doesn't move and what has to happen to make it move.

   Expected Student Responses (ESRs):

   - *I learned that there are many forces acting on the basketball.*
   - *I learned that a basketball sitting on my hand doesn't move because all the forces around it are even. But if I drop my hand, the forces are not balanced, and the force (gravity) pulls the ball to the ground.*
   - *I learned when I throw the ball, I unbalance the forces to make it move.*
   - *If I throw hard, that is pushing the ball, and the ball will go farther.*
   - *From my evidence, I learned that other forces can change the direction the ball moves by pushing or pulling it.*

2. Show the students a soccer ball. Conduct a brief conversation about how soccer is played. Review **3.1.C2: Soccer** (from Lesson 1: Movement on the Playground). Ask, "What were some of our questions and wonderings we hope to answer today?"

   TEACHER NOTE

   If your students do not know about soccer, explain the game to them by showing one of the video clips of a soccer game (Step 7 in Advance Preparation) so that they understand the game.

3. Have student pairs discuss what they can predict about how a soccer ball moves compared to how a basketball moves. Have several partners share their ideas and chart their responses on **3.1.C2: Soccer**. *ESRs:*

   - *They are both balls, so I think if the soccer ball is just sitting there, it will not move (just like the basketball did not move) when the forces are balanced.*
   - *I think the soccer ball will move, speed up, or change direction when the forces are unbalanced.*
   - *In basketball, we use our hands to unbalance the forces to move the ball, and in soccer, we use our feet to do the same thing.*
   - *In basketball I push with my hands; in soccer, I push (kick) with my feet. In both, I unbalance the force to make the ball move.*

- *Just like in basketball, if I push the soccer ball harder, it will go farther.*
- *In both soccer and basketball, I can change the direction of the ball's movement by pushing or pulling it.*

4. Review **3.1.C2: Soccer**, focusing on what the predicted movement of the soccer ball was and how it would happen.

Part II

Explore 1/Explain 1 (45 minutes)

Make observations to determine the types of data and patterns that are needed to design a new soccer game.

5. Remind students that they will be working on designing the new playground. Tell them, "Yesterday we worked on making a prototype for the basketball game using ping-pong balls. Today we are going to be working on a soccer prototype. Space will be limited for soccer, so the new soccer game is called touch soccer. In this game, four players must pass the ball in order to get it into the goal. Each person can only kick a certain distance."
6. Ask the students, "Using what you know about forces and movement, what data would you need to collect to design this new game?" Give students 30 seconds to think to themselves. Then have students pair-share their ideas. Select a few students to share with the class. Chart their ideas. *ESRs: How big is the field? How far can each person kick? Can they kick in any direction they want? How many defenders will try to get the ball away from the player?*
7. Explain to students that they will have an opportunity to try out this new game. Remind students they will be in teams of four. Their job is to pass the ball to each person once (for a total of four touches) before the ball is kicked into the goal. They will try the game several times and then will return to the classroom to add to their list of data they need to analyze to create the game for the new playground.

TEACHER NOTE

Set up two or three different soccer goals. Place each soccer ball in a different location 50 feet from the goal. If you don't have a soccer ball, a kickball will work. If you don't have a soccer goal, you can use two orange cones, two small trash cans, two brightly colored sticks, or anything else to create goalposts for the students to kick the ball between.

8. Go outside with the students. Ask one group to play the game while the other students watch. Have the kicker start at the 50 feet mark and as a team of four, move the ball to the goal marks. Tell observers to watch for use of strength, direction, and balanced and unbalanced forces.
9. Allow all groups to play, reminding students to think about what other data they will need to analyze before they can engineer the new game.

10. Bring students back into the classroom and have teams debrief their play. Ask them to consider what additional data they need to add to their chart. Add to the chart as they share. *ESRs:*
    - *What is the amount of force each person needs to do for four touches to go into goal?*
    - *How does the change in direction affect the distance the ball has to go to reach the goal?*
    - *Is the movement better if each player balances the forces on the ball by stopping it before they kick, or should they kick it when it is still moving?*
    - *Does it matter in what order the players move the ball?*
    - *How can we draw a diagram that will show the movement of the ball?*

Part IIIa

Explore 2/Explain 2 (60 minutes)

Represent data in tables to find patterns in the strength of a kick (force) on the soccer ball.

11. Say to the class, “In order to determine the engineering design for the new soccer game, we need to gather data. One of the questions we wanted to answer was, ‘What is the amount of force each person needs to make four touches into the goal?’”
12. Distribute **3.3.H1: Coach’s Notes**. Explain that this data came from a coach who tested 18 players about how far they can kick a soccer ball that is on the ground and not moving. Each player was given 3 chances to kick the ball.
13. Have student pairs discuss what they think they should do with this data and why. Have a couple of partners share. Listen for students’ ideas about organizing the data so that it is easier to understand. Ask students to determine good ways to organize the data. Hopefully, students will say to put the data into a table.

> **TEACHER NOTE**
>
> If this is the first time students are converting raw data into a table, model how to create a table with a title and labeled columns. In this case, the labeled columns are: name, distanced (yards) traveled in kick #1, distance (yards) traveled in kick #2, distance (yards) traveled in kick #3.

14. Distribute **3.3.H2: Data Table**. Divide the list of 18 players into groups of 3 players (i.e. 1–3, 4–6; 7–9; 10–12; 13–15; 16–18) and assign one group of 3 to each set of partners. It is ok if there are multiple assignments to the same group. Have partners complete their **3.3.H2: Data Table** using **3.3.H1: Coach’s Notes** for their players.

TEACHER NOTE

Alternatively, have students create their own data table to enter the data. Then select a few to put under the doc camera to discuss the variety of formats, entries on the data table, and what the tables reveals about patterns.

15. Display **3.3.C1: Class Data** on the document camera and ask different partner groups to fill in the data for their players. Ask the rest of the students to complete their **3.3.H2: Data Table**, using the data on the class chart. If there are several groups working on the same people's data, ask probing questions to make sure their data entries are the same.

16. Conduct a discussion about **3.3.C1: Class Data**. Ask these questions for student discussion:

    - "How easy is it to find patterns in what is displayed in the table?"
    - "Which of the three kicks should we use? Why?"
    - "Will that person kick the same way every time?"
    - "If the person was allowed a fourth kick, how far do you predict the ball would go? Why?"

TEACHER NOTE

This discussion is trying to give students an intuitive sense of what an average is. Averaging is a sixth-grade CCSS, and third graders are not expected to calculate it. However, in real life, they have probably heard the term (e.g., in sports) and through a discussion of analyzing data, students can understand that they could "even" up the kicking distances.

17. Distribute **3.3.H3: Even Table**. Continue with the same groupings as in Step 14. It is ok to have multiple partners looking at the same kickers. Give partners math counting manipulatives and ask them to put the length kicked by each person into a pile, and then "even" the three piles. Have them enter the number on the "even" column on **3.3.H3: Even Table**. Then call on partner groups to enter their data on **3.3.C2: Even Chart** on the document camera. As students enter their data, ask other students to complete their **3.3.H3: Even Table**. If there are several groups working on the same people's data, ask probing questions to make sure their data entries are the same.

TEACHER NOTE

If students don't understand, work an example with them:

Miquel kicks 20 feet, 19 feet and 18 feet. To make them three lengths even, you can take one of the 20 math counting manipulatives and put it on the 18 pile. Now all three piles are even, so the number in the "even" column would be 19.

The answers are in the "average" column on **3.3.R2: Possible Team Combinations**.

18. Use **3.3.C2: Even Chart** to ask students: "What patterns do you see in the "even" column? Why are there differences in the distances the ball traveled? (Some people kicked with a stronger force). Why is the "even" number an important data point?" *ESR: You can predict that a strong force will move the ball farther, but it is hard to predict the exact distance—the "even" number gives an approximate distance.*

> **TEACHER NOTE**
>
> This discussion is important for students to understand the importance of conducting multiple trials. Scientists will look for patterns in the data collected. Patterns can be used as evidence to support an explanation.

Part IIIb

Explore 3/ Explain 3 (45 minutes)

Represent data in a graph to find patterns in the strength of a kick (force) on the soccer ball.

19. Ask students if they know a better way to display the data that might show the patterns more easily. Hopefully, they will suggest graphing. If not, explain that scientists graph data to find patterns.
20. Ask table groups to use their whiteboards to graph their data and look for any patterns. Circulate to monitor students as they complete the line plot.

> **TEACHER NOTE**
>
> If students have little experience with graphing, it is important to take the time here to discuss different types of graphs (e.g., bar, line, pie, line plots) and help students understand that this data is best displayed as a line plot because it is comparing categories (yards the ball traveled and the number of people who kicked that far).
>
> See **3.3.R1: Line Plot Example**. Model setting up the graph with a title and labeling the axis, etc. For this graph, the horizontal axis (the x-axis) is labeled with the number of yards the ball traveled and the vertical axis (the y-axis) is the number of people who kicked at that distance.

21. Select table groups to display their graph and explain any patterns that they noticed. "How does the pattern indicate a relationship between the strength of a force and distance the ball travels?" If a pattern was already mentioned, ask the group to find another pattern or share something else that was interesting on the graph. *ESRs: no one kicked less than 8 yards; no one kicked more than 23 yards; the distance that the most number of people kicked was 19 yards—4 people could do that.*

22. Ask partners to summarize what they learned by creating a data table and graphing the data to explain force and motion. Have several partners share their ideas. Then ask each student to write their idea(s) in their science notebook. *ESRs:*
    - *Putting the data in a table made it more organized.*
    - *Graphing the data showed some patterns as to who could kick certain distances.*
    - *I knew that to move the soccer ball, people had to unbalance the forces by kicking (pushing) the ball.*
    - *I knew the harder the person kicked (the more strength of the force) caused the ball to travel farther.*
    - *I knew if the kick was a weak force, the ball didn't travel as far.*
    - *I predicted that a ball that traveled a shorter distance was caused by a weaker kick.*
    - *I predicted that a ball that traveled farther was caused by a stronger kick.*
    - *Not everyone kicked the ball as hard so the ball traveled different distances.*

Part IV

Explain 4 (45 minutes)

Analyze and interpret patterns in data to predict how to play the game using logic and mathematics.

23. Now that the students have some understanding about force on the motion of a soccer ball as well as how to predict its movement, they are ready to try a prototype design for the new touch soccer game. Tell students," The field size of a soccer field for 9 year olds might be 40 yards long. Your challenge is to select 4 players for your team. These are the rules:
    1. Start at the end line (the line on the opposite side of the field) and get the soccer ball to the goal.
    2. Use 4 players listed on **3.3.H1: Coach's Notes** and assume they will kick their 'even or average' distance.
    3. Create a least one change in direction.
    4. The ball will start not in motion (balanced force).

TEACHER NOTE

The shortest distance between two points is a straight line. Any path that is not a straight line (has a change of direction) is more than the distance to the goal. Students should focus on how to select the teams that can kick more than 40 yards to accommodate the change in direction; for example, they may need to kick a total of 50 yards to complete the task.

See **3.3.R2: Possible Team Combinations** as an example of possible teams to kick at 50 and 70 yards. These are not the only combinations that work.

24. Working in table groups of four, have students discuss, “Who would you select to be on a team? Why did you choose them? What can you predict about how the ball will be kicked?”
25. Ask table groups to draw on a whiteboard the movement of the ball using the size of arrows to denote the strength of the kick (force) from person to person and into the goal. Have them discuss if the order of the kickers matters or if the direction of the kick matters. What is their evidence for their decisions?
26. As students work, walk around the room, and select several tables to share their plan with the whole class. Pick different team selections and different strategies so that students can compare plans. As table groups share, have other table groups listen and ask questions about the plan. After each group shares, have the class determine what is similar and what is different in the plans. Make sure to explore these ideas: Does the order of the kickers matter and "How does the change of direction affect the distance."
27. Conduct a whole-class discussion using these questions: “What were important patterns of movement to consider in deciding who to put on the team? What patterns of strength were important to reach the goal? What patterns of less-strong kicks were evident? Why do these patterns matter?” *ESRs:*
    - *We had to look for a pattern in how the force moved the ball (how far people kicked the ball).*
    - *The pattern had to contain either a combination of all strong forces (kickers), or some strong and some not so strong.*
    - *If the pattern was only less-strong forces (kicks), we couldn’t reach the goal.*
    - *Patterns matter to predict the best team.*
    - *Cause and effect make up the patterns—if the player uses a strong force when kicking, the ball will go farther; the player uses a weak force when kicking, the ball will not travel as far.*
    - *Predictions help determine the team, but the players might not do what was predicted.*

Part V

Elaborate/Evaluate (60 minutes)

Communicate information about how the cause and effect of the strength of forces can be predicted and used to design a new soccer game.

28. Tell the whole class, “Good news! The new playground will provide for a soccer field that is 70 yards rather than 40. And there is a new rule. The ball needs to reach the goal which is 70 yards from the end line only this time without a change in direction. You also want the ball to just get to the goal line—not past the goal line. Working with a partner, determine if and how this changes who is on a team and why it matters.”
29. Have partners share at their table, and then have several tables share their ideas. *ESRs:*
    - *We need to select players who can provide a strong force when kicking the ball.*
    - *We must look at the data to find a pattern in the kickers and predict that a certain combination will move the ball exactly 70 yards.*

- *Patterns matter to predict the best team.*
- *Cause and effect make up the patterns—if the player uses a strong force when kicking, the ball will go farther; the player uses a weak force when kicking, the ball will not travel as far.*

30. Tell students that as an engineer, they will need to apply the claims and evidence that science provides for their design. Explain that when scientists observe patterns in data, they can make a claim that answers a question. Our question is: "How much force is needed in 4-touch soccer to get the ball into the goal?"
31. Based on their data from the players, their prototype teams for the 40-yard game, and their ideas for the 70-yard game, pose this question: "What claims can you make about the science behind force and motion of a soccer ball?"
32. Ask students to individually write a claim in their science notebook. *ESRs:*
    - *A greater force is needed to kick the ball a farther distance.*
    - *A combination of forces (kicks) is needed to get the ball into the goal whether the goal is 40 or 70 yards away.*
    - *If there is a weak kick (lesser force), the ball will not roll as far.*
    - *I can predict the movement of the ball based on the strength of the force. A weak force doesn't move the ball far; a strong force makes the ball move farther.*
33. Have students share their ideas in the table groups.
34. Then tell the class, "Newsflash! The soccer field can now be 80 yards, and there can be different rules (e.g., a 5-touch game). Ask the table groups to:
    - write the rules of their game.
    - select a team that can accomplish making a goal and explain why you choose those players.
    - draw a diagram of the possible plan using your five players.
    - describe the execution of their plan in terms of balanced and unbalanced forces; strength of force; changes in direction; and how motion can be predicted.

Sample student work:

We predict we will need the strongest kickers.

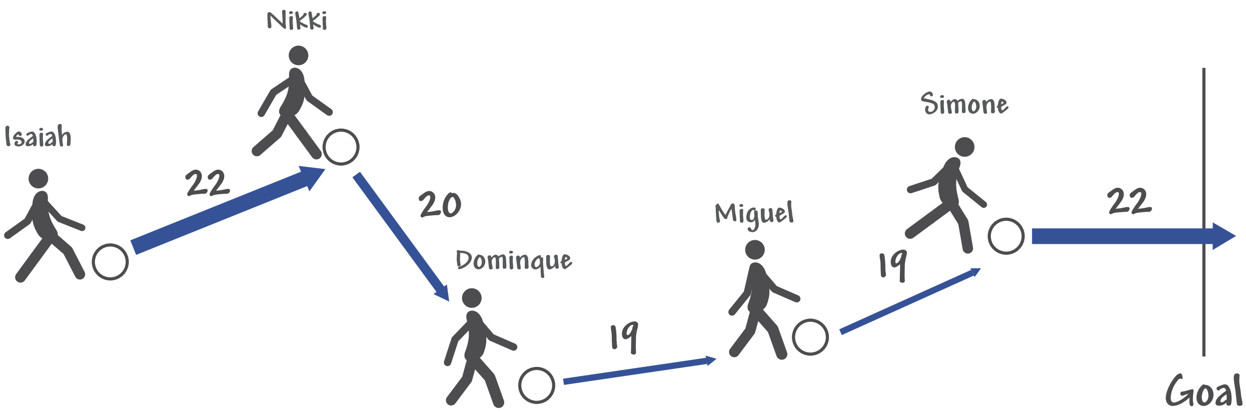
Possible players

Isaiah	22 yards
Nikki	20 yards
Simone	22 yards
Miguel	19 yards
Dominque	19 yards
	102 yards

Rules for 5-touch:

- Use 5 players, each who touches the ball once.
- The ball must change direction at least once
- The total yards the ball travels can be more than 80 yds but not less than 80 yds.
- The ball starts at rest—the forces are balanced.

Goal: Needs 5 players who can kick (unbalanced force) the ball with greater strength to make it go further. The ball starts at rest (balanced force). The five kicks (unbalanced force) must add up to more than 80 yards with the changes in direction.



Position of players to achieve the ball traveling more than 80 yards with the change in direction along with a change in motion.

Considerations

- Use the rules we stated—strength of the forces causes the ball to go farther
- Need a field that is about 80 yards long, but because of change the direction, our ball just needs to go over 80 yards. The field can be narrow but still allow the ball to change directions.

35. ▶ Have table groups share their ideas. Use **3.3.R3: Evaluation Rubric** to evaluate/assess how they applied their understanding of analyzing data, force and motion, cause and effect to their new game rules.
36. Close this lesson by referring the class back to the **3.1.C2: Soccer** chart. Have students identify any wonderings/questions for which they now have explanations.
37. Ask the class to share any new wonderings they would like to add to **3.1.C3: Tug-of-war** chart for their next investigation. Add any questions that will help them gather evidence for their final design for the new playground or further their understanding of movement on the playground.

Toolbox Table of Contents

Class Data

	Player	Yards Traveled			
		1st Kick	2nd Kick	3rd Kick	
1	Keaton				
2	Emmet				
3	Miguel				
4	Sierra				
5	Juan				
6	Dominque				
7	Ori				
8	Athena				
9	Bo				
10	Isaiah				
11	Erin				
12	Nikki				
13	Charly				
14	Gabby				
15	Oliver				
16	Simone				
17	Jesse				
18	Antonio				

Even Chart

	Player	Yards Traveled			
		1st Kick	2nd Kick	3rd Kick	Even Pile
1	Keaton	12	12	12	
2	Emmet	15	13	20	
3	Miguel	20	19	18	
4	Sierra	12	9	12	
5	Juan	11	13	15	
6	Dominque	16	20	21	
7	Ori	11	10	9	
8	Athena	15	10	11	
9	Bo	10	10	13	
10	Isaiah	20	22	24	
11	Erin	15	18	16	
12	Nikki	22	18	20	
13	Charly	10	13	16	
14	Gabby	16	16	16	
15	Oliver	10	11	12	
16	Simone	24	20	22	
17	Jesse	11	9	10	
18	Antonio	14	15	16	

Coach's Notes

Keaton: 12, 12, 12; Emmet 15, 13, 20; Miguel 20, 19, 18;

Sierra 12, 9, 12; Juan 11, 13, 15; Dominique 16, 20, 21;

Ori 11, 19, 9; Athena 15, 10, 11; Bo 10, 10, 13;

Isaiah 20, 22, 24; Erin 15, 18, 18; Nikki 22,18, 20;

Charly 10, 13, 16; Gabby 16, 16, 16; Oliver 10, 11, 12;

Simone 24, 20, 22; Jesse 11, 9, 10; Antonio 14, 15, 16;

Class Data

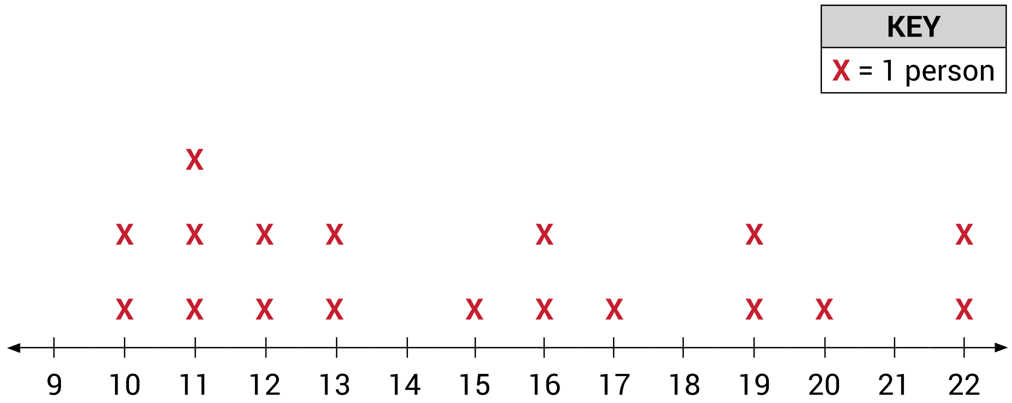
	Player	Yards Traveled			
		1st Kick	2nd Kick	3rd Kick	
1	Keaton				
2	Emmet				
3	Miguel				
4	Sierra				
5	Juan				
6	Dominque				
7	Ori				
8	Athena				
9	Bo				
10	Isaiah				
11	Erin				
12	Nikki				
13	Charly				
14	Gabby				
15	Oliver				
16	Simone				
17	Jesse				
18	Antonio				

Even Table

	Player	Yards Traveled			
		1st Kick	2nd Kick	3rd Kick	Even Pile
1	Keaton	12	12	12	
2	Emmet	15	13	20	
3	Miguel	20	19	18	
4	Sierra	12	9	12	
5	Juan	11	13	15	
6	Dominque	16	20	21	
7	Ori	11	10	9	
8	Athena	15	10	11	
9	Bo	10	10	13	
10	Isaiah	20	22	24	
11	Erin	15	18	16	
12	Nikki	22	18	20	
13	Charly	10	13	16	
14	Gabby	16	16	16	
15	Oliver	10	11	12	
16	Simone	24	20	22	
17	Jesse	11	9	10	
18	Antonio	14	15	16	

Line Plot Example

Average Yards Kicked Ball Traveled



Possible Team Combinations

Player		Yards Kicked							
		1st Kick	2nd Kick	3rd Kick	TOTAL	AVERAGE	70-yard game	Average	40-yard game
1	Keaton	12	12	12	36	12		12	51
2	Emmet	15	13	20	48	16	70		
3	Miguel	20	19	18	57	19			
4	Sierra	12	9	12	33	11		11	
5	Juan	11	13	15	39	13		13	
6	Dominque	16	20	21	57	19			
7	Ori	11	10	9	30	10		10	
8	Athena	15	10	11	36	12		12	
9	Bo	10	10	13	33	11			
10	Isaiah	20	22	24	66	22			
11	Erin	15	18	18	51	17		17	52
12	Nikki	22	18	20	60	20	70		
13	Charly	10	13	16	39	13		13	
14	Gabby	16	16	16	48	16			
15	Oliver	10	11	12	33	11			
16	Simone	24	20	22	66	22			
17	Jesse	11	9	10	30	10			
18	Antonio	14	15	16	45	15		15	

Evaluation Rubric

Component	4	3	2	1
Force and motion	Explanation included: • the use of balanced forces to explain the soccer ball at rest and unbalanced forces to move the ball • the strength of the force (kick) determined the distance the ball traveled • use of data to predict what types of kicks (force) was needed to score the goal with 5 people	Explanation included: • forces were unbalanced to move the ball • the strength of the force (kick) determined the distance the ball traveled • use of data to predict what types of kicks (force) was needed to score the goal	Explanation included: • forces moved the ball • strength of kick determine how far it went	Explanation included: • the kick was a push that moved the ball • a hard kick moved the ball better
Analyze and interpret data	• used data from tables and graphs to select a team capable of scoring at 80 yards • explained the selection of teams based on the strength of their force (kicks) to make the goal in 5 touches	• used data from tables or graphs to select a team capable of scoring at 80 yards • explained the selection of teams based on the strength of their force (kicks) to make the goal	• indicated data but did not use reasoning to make an explanation	• did not use data in their explanation
Cause and effect	A statement which included: • how the strength of the force affected the distance that the ball traveled • the selection of team distances affected whether or not the ball traveled 80 yards and how it relates to the game.	A statement which included: • how the strength of the force affected the distance that the ball traveled • a mention of cause and effect and how it relates to the game.	A statement which included: • a mention of cause and effect but not related to their game.	Their statement did not relate to patterns or cause and effect.

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
3-PS2-2	Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion. [Clarification Statement: Examples of motion with a predictable pattern could include a child swinging in a swing, a ball rolling back and forth in a bowl, and two children on a see-saw.] [*Assessment Boundary: Assessment does not include technical terms such as period and frequency.*]

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)
Analyzing and Interpreting Data
• Represent data in tables and/or various graphical displays (ex: bar graphs) to reveal patterns that indicate relationships.
• Analyze and interpret data to make sense of phenomena using logical reasoning, mathematics, and /or computation.
• Analyze data to refine a problem statement or the design of a proposed object, tool, or process.

DISCIPLINARY CORE IDEAS (DCI)
PS2.A: Forces and Motion
• Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's distance speed or direction of motion.
• The patterns of an object's motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it.

CROSSCUTTING CONCEPTS (CCC)
Patterns
• Patterns of change can be used to make predictions.
Cause and Effect
• Causes and effect relationships are routinely identified, tested, and used to explain change.

Appendix 3.3

Common Core State Standards (CCSS)

CCSS ELA SPEAKING AND LISTENING
CCSS.ELA-LITERACY. SL.3.1 Engage effectively in a range of collaborative discussions ~~(one-on-one, in groups, and teacher-led)~~ with diverse partners on *grade 3 topics and texts*, building on others' ideas and expressing their own clearly.
CCSS MATHEMATICS MEASUREMENT AND DATA
3.MD.B.4: Represent and interpret data. Generate measurement data by measuring lengths using rulers marked with halves and fourths of an inch. ~~Show the data by making a line plot, where the horizontal scale is marked o" in appropriate units—whole numbers, halves, or quarters.~~
3.MD.B.3: Represent and interpret data. Draw a scaled picture graph and a scaled bar graph to represent a data set with several categories. ~~Solve one- and two-step "how many more" and "how many less" problems using information presented in scaled bar graphs.~~

California English Language Development (ELD) Standards

CA ELD		
Part 1.3.1 Exchanging information and ideas.		
EMERGING	**EXPANDING**	**BRIDGING**
Contribute to conversations and express ideas by asking and answering *yes-no* and *wh-* questions and responding using short phrases.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, and adding relevant information.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, adding relevant information, building on responses, and providing useful feedback.
In addition to the standard above, you may find that you also touch on the following standard in this lesson as well: **P1.3.9** Plan and deliver brief oral presentations on a variety of topics and content areas.		

Balanced and Unbalanced Forces

3.4

Image via iStock.com/Wavebreakmedia

Anchoring Phenomenon

Objects move in different ways during physical activities on the playground.

Lesson Concept

Plan and conduct an investigation of the effects of balanced and unbalanced forces in a tug-of-war.

Investigative Phenomenon

Small children on the playground win a tug-of-war challenge against a group of bigger children.

Standards

Refer to Appendix 3.4 for NGSS, CCSS—ELA, and California ELD standards.

Storyline Link

In Lesson 3: Patterns in Motion, students continued to build on their fundamental understandings of force and motion with a soccer ball. They analyzed and interpreted data about how the strength of an unbalanced force impacts the distance the object moves.

In this lesson, the students work with a non-ball example (tug-of-war) to continue to explore the cause and effect of balanced and unbalanced forces on an object in addition to the effects of the strength and direction of the force. They apply that understanding to the design of the playground. In the next lesson, students apply their learning from the basketball, soccer, and tug-of-war games to design a new activity for the redesigned playground.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena or solving a problem.

Time

6 hours and 15 minutes (5–6 days to complete)

Part I	40 minutes	Engage
Part IIa	45 minutes	Explore 1
Part IIb	60 minutes	Explore 2/Explain 1
Part IIc	20 minutes	Explore 3/Explain 2
Part IId	60 minutes	Explore 4/Explain 3
Part III	60 minutes	Explain 4
Part IV	90 minutes	Elaborate/Evaluate

Materials

Whole class

- ❑ Tug of War video (https://www.youtube.com/watch?v=gSZCZ0UuI10)
- ❑ Unbalanced Force video (https://study.com/academy/lesson/unbalanced-force-definition-example-quiz.html)
- ❑ 2 Ropes for tug-of-war
- ❑ Large whiteboards for each table group (markers and erasers) OR poster paper
- ❑ 3.1.C3: Tug-of-war (from Lesson 1: Movement on the Playground)
- ❑ 3.2.C1: Observable Features of Models (from Lesson 2: Forces Move Objects)
- ❑ 3.4.C1: Number of Students Class Data Table
- ❑ 3.4.C2: Strength Class Data Table
- ❑ 3.4.C3: New Game Direction Rules

Optional

- A Force is a Push or Pull video (https://goo.gl/3xQVVz)
- PhET Forces & Motion simulation (https://phet.colorado.edu/en/simulation/legacy/forces-and-motion)

Individual

- Science notebook
- Sticky notes
- 3.4.H1: Number of Students Data Table
- 3.4.H2: Strength Data Table

Teacher

- TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf)

Advance Preparation

1. Prepare two sturdy ropes with a marker in the middle. Tie grip knots every 2 to 2.5 feet for controlled spacing and reduced slippage (which will cause rope burns).
2. Preview the Tug of War video (https://www.youtube.com/watch?v=gSZCZ0UuI10)
3. Preview the Unbalanced Force video (https://study.com/academy/lesson/unbalanced-force-definition-example-quiz.html) **STOP AT 1:15** (*after the forces in many directions acting on the barrel*). The rest of the video covers middle-school concepts.
4. Find **3.2.C1: Observable Features of Models** (from Lesson 2: Forces Move Objects). (It should be still up on the wall.)
5. Print out **3.4.C1: Number of Students Class Data Table**, **3.4.C2: Strength Class Data Table**, and **3.4.C3: New Game Direction Rules** to use with the document camera or make a chart.
6. Make copies of **3.4.H1: Number of Students Data Table** and **3.4.H2: Strength Data Table**.
7. Review TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf) to determine when best to use this resource for student-to-student discourse.

Procedure

Part I

Engage (40 minutes)

Relate information about forces and motion in balls to non-ball objects and observe the cause and effect of a tug-of-war.

1. ▶ Pair students and ask them to review the big ideas they have learned about force and motion using a basketball and a soccer ball. Have several partners share. *ESRs: Objects have forces acting on them. If the forces are balanced, the object does what it was doing (if still, it remains still; if moving, remains moving). If the forces are unbalanced, it will cause a change in the ball's speed or direction. Forces have strength and direction; we can predict future motion by looking at patterns.*
2. Tell students, "We have talked about forces on balls. What other objects are on the playground are not balls, but involve motion? *ESRs: swings; slides; see-saws, monkey bars.*

TEACHER NOTE

In this lesson, the students work with a non-ball example (tug-of-war) to continue to explore the cause and effect of balanced and unbalanced forces on an object in addition to the strength and direction of the force. This reinforcement of the basic concepts of force and motion provides struggling students with additional opportunities to make sense of the experiences they had in the first two lessons. Tug-of-war is a physical demonstration of balanced and unbalanced forces.

3. Show the students the rope. Ask if any one has any ideas about how this object can be used to show motion. Take a couple of ideas, and if necessary, introduce the game of tug-of-war. Have students discuss in pairs how their ideas of force and motion might work in a tug-of-war. Ask a couple of partners to share their ideas.

   Expected Student Responses (ESRs):

   - *Big kids can pull the rope harder and win.*
   - *Little kids can't pull the rope as hard.*
   - *A team has to unbalance the force to move the marker across the line.*
   - *The number of kids on each side matters to make it balanced.*
4. Say, "Let's see if any of our ideas happen in a tug-of-war." Play the Tug of War video and stop it at 10 seconds. Ask students to predict what is happening on both sides. Have them write their ideas in their science notebook.
5. Continue to play the Tug of War video and stop at 36 seconds. Ask students to predict who/what is on the other side of the rope and write their ideas in their science notebook.

6. Continue to play the Tug of War video to the end. Ask students to write any questions they have about this phenomenon in their science notebook. Have them pick two that they want to share and write them on sticky notes.
7. Ask individuals to share one or two of their questions with their table group. Then have the table group select three or four questions that they want to share with the class.
8. Invite table groups to share their sticky notes (clump those that are similar) on the class whiteboard. Review the questions.

Part IIa

Explore 1 (45 minutes)

Ask questions and plan an investigation to test the effect of the number of students on each side of a rope on the movement of the marker.

9. Ask, "Which of these questions can we investigate to find out what might have caused this to happen? Do we have any testable questions on our list? Circle those that are appropriate. Call out the variables in those questions (e.g., *number of students on the rope, size of the students on the rope, boys versus girls on the rope, strength of pulling the rope*).
10. Ask, "What do we need to think about in order to conduct an investigation of these variables?"

TEACHER NOTE

If this is the first time your students are planning an investigation, guide them in a discussion of:

- What is the phenomenon we are trying to understand? (e.g., in this case, how did the kids in the video win)?
- What is the question we are trying to investigate? (e.g., does changing the number of students on each side of the rope affect the way the rope is pulled?)
- What is the variable we are testing? (e.g., in this case, the number of students)
- What will we observe? (e.g., in this case, does the side with most students win by pulling the marker over the line?)
- How many times to we need to test it? (in this case at least 3 times)
- How many variables can we test at a time? (only one)

11. Explain that data can be observation or measurements. Ask students what they think they could observe or measure. (e.g., observe: when the marker moves; how the students move; number of back-and-forth movements; measure: distance marker moved; count the number of participants on each side, who is stronger). Remind students that sometimes measurement requires certain tools, and we don't have the tools to measure strength. Therefore, our data can be observations and counting the number of students and the distance the marker moves.

12. After the students have identified the question, variable to test, and what they will observe, ask them to share ideas on how they can collect their data.
13. Use their ideas to collaboratively plan the steps for their investigation. Show them the material that they have (i.e., two tug-of-war ropes, each with a marker in the middle and **3.4.H1: Number of Students Data Table**).

TEACHER NOTE

If students have never developed a plan for an investigation, guide them in understanding that the plan is a set of steps they will do to gather data about their question. Their steps should be sequential, and others should be able to follow them.

Below is a suggested plan.

Example Plan:

Before we go outside:

1. Divide the class into two teams of equal size. (32 students = 2 groups of 16)
2. Further divide each team into two groups of equal size. (16 students = 2 groups of 8)
3. Label groups of 8 as team A, B, C, D.
4. Teams A and B will work together. Teams C and D will work together.
5. Since what we are testing is does the number of players make a difference, have one or two members from team A participate on team B for this test so you have uneven teams.
6. Teams A and C will tug-of-war. They get two turns.
7. Teams B will observe team A, and team D will observe team C. They will record their observations in a data table.

When we get outside

8. Give one rope to team A and show them their designated spot. Give the other rope to team C/D and show them their designated spot.
9. Distribute **3.4.H1: Number of Students Data Table** to the observing teams.
10. Have team A and C get into position.
11. Have team B and D get close enough to watch the tug-of-war without getting in the way.
12. Have the two teams pick up the rope. Remind students to not wrap the rope around their wrists!
13. Tell the teams to pull as hard as they can on the rope and that the winning team will be the one who can pull the first person of the other team across the line towards them.
14. Yell “start,” and the teams begin the pull.
15. Yell “stop,” and the teams drop the rope where they are.
16. Repeat the process with the same teams one more time. Make sure teams B and D complete **3.4.H1: Number of Students Data Table**.

TEACHER NOTE (continued)

17. Switch the roles of the teams: Team B and D now pull the rope, team A and C record observations. Then repeat with Teams A and D and Teams B and C.
18. Repeat the process with the new teams, making sure they have two trials.
19. Return to the classroom to discuss the data.

TEACHER NOTE

If some students cannot participate in this activity, they could be given the opportunity to video the activity to help the teams in the Elaborate portion of this lesson.

Part IIb

Explore 2/Explain 1 (60 minutes)

Conduct an investigation to test the effect of the number of students on each side of a rope to the movement of the marker.

14. Take the students outside to conduct their investigation.
15. Return to the classroom and provide time for the observers to look at their data sheet and make sure it is complete. Then ask a representative of each team to contribute their data to **3.4.C1: Number of Students Class Data Table**.
16. Conduct a class discussion (still in the same teams) using these leading questions:
    - Does our data match what we saw in the video? Why or why not? *ESR: Our data is different from the video because it didn't always work that the side with the most students won.*
    - Did the side with the most number of people always win? *ESR: The side with the most students did not always win.*
    - How many times did the side with the most number win? *ESR: We have 8 trials. X of the trials shown that the side with the most number of students won.*
    - How many times did the side with the least number win? *ESRs: We have 8 trials. X of the trials show that the side with the least number of students won.*
    - What patterns do you see in the data? Does something always happen (e.g., more students on one side always wins)? *ESR: The pattern is not predictable because the data shows sometimes the number of students on a side wins and sometime they do not.*
    - Are there multiple trials for the data? How many data points do you have?
    - Are the data sufficient to make a summary statement? Were you able to control the variable (numbers)? Why or why not? *ESR: We think we can make a summary statement that says sometimes the number works and sometimes it doesn't. In our data it worked 5 times, but didn't work 3 times.*

- What evidence can we use to make a claim? *ESR: We can make a claim that a greater number of students on a side does not mean that side will win. Our evidence for that is that our data shows it didn't work 3 times out of the 8 trials.*

Part IIc

Explore 3/Explain 2 (20 minutes)

Make observations about the effect of the size of students on each side of a rope to the movement of the marker.

> **TEACHER NOTE**
>
> If you go outside to test the second variable, add about 45 minutes to this part.

17. If the variable of the number of students didn't cause the team to win, what other variables can we test? Look at the list that was generated and select the variable of size. Ask students to predict the outcome if size matters (e.g., the marker will move in the direction of the bigger kids).
18. Ask students how they can investigate size without going outside. Hopefully someone will suggest the video. If they don't, ask them to recall what they saw in the video, and then replay it.
19. Conduct a discussion with what they noticed. *ESRs: I observed that the side with the larger kids lost. Therefore, I think participant size doesn't seem to matter.*

> **TEACHER NOTE**
>
> If the class agrees that participant size doesn't matter, then go to the next step in the lesson. However, if the students recognize that this is only one trial, acknowledge that they are correct. Explain that the class will play the game again to test this idea.

Part IId

Explore 4/Explain 3 (60 minutes)

Conduct an investigation to test the effect of the strength on each side of a rope to the movement of the marker.

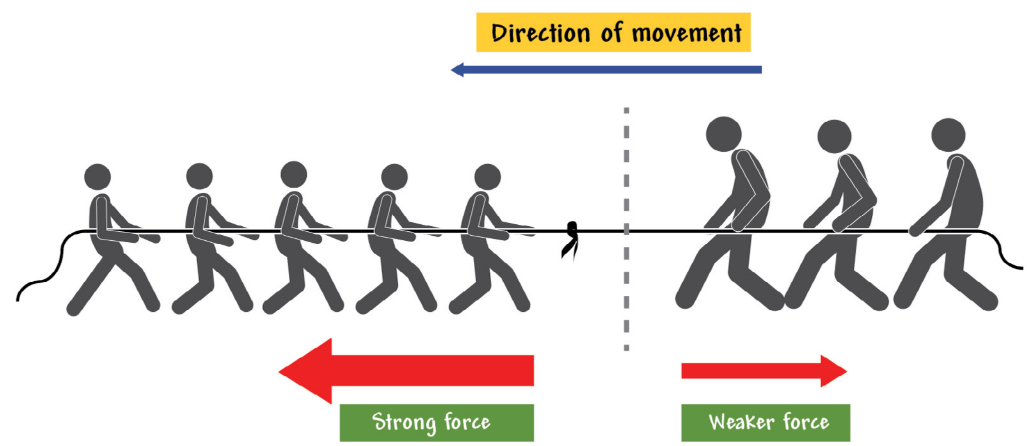
20. Ask students which variables have they identified as not an important factor in the tug-of-war game (number of students on a side; size of students on the rope). What strategies have we learned from the other lessons that can help us understand what is going on in the tug-of-war game? Hopefully they will say models and discuss how drawing arrows to represent the forces and direction might help explain the tug-of-war game.

21. Have students review **3.2.C1: Observable Features of Models** (from Lesson 2: Forces Move Objects). Replay the Tug of War video again. Ask students to work with a partner to make a model.

22. Ask partners to share their model with the table. The table group uses their whiteboard to make a consensus model with an explanation that includes what they learned from the two previous investigations (number of students, size).

23. As table groups are constructing their model, walk around the room and find one or two models for table groups to share.

    ESR:



Explanation: the marker is pulled in the direction of the strongest force. We learned that the number of kids on each side don't always affect the strength and that the size of the participants doesn't mean they can pull with more force.

TEACHER NOTE

Make sure the model shows the direction of the marker. It must also include an explanation about the strength force that caused the movement and not that it is the number of students on the sides of the rope (since they discarded that idea in the investigation).

24. Ask table groups to share their models, and have table groups compare each model shared with their model. Discuss the direction in which the marker moved.

    Leading Questions:

    - What do you notice about the arrows and labels in this model? *ESRs: I noticed the direction arrow and strength arrow go the same way. I noticed the stronger strength arrow was bigger than the weaker strength arrow.*

- What evidence do you have that it is the strength of the force and not the number or size of the students? *ESRs: I know it wasn't the number of kids since we have different results in our investigation data.*
- How does your model show the strength and direction of the forces? *ESRs: My model shows the bigger strength with a bigger arrow.*
- How does your model indicate balanced and unbalanced forces? *ESRs: I have two arrows that are not equal sized to show that they are unbalanced.*

25. Ask the class to predict how strength affects the movement of the marker. Based on this prediction, ask how they would modify their original tug-of-war game to test for strength. *ESRs: Keep the original plan for team A, B, C, D, but this time think about strength and who should go on each side of the rope. Have teams A/B and C/D, each determine one team you think will be strong but less players on it and then one team they think will not be as strong. Each team has 2 trials; now record data on* ***3.4.H2: Strength Data Table****.*
    Ask observers to watch for strength and direction that the marker moves.

26. Hand out **3.4.H2: Strength Data Table** and take teams outside again. Have teams A/B divide their players into two teams—one they think will be strong but has few players on it and one that they think will be not as strong but has more players on it.
    Have team C/D do the same thing. Ask teams A/B to have their "strong" team go to one side of the rope and teams C/D "not as strong" team go to the other side of the rope.

27. When teams are ready, ask them pick up the rope and yell, "start." When you yell "stop," the teams will drop the rope. Record the results on **3.4.H2: Strength Data Table**. Switch teams and repeat the investigation.

28. After returning to the classroom, ask a representative of each team to contribute their data to **3.4.C2: Strength Class Data Table**.

29. Conduct a class discussion. Use these leading questions:

- What was the configuration of the different teams? *ESR: The configurations were _____, _____, and _____.*
- How many teams had the same configuration (e.g., girls vs. boys) but got different results? *ESRs: Sometimes the same configurations had different results.*
- What does that tell you about the variable that caused the motion?
- What patterns do you see in the data? Does something always happen? (e.g., it didn't matter what the configuration of the team was, the side with the greatest strength moved the marker) *ESRs: The pattern is predictable because the data shows the side with the greatest strength always won.*
- Are there multiple trials for the data? How many data points do you have? *ESRs: We had 4 trials to compare data.*
- What evidence can we use to make a claim? *ESRs: Our evidence is that our data shows whoever was able to pull the rope the hardest won; that the greater force moved the marker across the line.*

Part III

Explain 4 (60 minutes)

Construct a tentative explanation about which variable affects the change in motion of the marker in a tug-of-war.

30. Scientists use their data to create evidence for their claims. How can we write a tentative explanation about which variable is most likely to affect how the rope moves in a tug-of-war?

TEACHER NOTE

If this is the first time your students have written an explanation with a claim and evidence, guide them to understand:

- a claim is a statement supported by evidence that answers a question
- evidence is supported by data
- evidence needs to be adequate and sufficient to support the claim
- there should be more than one source of evidence

31. Ask students to write the question in their science notebook that they were trying to answer. Ask a couple of students to share their questions. Use their ideas to create a class question (e.g. What factors/variables cause the rope marker to move in a tug-of-war?).

TEACHER NOTE

Emphasize the crosscutting concept of cause and effect while having the discussions about:

- the questions students are trying to answer
- the way they write their claim (Step 32)
- the evidence identified from the trends in the data (Step 33)

32. Provide a sentence starter for students to write a claim in their science notebook.

    My claim is _____.

    Ask partners to share what they wrote in their science notebook and allow them to edit based on their sharing. *ESRs: My claim is that strength is a factor that causes the marker to move in a tug-of-war. My claim is that the number of students on one side does not cause the marker to move in a tug-of-war. My claim is that the marker moved because one side pulled harder. My claim is that the marker moved because there was a stronger force on one side. My claim is that the marker moved because there was a strong unbalanced force on one side.*

33. When scientists make a claim, they need to support it with evidence. Ask partners to think of evidence statements that support their claim. Encourage them to use this sentence frame:

    The evidence that supports my claim is _____. Another piece of evidence is _____.

    Expected Student Responses (ESRs):

    - *The evidence that supports my claim is our data showed that the number of students on each side did NOT <u>affect</u> the movement of the marker.*
    - *The evidence that supports my claim is that the video showed the smaller students moving the marker, so participant size does NOT <u>affect</u> the movement of the marker.*
    - *The evidence that supports my claim is our data showed that no matter who was on the sides of the rope, the side that used a stronger force <u>caused</u> the marker to move.*
    - *The marker moves in the direction of the stronger force <u>because</u> a bigger force was applied to that side.*

34. Ask students to share their evidence statement with the whole group. Try to elicit several different statements. Then ask, "Does anyone have a different evidence statement?" Write the statements on sentence strips and post on the class whiteboard. Group and review the evidence statements. Ask students if they want to modify any or add any new ideas.

35. Explain that scientists not only gather evidence from investigations, they also can gather evidence from media (e.g., reading text, viewing drawings, and watching videos). Today, students will have a chance to watch a video to see what other information that can be used as evidence in their explanation.

36. Ask students to take notes in their science notebook as they watch the Unbalanced Force video. **STOP AT 1:15** (after the forces in many directions acting on the barrel) because the rest of the video covers middle-school concepts.

37. Give students time to review their notes. Then ask if there were any pieces of evidence they saw/learned in the video that could support their claim. Chart their ideas and ask students to add information to their claim and evidence statements. *ESRs: The video showed if the forces were equal they were balanced, and the rope did not move. The video showed that when one team pulled harder, the forces were not equal, and the rope moved. The rope moving looked like what happened when we tested the strength variable.*

    TEACHER NOTE

    The media input must be played AFTER the students had explored their ideas. The video is used to support students as another piece of evidence, and also support students who are still struggling with the concepts or vocabulary and need to experience it in a different way.

38. Have a couple of students share their final claim and evidence statements using the document camera.

TEACHER NOTE

▶ These explanations can be used as a formative assessment to see if students can transfer their learning from basketball and soccer about forces, the direction of forces, and force strength to the tug-of-war.

Part IV

Elaborate/Evaluate (90 minutes)

Design a process for a new tug-of-war game that uses the cause and effect of the strength of unbalanced forces on the outcome of the game.

39. Now that the students have some understanding about force and motion as it applies to a tug-of-war, they are ready to think about their design for the new playground. Explain that engineers develop new tools, new products, and sometimes even new processes.

40. The students' challenge is to develop a process by writing new directions for a tug-of-war game between kindergartners and third graders in which both of these can happen:

    a. the kindergarten team, though challenged, will win

    b. the kindergarten team and third grade team will have a draw (neither team moves the marker)

41. Display **3.4.C3: New Game Direction Rules**. In their directions for the game, table groups must include how the following science ideas are used to design the game:

    - An object has many forces acting on it.
    - Forces have strength and motion.
    - If forces on an object are equal, the forces are balanced.
    - If forces on an object are unequal, the forces are unbalanced.
    - An unbalanced force on an object at rest will cause it to move.
    - An unbalanced force on an object that is moving can cause it to stop.
    - Unbalanced forces cause changes in the object's direction of motion.

42. The directions must include a drawing of the forces acting on the tug-of-war when the kindergartners win and when the tug-of-war is a draw.

43. Once the students understand their challenge, have them work in pairs to think about challenge A (kindergartners win) and sketch a force diagram. Then have partners share at their table. Have the table create a consensus diagram. From that diagram, have the table group write the directions for this game on poster paper and draw a model.

44. Partner table groups and have them share their directions. One table group shares while the other writes their feedback on sticky notes. Then the other group shares, and the first group writes their feedback on sticky notes. Use these student feedback prompts:

    For each poster, provide your classmates with feedback using sticky notes using one of the following stems:

    I agree with _____.

    I wonder _____.

    This makes me think _____.

    I disagree because _____.

45. Ask table groups to return to their table, review the comments on sticky notes, and make any edits to their directions.

46. Repeat this process (Steps 41 – 4 5) with Challenge B where the result of the game is a draw.

Sample Directions for Challenge A (kindergartners win)

Decide how many kindergartners are on one side and how many third graders are on the other side. *ESRs: I know to move the marker, I need to unbalance the forces by having a greater force on the kindergartner side. If I increase the number of kindergarten kids, they will have more strength than just a few third graders.*

> <u>Model with arrows in different directions due to a greater or lesser force. Use a large arrow for the stronger force and a smaller arrow for the weaker force.</u>

Line up the kindergartners closer to the flag; make the third graders move a couple of feet away from the flag. *ESRs: I know that a strong unbalanced force can change the direction of motion. I know that a strong force can move things farther. If the flag is closer to the kindergartners, they don't have to pull as hard to make the flag cross the line. If the third graders are farther back, they have to pull really hard.*

> <u>Model with arrows showing the distance traveled that match where the stronger force is.</u>

Make sure the rope is not too fat. *ESRs: the kindergartners need to be able to grab unto the rope and use the full strength in their hands and arms to cause a strong unbalanced force.*

Sample Directions for Challenge B (draw)

Decide how to make the forces equal on both sides of the rope. Let students know that they can experiment two times, and then they must decide who is on what side. *ESRs: I know that I can use patterns to predict future motion, so if I try my ideas, I can see the pattern that works best.*

You can choose to use different numbers of players or have enough students with strength on one side to equal the strength on the other side. *ESRs: I know that for the marker to NOT move, the forces acting on it must be equal or balanced.*

Model with arrows going in different directions that are the same size, showing that the forces are equal.

47. Identify several posters that address the science concepts in their directions. Use these posters to review with the class about force and motion so that they are ready for their design challenge in the next lesson.

Return to **3.1.C3: Tug-of-war** (from Lesson 1: Movement on the Playground) and ask students if they have answered the science behind some of their questions.

▶ Collect the posters from each table for Challenge A and B to use as an assessment of learning. Review the student directions and science cause-and-effect statements for:

An object has many forces acting on it.

Forces have strength and motion.

If forces on an object are equal, the forces are balanced.

If forces on an object are unequal, the forces are unbalanced.

An unbalanced force on an object at rest will cause it to move.

An unbalanced force on an object that is moving can cause it to stop.

Unbalanced forces can cause changes in the object's direction of motion.

The student directions must include a drawing of the forces acting on the tug-of-war when the kindergartners win and when the tug-of-war is a draw. Evaluate the drawings of the forces acting on the tug-of-war when the kindergartners win and when the tug-of-war is a draw. Determine which ideas students are understanding and which ideas they are not understanding to modify how you begin the next lesson.

References

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Stem Teaching Tools. (n.d.). Talk Science Printable. Retrieved from (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf)

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Toolbox Table of Contents

Number of Students Class Data Table

Team Trial #	Number of students to the left of the marker	Number of students to the right of the marker	Who won
A/C trial 1			
A/C trial 2			
B/D trial 1			
B/D trial 2			
A/D trial 1			
A/D trial 2			
B/C trial 1			
B/C trial 2			

Strength Class Data Table

Team Trial #	Description of students to the left of the marker	Description of students to the right of the marker	Size and direction of strength arrow and direction of movement	Observations
Trial 1 A/B Strong C/D Not as Strong				
Trial 2 A/B Strong C/D Not as Strong				
Trial 1 A/B Not as Strong C/D Strong				
Trial 1 A/B Not as Strong C/D Strong				

New Game Direction Rules

Directions must include how the following science ideas are used to design the game:

- An object has many forces acting on it.
- Forces have strength and motion.
- If the forces on an object are equal, the forces are balanced.
- If the forces on an object are unequal, the forces are unbalanced.
- An unbalanced force on an object at rest will cause it to move.
- An unbalanced force on an object that is moving can cause it to stop.
- Unbalanced forces cause changes in an object's direction of motion.

Directions must also include a drawing of the forces acting on the tug-of-war when the kindergartners win and when the tug-of-war is a draw.

Number of Students Data Table

Team Trial #	Number of students to the left of the marker	Number of students to the right of the marker	Observations
A/C trial 1			
A/C trial 2			
B/D trial 1			
B/D trial 2			
A/D trial 1			
A/D trial 2			
B/C trial 1			
B/C trial 2			

Strength Data Table

Team Trial #	Description of students to the left of the marker	Description of students to the right of the marker	Size and direction of strength arrow and direction of movement	Observations
Trial 1 A/B Strong C/D Not as Strong				
Trial 2 A/B Strong C/D Not as Strong				
Trial 1 A/B Not as Strong C/D Strong				
Trial 1 A/B Not as Strong C/D Strong				

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
3-PS2-1	Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. [Clarification Statement: Examples could include an unbalanced force on one side of a ball can make it start moving; and, balanced forces pushing on a box from both sides will not produce any motion at all.] [*Assessment Boundary: Assessment is limited to one variable at a time: number, size, or direction of forces. Assessment does not include quantitative force size, only qualitative and relative. Assessment is limited to gravity being addressed as a force that pulls objects down.*]

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)

Planning and Carrying Out Investigations

- Evaluate appropriate methods and/or tools for collecting data.
- Make observations ~~and/or measurements~~ to produce data to serve as the basis for evidence for an explanation of a phenomenon or to test a design solution.
- Make predictions about what would happen if a variable changes.

Developing and Using Models

- Develop and/or use models to describe and/or predict phenomena.

Constructing Explanations and Designing Solutions

- Construct an explanation of observed relationships.
- Use evidence (e.g., ~~measurement~~, observations, patterns) to construct or support an explanation or a design a solution to a problem.
- Apply scientific ideas to solve design problems.

DISCIPLINARY CORE IDEAS (DCI)

PS2.A: Forces and Motion

- Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object’s speed or direction of motion.
- The patterns of an object’s motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it.

Appendix 3.4

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Students routinely identify and test causal relationships and use these relationships to explain change. They understand events that occur together with regularity might or might not signify a cause and effect relationship.
Patterns
• Patterns of change can be used to make predictions.

Common Core State Standards (CCSS)

CCSS ELA READING
CCSS.ELA-LITERACY.RI.3.3 Describe the relationship between ~~a series of historical events~~, scientific ideas or concepts, or steps in technical procedures in a text, using language that pertains to time, sequence, and cause/effect.
CCSS ELA WRITING
CCSS.ELA-LITERACY.W.3.8 Recall information from experiences or gather information from print and digital sources; take brief notes on sources and sort evidence into provided categories.
CCSS ELA SPEAKING AND LISTENING
CCSS.ELA-LITERACY.SL.3.1 Engage effectively in a range of collaborative discussions ~~(one-on-one, in groups, and teacher-led)~~ with diverse partners on grade 3 topics and texts, building on others' ideas and expressing their own clearly.
CCSS.ELA-LITERACY.SL.3.4 Report on a topic or text, or recount an experience with appropriate facts and relevant, descriptive details, speaking clearly at an understandable level.

Appendix 3.4

California English Language Development (ELD) Standards

CA ELD		
Part 1.3.6 Reading/Viewing Closely		
EMERGING	**EXPANDING**	**BRIDGING**
Describe ideas, phenomena (e.g., insect metamorphosis), ~~and text elements (e.g., main idea, characters, setting)~~ based on understanding of a select set of grade-level texts and viewing of multimedia with substantial support.	Describe ideas, phenomena (e.g., how cows digest food), ~~and text elements (e.g., main idea, characters, events)~~ in greater detail based on understanding of a variety of grade-level texts and viewing of multimedia with moderate support.	Describe ideas, phenomena (e.g., how cows digest food), and text elements (e.g., main idea, characters, events) in greater detail based on understanding of a variety of grade-level texts and viewing of multimedia with light support.
In addition to the standard above, you may find that you also touch on the following standard in this lesson as well: **P1.3.1** Exchanging information and ideas. Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, and adding relevant information. **P1.3.9** Plan and deliver brief oral presentations on a variety of topics and content areas.		

Playground Design

3.5

Image via iStock.com/prescott09

Anchoring Phenomenon

Objects move in different ways during physical activities on the playground.

Lesson Concept

Using the characteristics of forces and their effects on motion, design a solution for a new piece of playground equipment or game.

Identified Problem

A school can't reopen the playground until it receives a design for a new playground structure.

Standards

Refer to Appendix 3.5 for NGSS, CCSS—ELA, and California ELD standards.

Storyline Link

This is the culminating lesson in the learning sequence. This lesson introduces the concepts of engineering design and the use of the knowledge gained about forces and motion to solve a problem. The previous lessons had students constructing explanations and models about the cause and effect of forces by observing patterns and collecting data from their investigations. Students will use this information to design and construct a new playground activity or piece of equipment to solve the problem of replacing an old, unusable playground structure.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena or solving a problem.

Time

5.75–7.0 hours (5–10 days to complete)

Part I	60 minutes	Engage
Part II	60 minutes	Explore 1
Part III	60–120 minutes	Explore 2
Part IV	60 minutes	Explain
Part V	60 minutes	Elaborate
Part VI	45–60 minutes	Evaluate

Materials

Whole Class

- ❑ 3.1.R1: Design a Playground (from Lesson 1: Movement on the Playground)
- ❑ 3.5.R1: Map of New Playground
- ❑ 3.5.R2: EiE Engineering Design Process
- ❑ 3.5.R3: NGSS Engineering Design Process
- ❑ 3.5.R4: Criteria and Constraints
- ❑ Rulers
- ❑ Rubber bands
- ❑ Pencils
- ❑ Tape
- ❑ Paper clips
- ❑ String/yarn
- ❑ Binder clips
- ❑ Paper

- ❑ Index cards
- ❑ Glue
- ❑ Cardboard
- ❑ Cardboard rolls
- ❑ Water bottles
- ❑ Wooden craft sticks
- ❑ Ping-pong balls or other small, bouncy balls

Group (Groups of 4)

- ❑ Poster paper
- ❑ Marking pens
- ❑ Sticky notes: green, yellow, and orange

Individual

- ❑ Science notebook

Teacher

- ❑ 3.5.R5: Playground Rubric
- ❑ TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf)

Advance Preparation

1. Gather materials.
2. Draw **3.5.R2: EiE Engineering Design Process** on chart paper.
3. Make a copy of **3.1.R1: Design a Playground** (from Lesson 1: Movement on the Playground), **3.5.R1: Map of New Playground**, and **3.5.R4: Criteria and Constraints** for use with the document camera.
4. Make a chart labeled Design Questions.
5. Review TalkScience resource (http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf) to determine when best to use this resource in student-to-student discourse.

Procedure

Part I

Engage (60 minutes)

Obtain information about the new playground design that will use force and motion and cause and effect.

1. Ask students to reread **3.1.R1: Design a Playground** which they read in Lesson 1: Movement on the Playground. Ask the class, "What are the concepts we have learned in this unit?" Direct students to review their science notebook entries (from Lessons 1–4) on the cause and effect of force and motion on the playground. Based on your assessment from Lesson 4: Balanced and Unbalanced Forces, discuss some of the major things students now understand regarding forces that caused objects to move, changed the rate they moved, or the direction in which they moved. Emphasize areas that students were not clear on in the assessment. Chart these ideas. *ESRs: I learned that a force acts on an object that stays still or moves. I learned if forces are unbalanced then there will be a change in direction or speed. I learned that gravity is a force that pulls things down. I learned that identifying a pattern in motion can help predict future motion.*
2. Tell the class, "Your challenge is to use these science concepts about force and motion and the engineering process to design and build a model for a new playground structure or activity. You must also explain its function. To get started on thinking about our design, let's look at the district's architect's blueprint of the new playground area."
3. Show **3.5.R1: Map of New Playground** on the document camera, or draw it on chart paper. Point out where the new basketball court, soccer field, and tug-of-war areas will be. Remind the class that they worked on prototypes for designs for these areas earlier in the lessons.
4. Point out the area on **3.5.R1: Map of New Playground** where the new playground space is located. Explain that this is the area where they will be creating activities or structures to be built. This area can be used for one large activity/structure or multiple activities/structures.
5. Take students out to the playground and re-define the challenge. Have them envision what the design of the new structure or activity might be and how it will be located in the playground space. Ask them to write any questions they have about the challenge in their science notebook. Encourage them to write questions that will help them with their design.

   Possible student-driven questions:

   - *What can we design it to do?*
   - *Does it have to have _____? _____?*
   - *Should/Can there be moving parts in the structure?*
   - *Should/Can there be more than _____ sections (or parts) in the structural design?*
   - *Should/Will the different parts of the structure work together?*
   - *Is there a purpose in the design that supports physical education or science goals?*
   - *How will what I have learned about force and motion influence my design?*

6. On another page in their science notebook, have students make a quick diagram of their ideas for the new playground structures or activities.
7. Return to the classroom and have students share their questions as you write them on a chart. Then, give them time to explain some of their design ideas.

> **TEACHER NOTE**
>
> Explain to students that the questions about size, materials, and time will be answered during your explanation of the engineering design process. Also explain that they will work to figure out the answers to many of their other questions during this lesson.

8. Introduce the **3.5.R2: EiE Engineering Design Process**. In the goal area ask students to write the challenge: Design a new playground structure or activity that includes force and motion.

> **TEACHER NOTE**
>
> **3.5.R2: EiE Engineering Design Process** is an example of the engineering design process by Engineering is Elementary (EiE) a division of the Museum of Science, Boston (https://www.eie.org/). **3.5.R3: NGSS Engineering Design Process** is another example of the engineering design process taken from the NGSS Science Frameworks (Appendix I).
>
> Note: The design process is called out in ETS1.A [Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (3-5-ETS1-1)]

9. Begin with the **ASK** circle. Guide students with the process of asking questions and defining problems, such as: "What do you know? What do you need to do? What questions do you have about the activity they will complete?" (Refer to the chart made earlier, and if necessary, add more questions.)
10. Explain that the school administration has decided on criteria which the playground design needs to meet. All criteria must be met or the design will not be accepted. Display the top of **3.5.R4: Criteria and Constraints** on the document camera and conduct a discussion for each of the criteria for the project.

    The design and explanation must include:

    a. At least two different places where forces will be used to produce movement. The explanation must describe those forces as balanced and/or unbalanced.
        - Ask students for an example. *ESRs: movement with an unbalanced force of a push or a pull (e.g., dragging an object; hitting/kicking, bouncing an object)*

b. The strength and direction of the forces on the object.
   - Ask students for examples. *ESRs: a hand throwing a basketball straight at a basketball hoop, a strong kick of a soccer ball that travels a big distance*

c. A change in either direction of motion or distance.
   - Ask students for examples. *ESRs: one person kicks a soccer ball a distance toward another player who kicks the ball farther down the soccer field; a basketball thrown upward toward the hoop hits the backstop before falling into the hoop and toward the ground.*

d. The pattern of motion that would be observed.
   - Ask students for examples. *ESRs: a merry-go-round moves as a result of a force, and the pattern of the speed depends on the strength of the force; every time a soccer ball is kicked very weakly, it doesn't go very far.*

e. Motivate students to want to use the playground structure or activity.
   - Ask students for examples. *ESRs: a climbing wall that looks like a real mountainside, a tall merry-go-round that has swings underneath it, etc.*

11. Explain that in addition to criteria, engineers must contend with a variety of limitations or constraints. These constraints describe the conditions under which the design must be done. Constraints are things like time to complete the project, size, weight, use of materials, and budgets.
12. Display the bottom of **3.5.R4: Criteria and Constraints** on the document camera and review the constraints for the project:

    a. Materials are limited to what is available on the supply table.
       - Show students the materials on the supply table.

    b. The prototype of the playground structure or activity size must be limited to the size of your desktop.
       - Show students the area of the desktop.

    c. The prototype of the playground structure or activity must be designed in a specified numbers of class periods.
       - Tell students how many class periods they will have to design their prototypes.

Part II

Explore 1 (60 minutes)

Communicate ideas about the new playground design using force and motion and cause and effect.

13. Point to the **IMAGINE** circle on **3.5.R2: EiE Engineering Design Process**. Explain that this is the time when engineers use their imaginations to help them brainstorm as many possible design solutions as they can.

14. Give time for students to individually brainstorm ideas that they would like to design, reminding them of the criteria. Have them record their ideas in their science notebook. Remind them that this is a “dream session” in which they can use force, motion, and direction symbols.
15. Divide the class into design teams. One way to do this is to have students share the type of design they thought about (e.g., design an activity; design a structure for students to climb or slide; design obstacle course for climbing, jumping, rolling) and then see if there are others who have a similar idea. Group those students together. Another idea is to just number students off into groups of 4 and let them share their ideas.
16. Point to the **PLAN** circle on **3.5.R2: EiE Engineering Design Process**. Ask group members to share their ideas with each other. It is okay to continue to brainstorm or build on each other’s ideas. However, their goal is to come to agreement on one possible design idea.
17. Once the team has decided on one possible design idea, remind teams of the criteria. Encourage students to include what they know about force and motion to explain their design. (See Teacher Note below.)
18. Have the teams review the constraints to see if they need to adjust any of their thinking.
19. Finally ask teams to review the materials that are available for building and determine if they need to make any changes. Then ask teams to agree on what materials to use.
20. Distribute poster paper to each group and ask them to create a team design diagram.
21. Have groups share their plan and materials list with you for approval and gather their supplies.

TEACHER NOTE

▶ When students share their plan, one thing to have them explain is what type of force will be used (balanced, unbalanced); how the forces lead to motion (cause and effect); as well as making sure they are showing the predicted direction and strength of the forces with arrows. This is an important part of their design, as it makes them reflect on what they’ve learned about forces and motion. This can be used as a point of formative assessment.

TEACHER NOTE

This activity allows for integrating mathematics, and you can choose to put a “price” on the materials, and give groups a limit of how much they can “spend.” It would tie in to 3.NBT.A.2: Use place value understanding and properties of operations to perform multi-digit arithmetic.

Part III

Explore 2 (60–120 minutes)

Build a physical model that is the prototype design showing the cause and effect of how force and motion are used in the new activity/structure.

> **TEACHER NOTE**
>
> For the purposes of this lesson, a physical model can be either building a model with real stuff or making a detailed diagram.

22. Point to the **CREATE** circle on the chart of **3.5.R2: EiE Engineering Design Process**. Ask teams to build a model of their playground structure or activity based on their design plan.
23. Ask teams to test the model, doing several trials and recording their observations and data in their science notebook.
24. Ask teams to write their explanation of how their design met all the criteria.

Part IV

Explain (60 minutes)

Compare multiple solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

25. Have teams share results and explain their design: "What were they trying to do? What results did they get? Did the design stay within the constraints? Did it meet the criteria? Does it have an explanation based on the science concepts of force and motion?"

> **TEACHER NOTE**
>
> The goal is for the teams to present their design and its effectiveness for solving the problem. It would be best if all groups could hear from each other, but this is time consuming. One option is to partner groups, or put them in trios so that they hear at least 1 or 2 other groups reporting. Another way is to do a gallery walk where students visit different teams. One member of each team remains with the design to share results; the rest of the team travels and then returns and shares what they learned.
>
> It is a good idea to take pictures of the students' prototypes at this point. When students do revisions to their models, it is helpful for the students to have documentation of their initial model for reflection.

Students may need scaffolding to stay on topic and to generate questions of each other that are helpful. You can choose to offer some sentence frames that show how engineers talk to one another about designs:

For sharing ideas:

We observed ____.

Our data shows ____.

We think ____ because ____.

We are wondering about ____.

For responding to others' ideas:

Can you explain ____ to me?

Why do you think ____?

What evidence do you have....?

I agree with ____ because ____.

I respectfully disagree with ____ because ____.

26. Bring the class together for a final discussion of what they found out about each other's designs.

TEACHER NOTE

Explain that this engineering design process is a simplified version built on specific components within a more complex design process. This is called out in the standard ETS1.B: At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.

Part V

Elaborate (60 minutes)

Communicate with peers about proposed solutions and possible revisions and redesigns of their model to better meet the criteria and constraints of their design.

27. Point to the **Improve** circle on the chart of **3.5.R2: EiE Engineering Design Process**. Explain that engineers often try to improve on a design. Ask students to think of things (or technologies) that have been improved in their lives. *ESRs: many versions of video game boxes; improved cell phones; bigger, thinner TVs.*

TEACHER NOTE

Point out to students that engineers strive to improve existing technologies or develop new ones to increase their benefits (to man, living creatures, or the environment), decrease known risks, and to meet societal demands. If you are able to show an example of an old, big cell phone (or a flip phone) and a newer version, this real object can help students connect with this concept.

28. Request teams to think of and discuss what they learned from the other teams' designs. Say, "Can you use any ideas from other projects to make your model work better?" Have the teams brainstorm new ideas to improve their design and support their brainstorming with reasoning.
29. Distribute chart paper (or have students return to their original design) for students to refine or modify their design plan. Have students add an explanation of the changes they decided to make in their design and from where or whom they got the idea.

    Provide sentence frames if necessary:

    After discussing and sharing ideas with _____, we decided to improve our design by _____.

    After observing other teams' proposed solutions, we decided to improve our design by _____.
30. Then, have students post their modified/revised designs, and have the groups do a gallery walk. During the gallery walk, students walk around the room evaluating their peers' designs and use the sticky notes to leave comments about the design.
    a. They may ask a question or request clarification on yellow sticky notes.
    b. They may write an observation on green sticky notes.
    c. They may make a suggestion for improvement on orange sticky notes.

TEACHER NOTE

Remind students to use the sentence frames that show how engineers talk (from Step 25).

31. Once all teams have had a chance to leave their critiques, give teams time to discuss the feedback they received, and then rebuild or modify their model. Allow time for students to test it again, if they wish.
32. Ask teams to write an evaluation of their new design in their science notebook. "Did it work better? What is the evidence?"

Part VI

Evaluate (45–60 minutes)

Construct an argument that explains how motion on the playground is the result of unbalanced forces and can be supported by specific designs.

33. Ask each student to review his or her final design and evaluate if it:
    a. meets the design specifications of the original plan AND
    b. was tested and worked.

34. ▶ Direct students to write a letter to the school board that includes the diagram of their finalized piece of playground structure or activity. The letter must explain:
    - how it works and how students would use it.
    - why their design should be chosen for a new playground structure or activity based on evidence that it uses force and motion.
    - how the causal relationship between the direction and strength of forces are used in their playground structure or activity by creating a change in motion.
    - how this created balanced or unbalanced forces and what patterns of motion were observed.
    - how they used the engineering design process to create, test, and revise their solution.
    - what they learned along the way.

TEACHER NOTE

Writing a letter gives students an opportunity to communicate scientific information in a written format, including various forms of media as well as tables, diagrams, and charts which is a grade-level element of the SEP "Obtaining, Evaluating, and Communicating Information." You could add an oral presentation to this assignment as well. Writing a letter of this type also supports the SEP of Constructing Explanations.

▶ You can use the letter to assess students' knowledge of the three dimensions they used to solve the problem and their use of the engineering design process to explain change through the relationships (cause and effect) between forces and motion. Use **3.5.R5: Playground Rubric** for this assessment.

References

2016 Science Framework. (n.d.). Retrieved August 04, 2020, from (https://www.cde.ca.gov/ci/sc/cf/cascienceframework2016.asp.)

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Appendix I: Engineering Design in the Next Generation Science Standards. Washington, DC: The National Academies Press.

Museum of Science: Boston. (2020). *The Engineering Design Process*. EiE.org. (https://www.eie.org/overview/engineering-design-process.)

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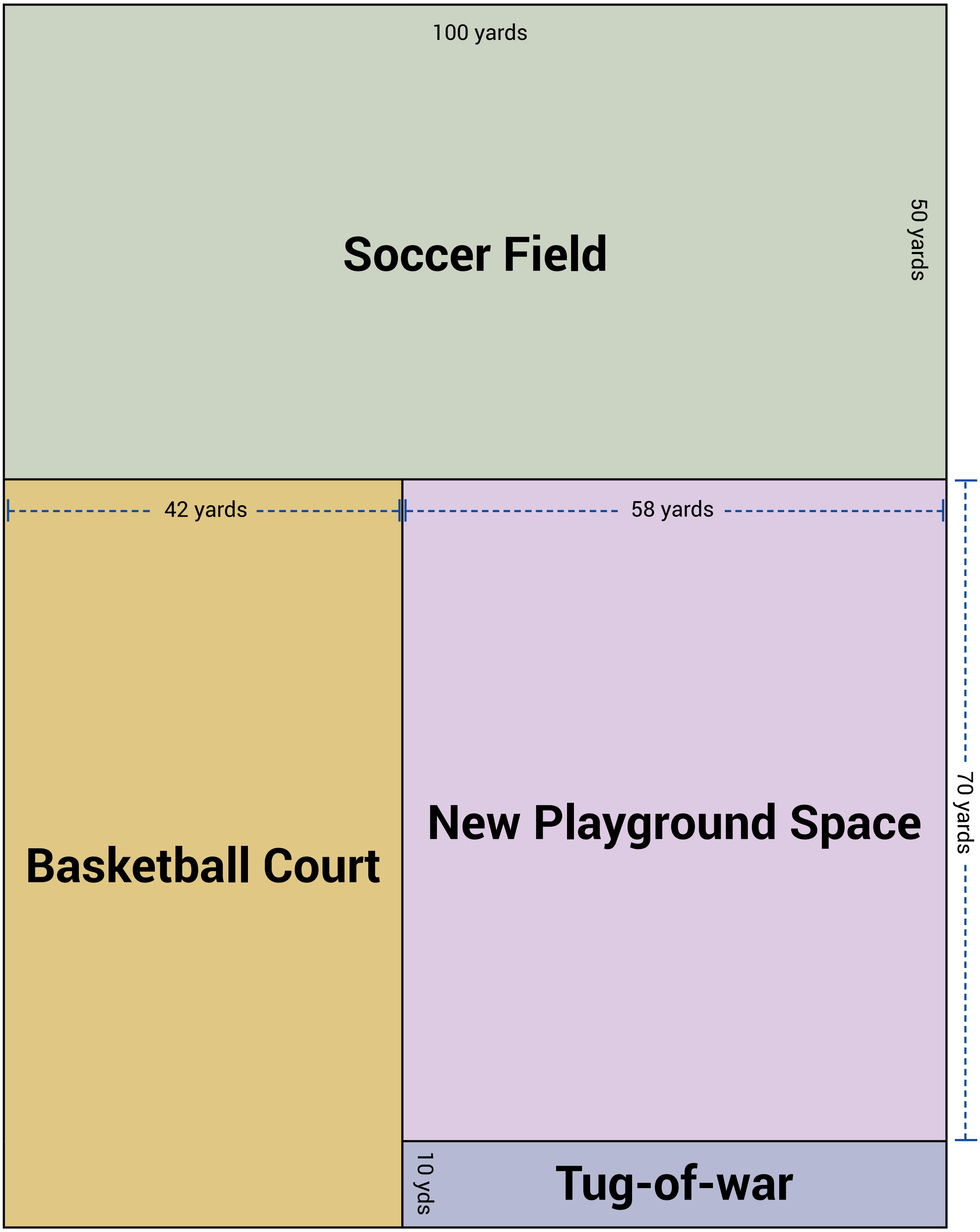
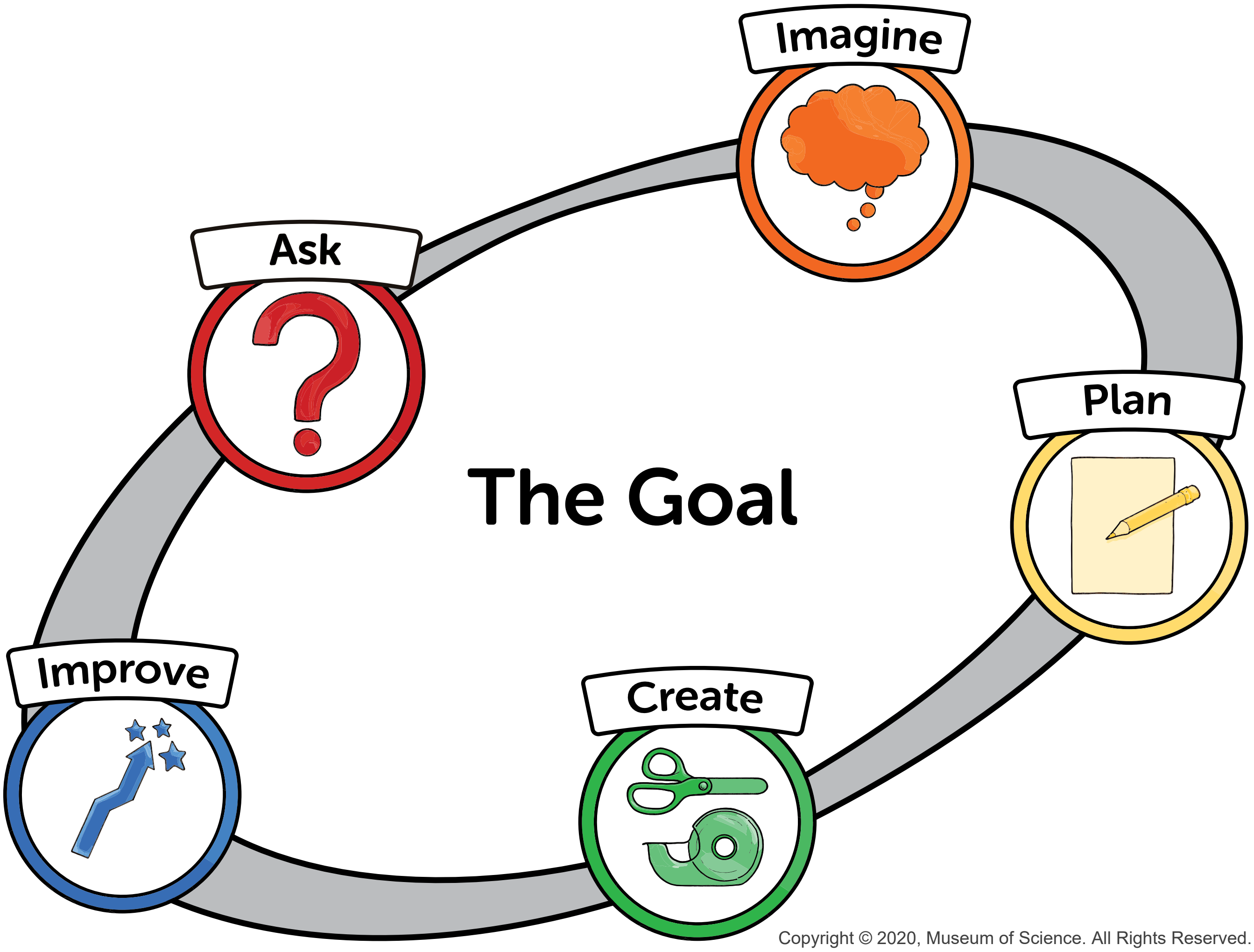
Toolbox Table of Contents

Map of New Playground



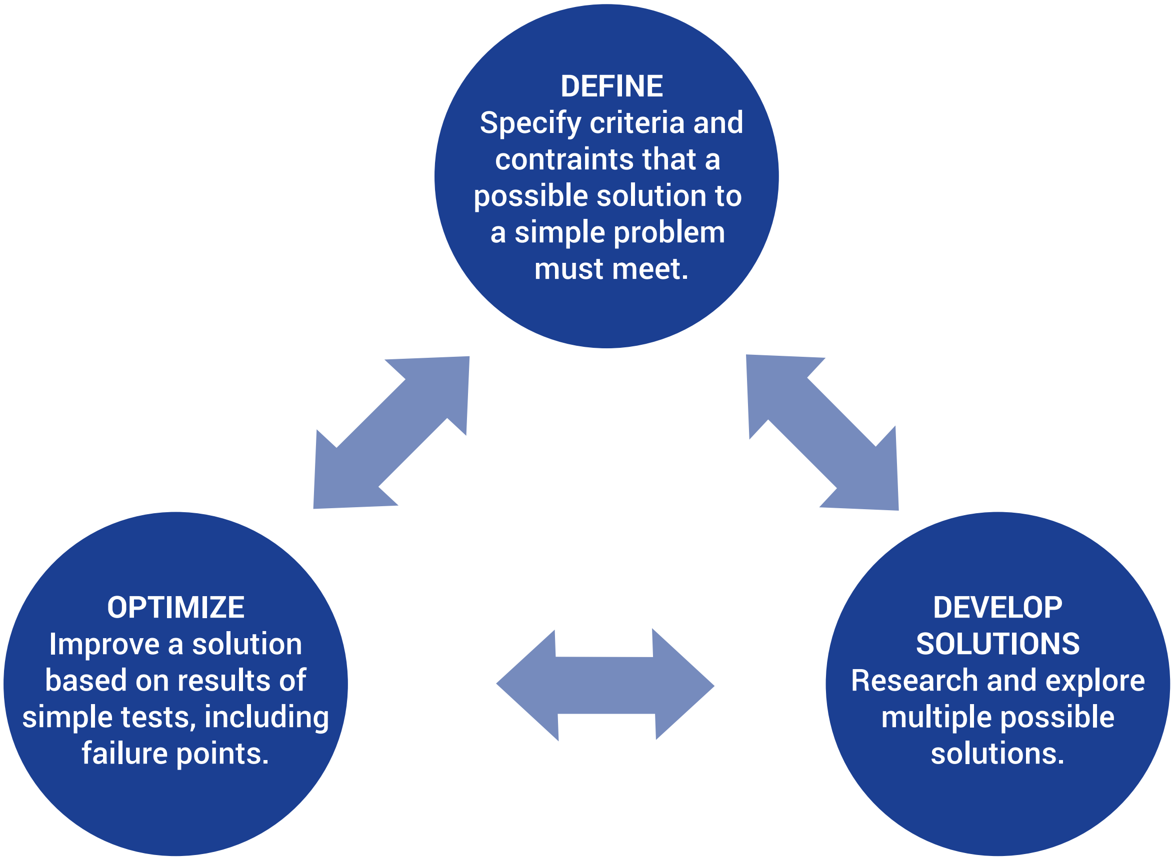
EiE Engineering Design Process



The Engineering Design Process created by EIE.org.
https://www.eie.org/overview/engineering-design-process. Used with Permission.

NGSS Engineering Design Process

Grades 3–5



NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Appendix I: Engineering Design in the Next Generation Science Standards, page 439. Washington, DC: The National Academies Press.

Criteria and Constraints

Criteria

The design and explanation must:

1. show at least 2 different places where forces will be used to produce movement, and the explanation must describe those forces as balanced and/or unbalanced;
2. include the strength and direction of the forces on the object;
3. include a change in either direction of motion or distance;
4. describe the pattern of motion that would be observed; and,
5. motivate students to want to use the playground structure or activity.

Constraints

The constraints include:

1. materials for prototype are limited to what is available on the supply table like the list above
2. prototype of the playground structure or activity must be limited to the size of your desktop; and
3. prototype of the playground structure or activity must be designed in “x” class periods.

Playground Rubric

Component	4	3	2	1
Overall Design is Based on Sound Scientific Concepts (DCI)	Uses at least two forces, either balanced and unbalanced, or two unbalanced forces **AND** includes forces that act on the object with either strength or direction **AND** includes a change in either direction of motion or distance.	Uses at least two forces, either balanced and unbalanced, or two unbalanced forces **AND** includes forces that act on the object with either strength or direction **AND** includes a change in either direction of motion or distance.	Uses at least two forces, either balanced and unbalanced, or two unbalanced forces **AND** includes forces that act on the object with either strength or direction **OR** includes a change in either direction of motion or distance.	Uses at least two forces, either balanced and unbalanced, or two unbalanced forces **OR** includes forces that act on the object with either strength or direction **OR** includes a change in either direction of motion or distance.
Explanation of the causal relationship of change (CCC)	Shows comprehension of the fact that a force that is unbalanced causes a change in direction and distance **AND** a force that is balanced has no change in motion (a balanced force on an object means it is not moving).	Shows comprehension of the fact that a force that is unbalanced causes change in direction and distance **OR** a force that is balanced has no change in motion (a balanced force on an object means it is not moving).	Shows comprehension of the fact that a force causes motion.	Shows comprehension of the fact that a push or pull causes the motion.
Communication of scientific information (SEP)	Communicates information orally **AND** in written form using tables, diagrams, and charts.	Communicates information orally **OR** in written form using tables, diagrams, and charts.	Communicates information in written form using tables, diagrams, or charts.	Communicates information only in written form.

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
3-PS2-1	Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. [Clarification Statement: Examples could include an unbalanced force on one side of a ball can make it start moving; and, balanced forces pushing on a box from both sides will not produce any motion at all.] [*Assessment Boundary: Assessment is limited to one variable at a time: number, size, or direction of forces. Assessment does not include quantitative force size, only qualitative and relative. Assessment is limited to gravity being addressed as a force that pulls objects down.*]
3-5-ETS1-1	Define a simple design problem reflecting a need or want that includes specified criteria for success and constraints on materials, time, or cost. [*K-2-ETS1-1: Ask questions, make observations and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.*]
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. [*K-2-ETS1-2: Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.*]

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)
Asking Questions and Defining Problems
• Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.
Constructing Explanations and Designing Solutions
• Apply scientific ideas to solve design problems.
• Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.
Developing and Using Models
• Develop and/or use models to describe and/or predict phenomena.
• Develop a diagram or simple physical prototype to convey a proposed object, tool, or process.
• Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.
Obtaining, Evaluating, and Communicating Information
• Communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.

Appendix 3.5

Next Generation Science Standards (NGSS) (continued)

SCIENCE AND ENGINEERING PRACTICES (SEP) (continued)
Engaging in Arguments from Evidence
• Construct an argument with evidence, data, and/or a model.

DISCIPLINARY CORE IDEAS (DCI)
ETS1.A: Defining and Delimiting Engineering Problems
• Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.
ETS1.B: Developing Possible Solutions
• At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.
PS2.A: Forces and Motion
• The patterns of an object's motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it. • Each force acts on one particular object and has both strength and a direction. An object as rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion.
PS2.B: Types of Interaction
• Objects in contact exert forces on each other.

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Students identify and test causal relationships and use these relationships to explain change. They understand events that occur together with regularity might or might not signify a cause and effect relationship.
Influence of Engineering, Technology, and Science on Society in the Natural World
• Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands.

Appendix 3.5

Common Core State Standards (CCSS)

CCSS ELA WRITING
CCSS.ELA-LITERACY.W.3.8 Recall information from experiences or gather information from print and digital sources; take brief notes on sources and sort evidence into provided categories.
CCSS ELA SPEAKING AND LISTENING
CCSS.ELA-LITERACY.SL.3.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 3 topics and texts, building on others' ideas and expressing their own clearly.
CCSS.ELA-LITERACY.SL.3.3 Ask and answer questions about information from a speaker, offering appropriate elaboration and detail.
CCSS.ELA-LITERACY.SL.3.4 Report on a topic or text, or recount an experience with appropriate facts and relevant, descriptive details, speaking clearly at an understandable level.

California English Language Development (ELD) Standards

CA ELD		
P1.3.3 Offering Opinions		
EMERGING	**EXPANDING**	**BRIDGING**
Offer opinions and negotiate with others in conversations using basic learned phrases (e.g., *I think . . .*), as well as open responses in order to gain and/or hold the floor.	Offer opinions and negotiate with others in conversations using an expanded set of learned phrases (e.g., *I agree with X, and . . .*), as well as open responses in order to gain and/or hold the floor, provide counter-arguments, etc.	Offer opinions and negotiate with others in conversations using a variety of learned phrases (e.g., *That's a good idea, but X*), as well as open responses in order to gain and/or hold the floor, provide counter-arguments, elaborate on an idea, etc.

In addition to the standard above, you may find that you also touch on the following standard in this lesson as well:

P1.3.1 Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, and adding relevant information.

P1.3.5 Demonstrate active listening to oral presentations by asking and answering questions, with occasional prompting and moderate support.

P1.3.9 Plan and deliver brief oral presentations on a variety of topics and content areas.