

Progressions for the Common Core State
Standards in Mathematics (draft)

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K–5, Geometric Measurement

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Overview

Geometric measurement connects the two most critical domains of early mathematics, geometry and number, with each providing conceptual support to the other. Measurement is central to mathematics, to other areas of mathematics (e.g., laying a sensory and conceptual foundation for arithmetic with fractions), to other subject matter domains, especially science, and to activities in everyday life. For these reasons, measurement is a core component of the mathematics curriculum.

Measurement is the process of assigning a number to a magnitude of some attribute shared by some class of objects, such as length, relative to a unit. Length is a *continuous* attribute—a length can always be subdivided in smaller lengths. In contrast, we can count 4 apples exactly—cardinality is a discrete attribute. We can add the 4 apples to 5 other apples and know that the result is exactly 9 apples. However, the *weight* of those apples is a continuous attribute, and scientific measurement with tools gives only an approximate measurement—to the nearest pound (or, better, kilogram) or the nearest 1/100th of a pound, but always with some error.[•]

Before learning to measure attributes, children need to recognize them, distinguishing them from other attributes. That is, the attribute to be measured has to “stand out” for the student and be discriminated from the undifferentiated sense of amount that young children often have, labeling greater lengths, areas, volumes, and so forth, as “big” or “bigger.”

Students then can become increasingly competent at *direct comparison*—comparing the amount of an attribute in two objects without measurement. For example, two students may stand back to back to directly compare their heights. In many circumstances, such direct comparison is impossible or unwieldy. Sometimes, a third object can be used as an intermediary, allowing *indirect comparison*. For example, if we know that Aleisha is taller than Barbara and that

- The Standards do not differentiate between weight and mass. Technically, mass is the amount of matter in an object. Weight is the force exerted on the body by gravity. On the earth’s surface, the distinction is not important (on the moon, an object would have the same mass, would weight less due to the lower gravity).

¹This progression concerns Measurement and Data standards related to geometric measurement. The remaining Measurement and Data standards are discussed in the K–3 Categorical Data and Grades 2–5 Measurement Data Progressions.

Barbara is taller than Callie, then we know (due to the transitivity of "taller than") that Aleisha is taller than Callie, even if Aleisha and Callie never stand back to back. •

The purpose of measurement is to allow indirect comparisons of objects' amount of an attribute using numbers. An attribute of an object is measured (i.e., assigned a number) by comparing it to an amount of that attribute held by another object. One measures length with length, mass with mass, torque with torque, and so on. In geometric measurement, a unit is chosen and the object is subdivided or partitioned by copies of that unit and, to the necessary degree of precision, units subordinate to the chosen unit, to determine the number of units and subordinate units in the partition.

Personal benchmarks, such as "tall as a doorway" build students' intuitions for amounts of a quantity and help them use measurements to solve practical problems. A combination of internalized units and measurement processes allows students to develop increasing accurate estimation competencies.

Both in measurement and in estimation, the concept of *unit* is crucial. The concept of basic (as opposed to subordinate) unit just discussed is one aspect of this concept. The basic unit can be informal (e.g., about a car length) or standard (e.g., a meter). The distinction and relationship between the notion of discrete "1" (e.g., one apple) and the continuous "1" (e.g., one inch) is important mathematically and is important in understanding number line diagrams (e.g., see Grade 2) and fractions (e.g., see Grade 3). However, there are also superordinate units or "units of units." A simple example is a kilometer consisting of 1,000 meters. Of course, this parallels the number concepts students must learn, as understanding that tens and hundreds are, respectively, "units of units" and "units of units of units" (i.e., students should learn that 100 can be simultaneously considered as 1 hundred, 10 tens, and 100 ones).

Students' understanding of an attribute that is measured with derived units is dependent upon their understanding that attribute as entailing other attributes simultaneously. For example,

- Area as entailing two lengths, simultaneously;
- Volume as entailing area and length (and thereby three lengths), simultaneously.

Scientists measure many types of attributes, from hardness of minerals to speed. This progression emphasizes the geometric attributes of length, area, and volume. Nongeometric attributes such as weight, mass, capacity, time, and color, are often taught effectively in science and social studies curricula and thus are not extensively discussed here. Attributes derived from two different attributes, such as speed (derived from distance and time), are discussed in the high school Number and Quantity Progression and in the 6-7 Ratio and Proportion Progression.

- "Transitivity" abbreviates the Transitivity Principle for Indirect Measurement stated in the Standards as:

If the length of object A is greater than the length of object B, and the length of object B is greater than the length of object C, then the length of object A is greater than the length of object C. This principle applies to measurement of other quantities as well.

Students should apply the principle of transitivity of measurement to make indirect comparisons, but they need not use this technical term.

Length is a characteristic of an object found by quantifying how far it is between the endpoints of the object. “Distance” is often used similarly to quantify how far it is between any two points in space. Measuring length or distance consists of two aspects, choosing a unit of measure and *subdividing* (mentally and physically) the object by that unit, placing that unit end to end (*iterating*) alongside the object. The length of the object is the number of units required to iterate from one end of the object to the other, without gaps or overlaps.

Length is a core concept for several reasons. It is the basic geometric measurement. It is also involved in area and volume measurement, especially once formulas are used. Length and unit iteration are critical in understanding and using the number line in Grade 3 and beyond (see the Number and Operations—Fractions Progression). Length is also one of the most prevalent metaphors for quantity and number, e.g., as the master metaphor for magnitude (e.g., vectors, see the Number and Quantity Progression). Thus, length plays a special role in this progression.

Area is an amount of two-dimensional surface that is contained within a plane figure. Area measurement assumes that congruent figures enclose equal areas, and that area is *additive*, i.e., the area of the union of two regions that overlap only at their boundaries is the sum of their areas. Area is measured by tiling a region with a two-dimensional unit (such as a square) and parts of the unit, without gaps or overlaps. Understanding how to spatially structure a two-dimensional region is an important aspect of the progression in learning about area.

Volume is an amount of three-dimensional space that is contained within a three-dimensional shape. Volume measurement assumes that congruent shapes enclose equal volumes, and that volume is *additive*, i.e., the volume of the union of two regions that overlap only at their boundaries is the sum of their volumes. Volume is measured by packing (or tiling, or tessellating) a region with a three-dimensional unit (such as a cube) and parts of the unit, without gaps or overlaps. Volume not only introduces a third dimension and thus an even more challenging spatial structuring, but also complexity in the nature of the materials measured. That is, solid units might be “packed,” such as cubes in a three-dimensional array or cubic meters of coal, whereas liquids “fill” three-dimensional regions, taking the shape of a container, and are often measured in units such as liters or quarts.

A final, distinct, geometric attribute is *angle measure*. The size of an angle is the amount of rotation between the two rays that form the angle, sometimes called the sides of the angles.

Finally, although the attributes that we measure differ as just described, it is important to note: *central characteristics of measurement are the same for all of these attributes*. As one more testament to these similarities, consider the following side-by-side comparison of the Standards for measurement of area in Grade 3 and the measurement of volume in Grade 5.

Grade 3

Understand concepts of area and relate area to multiplication and to addition.

3.MD.5. Recognize area as an attribute of plane figures and understand concepts of area measurement.

- a. A square with side length 1 unit, called "a unit square," is said to have "one square unit" of area, and can be used to measure area.
- b. A plane figure which can be covered without gaps or overlaps by n unit squares is said to have an area of n square units.

3.MD.6. Measure areas by counting unit squares (square cm, square m, square in, square ft, and improvised units).

3.MD.7. Relate area to the operations of multiplication and addition.

- a. Find the area of a rectangle with whole-number side lengths by tiling it, and show that the area is the same as would be found by multiplying the side lengths.
- b. Multiply side lengths to find areas of rectangles with whole-number side lengths in the context of solving real world and mathematical problems, and represent whole-number products as rectangular areas in mathematical reasoning.
- c. Use tiling to show in a concrete case that the area of a rectangle with whole-number side lengths a and $b + c$ is the sum of $a \times b$ and $a \times c$. Use area models to represent the distributive property in mathematical reasoning.
- d. Recognize area as additive. Find areas of rectilinear figures by decomposing them into non-overlapping rectangles and adding the areas of the non-overlapping parts, applying this technique to solve real world problems.

Grade 5

Understand concepts of volume and relate volume to multiplication and to addition.

5.MD.3 Recognize volume as an attribute of solid figures and understand concepts of volume measurement.

- a. A cube with side length 1 unit, called a "unit cube," is said to have "one cubic unit" of volume, and can be used to measure volume.
- b. A solid figure which can be packed without gaps or overlaps using n unit cubes is said to have a volume of n cubic units.

5.MD.4 Measure volumes by counting unit cubes, using cubic cm, cubic in, cubic ft, and improvised units.

5.MD.5 Relate volume to the operations of multiplication and addition and solve real world and mathematical problems involving volume.

- a. Find the volume of a right rectangular prism with whole-number side lengths by packing it with unit cubes, and show that the volume is the same as would be found by multiplying the edge lengths, equivalently by multiplying the height by the area of the base. Represent threefold whole-number products as volumes, e.g., to represent the associative property of multiplication.
- b. Apply the formulas $V = l \times w \times h$ and $V = b \times h$ for rectangular prisms to find volumes of right rectangular prisms with whole-number edge lengths in the context of solving real world and mathematical problems.
- c. Recognize volume as additive. Find volumes of solid figures composed of two non-overlapping right rectangular prisms by adding the volumes of the non-overlapping parts, applying this technique to solve real world problems.

Kindergarten

Describe and compare measurable attributes Students often initially hold undifferentiated views of measurable attributes, saying that one object is “bigger” than another whether it is longer, or greater in area, or greater in volume, and so forth. For example, two students might both claim their block building is “the biggest.” Conversations about how they are comparing—one building may be taller (greater in length) and another may have a larger base (greater in area)—help students learn to discriminate and name these measureable attributes. As they discuss these situations and compare objects using different attributes, they learn to distinguish, label, and describe several measureable attributes of a single object.^{K.MD.1} Thus, teachers listen for and extend conversations about things that are “big,” or “small,” as well as “long,” “tall,” or “high,” and name, discuss, and demonstrate with gestures the attribute being discussed (length as extension in one dimension is most common, but area, volume, or even weight in others).

Length Of course, such conversations often occur in comparison situations (“He has more than me!”). Kindergartners easily directly compare lengths in simple situations, such as comparing people’s heights, because standing next to each other automatically aligns one endpoint.^{K.MD.2} However, in other situations they may initially compare only one endpoint of objects to say which is longer. Discussing such situations (e.g., when a child claims that he is “tallest” because he is standing on a chair) can help students resolve and coordinate perceptual and conceptual information when it conflicts. Teachers can reinforce these understandings, for example, by holding two pencils in their hand showing only one end of each, with the longer pencil protruding less. After asking if they can tell which pencil is longer, they reveal the pencils and discuss whether children were “fooled.” The necessity of aligning endpoints can be explicitly addressed and then re-introduced in the many situations throughout the day that call for such comparisons. Students can also make such comparisons by moving shapes together to see which has a longer side.

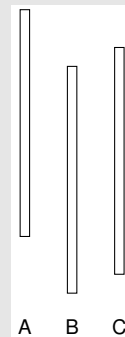
Even when students seem to understand length in such activities, they may not conserve length. That is, they may believe that if one of two sticks of equal lengths is vertical, it is then longer than the other, horizontal, stick. Or, they may believe that a string, when bent or curved, is now shorter (due to its endpoints being closer to each other). Both informal and structured experiences, including demonstrations and discussions, can clarify how length is maintained, or conserved, in such situations. For example, teachers and students might rotate shapes to see its sides in different orientations. As with number, learning and using language such as “It looks longer, but it really isn’t longer” is helpful.

Students who have these competencies can engage in experiences that lay the groundwork for later learning. Many can begin

K.MD.1 Describe measurable attributes of objects, such as length or weight. Describe several measurable attributes of a single object.

K.MD.2 Directly compare two objects with a measurable attribute in common, to see which object has “more of”/“less of” the attribute, and describe the difference.

Sticks whose endpoints are not aligned



When shown this figure and asked which is “the longest stick,” students may point to A because it “sticks out the farthest.” Similarly, they may recognize a 12-inch vertical line as “tall” and a 12-inch horizontal line as “long” but not recognize that the two are the same length.

to learn to compare the lengths of two objects using a third object, order lengths, and connect number to length. For example, informal experiences such as making a road “10 blocks long” help students build a foundation for measuring length in the elementary grades. See the Grade 1 section on length for information about these important developments.

Area and volume Although area and volume experiences are not instructional foci for Kindergarten, they are attended to, at least to distinguish these attributes from length, as previously described. Further, certain common activities can help build students’ experiential foundations for measurement in later grades. Understanding area requires understanding this attribute as the amount of two-dimensional space that is contained within a boundary. Kindergartners might informally notice and compare areas associated with everyday activities, such as laying two pieces of paper on top of each other to find out which will allow a “bigger drawing.” Spatial structuring activities described in the Geometry Progression, in which designs are made with squares covering rectilinear shapes also help to create a foundation for understanding area.

Similarly, kindergartners might compare the capacities of containers informally by pouring (water, sand, etc.) from one to the other. They can try to find out which holds the most, recording that, for example, the container labeled “J” holds more than the container labeled “D” because when J was poured into D it overflowed. Finally, in play, kindergartners might make buildings that have layers of rectangular arrays. Teachers aware of the connections of such activities to later mathematics can support students’ growth in multiple domains (e.g., development of self-regulation, social-emotional, spatial, and mathematics competencies) simultaneously, with each domain supporting the other.

Grade 1

Length comparisons First graders should continue to use direct comparison—carefully, considering all endpoints—when that is appropriate. In situations where direct comparison is not possible or convenient, they should be able to use indirect comparison and explanations that draw on transitivity (MP3). Once they can compare lengths of objects by direct comparison, they could compare several items to a single item, such as finding all the objects in the classroom the same length as (or longer than, or shorter than) their forearm.^{1.MD.1} Ideas of transitivity can then be discussed as they use a string to represent their forearm’s length. As another example, students can figure out that one path from the teachers’ desk to the door is longer than another because the first path is longer than a length of string laid along the path, but the other path is shorter than that string. Transitivity can then be explicitly discussed: If A is longer than B and B is longer than C , then A must be longer than C as well.

Seriation Another important set of skills and understandings is ordering a set of objects by length.^{1.MD.1} Such sequencing requires multiple comparisons. Initially, students find it difficult to seriate a large set of objects (e.g., more than 6 objects) that differ only slightly in length. They tend to order groups of two or three objects, but they cannot correctly combine these groups while putting the objects in order. Completing this task efficiently requires a systematic strategy, such as moving each new object “down the line” to see where it fits. Students need to understand that each object in a seriation is larger than those that come before it, and shorter than those that come after. Again, reasoning that draws on transitivity is relevant.

Such seriation and other processes associated with the measurement and data standards are important in themselves, but also play a fundamental role in students’ development. The general reasoning processes of seriation, conservation (of length and number), and classification (which lies at the heart of the standards discussed in the K–3 Categorical Data Progression) predict success in early childhood as well as later schooling.

Measure lengths indirectly and by iterating length units Directly comparing objects, indirectly comparing objects, and ordering objects by length are important practically and mathematically, but they are not length measurement, which involves assigning a number to a length. Students learn to lay physical units such as centimeter or inch manipulatives end-to-end and count them to measure a length.^{1.MD.2} Such a procedure may seem to adults to be straightforward, however, students may initially iterate a unit leaving gaps between subsequent units or overlapping adjacent units. For such students, measuring may be an activity of placing units along a

1.MD.1 Order three objects by length; compare the lengths of two objects indirectly by using a third object.

1.MD.1 Order three objects by length; compare the lengths of two objects indirectly by using a third object.

1.MD.2 Express the length of an object as a whole number of length units, by laying multiple copies of a shorter object (the length unit) end to end; understand that the length measurement of an object is the number of same-size length units that span it with no gaps or overlaps.

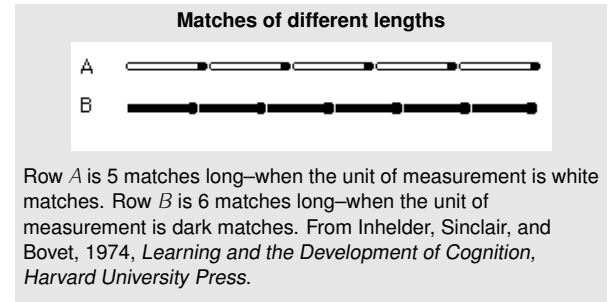
path in some manner, rather than the activity of covering a region or length with no gaps.

Also, students, especially if they lack explicit experience with continuous attributes, may make their initial measurement judgments based upon experiences counting discrete objects. For example, researchers showed children two rows of matches. The matches in each row were of different lengths, but there was a different number of matches in each so that the rows were the same length. Although, from the adult perspective, the lengths of the rows were the same, many children argued that the row with 6 matches was longer because it had more matches. They counted units (matches), assigning a number to a *discrete* attribute (cardinality). In measuring *continuous* attributes, the sizes of the units (white and dark matches) must be considered. First grade students can learn that objects used as basic units of measurement (e.g., “match-length”) must be the same size.

As with transitive reasoning tasks, using comparison tasks and asking children to compare results can help reveal the limitations of such procedures and promote more accurate measuring. However, students also need to see agreements. For example, understanding that the results of measurement and direct comparison have the same results encourages children to use measurement strategies.

Another important issue concerns the use of standard or nonstandard units of length. Many curricula or other instructional guides advise a sequence of instruction in which students compare lengths, measure with nonstandard units (e.g., paper clips), incorporate the use of manipulative standard units (e.g., inch cubes), and measure with a ruler. This approach is probably intended to help students see the need for standardization. However, the use of a variety of different length units, *before students understand the concepts, procedures, and usefulness of measurement*, may actually deter students’ development. Instead, students might learn to measure correctly with standard units, and even learn to use rulers, before they can successfully use nonstandard units and understand relationships between different units of measurement. To realize that arbitrary (and especially mixed-size) units result in the same length being described by different numbers, a student must reconcile the varying lengths and numbers of arbitrary units. Emphasizing nonstandard units too early may defeat the purpose it is intended to achieve. Early use of many nonstandard units may actually interfere with students’ development of basic measurement concepts required to understand the need for standard units. In contrast, using manipulative standard units, or even standard rulers, is less demanding and appears to be a more interesting and meaningful real-world activity for young students.

Thus, an instructional progression based on this finding would start by ensuring that students can perform direct comparisons. Then, children should engage in experiences that allow them to connect number to length, using manipulative units that have a stan-



standard unit of length, such as centimeter cubes. These can be labeled "length-units" with the students. Students learn to lay such physical units end-to-end and count them to measure a length. They compare the results of measuring to direct and indirect comparisons.

As they measure with these manipulative units, students discuss the concepts and skills involved (e.g., as previously discussed, not leaving space between successive length-units). As another example, students initially may not extend the unit past the endpoint of the object they are measuring. If students make procedural errors such as these, they can be asked to tell in a precise and elaborate manner *what* the problem is, *why* it leads to incorrect measurements, and *how* to fix it and measure accurately.

Measurement activities can also develop other areas of mathematics, including reasoning and logic. In one class, first graders were studying mathematics mainly through measurement, rather than counting discrete objects. They described and represented relationships among and between lengths (MP2, MP3), such as comparing two sticks and symbolizing the lengths as " $A < B$." This enabled them to reason about relationships. For example, after seeing the following statements recorded on the board, if $V > M$, then $M \neq V$, $V \neq M$, and $M < V$, one first-grader noted, "If it's an inequality, then you can write four statements. If it's equal, you can only write two"(MP8)

This indicates that with high-quality experiences (such as those described in the Grade 2 section on length), many first graders can also learn to use reasoning, connecting this to direct comparison, and to measurement performed by laying physical units end-to-end.

Area and volume: Foundations As in Kindergarten, area and volume are not instructional foci for first grade, but some everyday activities can form an experiential foundation for later instruction in these topics. For example, in later grades, understanding area requires seeing how to decompose shapes into parts and how to move and recombine the parts to make simpler shapes whose areas are already known (MP7). First graders learn the foundations of such procedures both in composing and decomposing shapes, discussed in the Geometry Progression, and in comparing areas in specific contexts. For example, paper-folding activities lend themselves not just to explorations of symmetry but also to equal-area congruent parts. Some students can compare the area of two pieces of paper by cutting and overlaying them. Such experiences provide only initial development of area concepts, but these key foundations are important for later learning.

Volume can involve liquids or solids. This leads to two ways to measure volume, illustrated by "packing" a space such as a three-dimensional array with cubic units and "filling" with iterations of a fluid unit that takes the shape of the container (called liquid volume). Many first graders initially perceive filling as having a one-

dimensional unit structure. For example, students may simply “read off” the measure on a graduated cylinder. Thus, in a science or “free time” activity, students might compare the volume of two containers in at least two ways. They might pour each into a graduated cylinder to compare the measures. Or they might practice indirect comparison using transitive reasoning by using a third container to compare the volumes of the two containers. By packing unit cubes into containers into which cubes fit readily, students also can lay a foundation for later “packing” volume.

Grade 2

Measure and estimate lengths in standard units Second graders learn to measure length with a variety of tools, such as rulers, meter sticks, and measuring tapes.^{2.MD.1} Although this appears to some adults to be relatively simple, there are many conceptual and procedural issues to address. For example, students may begin counting at the numeral “1” on a ruler. The numerals on a ruler may signify to students when to start counting, rather than the amount of space that has already been covered. It is vital that students learn that “one” represents the space from the beginning of the ruler to the hash mark, not the hash mark itself. Again, students may not understand that units must be of equal size. They will even measure with tools subdivided into units of different sizes and conclude that quantities with more units are larger.

To learn measurement concepts and skills, students might use both simple rulers (e.g., having only whole units such as centimeters or inches) and physical units (e.g., manipulatives that are centimeter or inch lengths). As described for Grade 1, teachers and students can call these “length-units.” Initially, students lay multiple copies of the same physical unit end-to-end along the ruler. They can also progress to iterating with one physical unit (i.e., repeatedly marking off its endpoint, then moving it to the next position), even though this is more difficult physically and conceptually. To help them make the transition to this more sophisticated understanding of measurement, students might draw length unit marks along sides of geometric shapes or other lengths to see the unit lengths. As they measure with these tools, students with the help of the teacher discuss the concepts and skills involved, such as the following.

- *length-unit iteration.* E.g., not leaving space between successive length-units;
- *accumulation of distance.* Understanding that the counting “eight” when placing the last length-unit means the space covered by 8 length-units, rather than just the eighth length-unit (note the connection to cardinality^{K.CC.4});
- *alignment of zero-point.* Correct alignment of the zero-point on a ruler as the beginning of the total length, including the case in which the 0 of the ruler is not at the edge of the physical ruler;
- *meaning of numerals on the ruler.* The numerals indicate the number of length units so far;
- *connecting measurement with physical units and with a ruler.* Measuring by laying physical units end-to-end or iterating a physical unit and measuring with a ruler both focus on finding the total number of unit lengths.

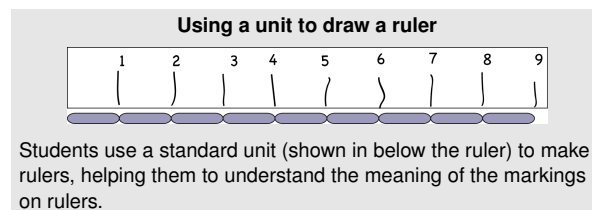
2.MD.1 Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, meter sticks, and measuring tapes.

K.CC.4 Understand the relationship between numbers and quantities; connect counting to cardinality.

Students also can learn accurate procedures and concepts by drawing simple unit rulers. Using copies of a single length-unit such as inch-long manipulatives, they mark off length-units on strips of paper, explicitly connecting measurement with the ruler to measurement by iterating physical units. Thus, students' first rulers should be simply ways to help count the iteration of length-units. Frequently comparing results of measuring the same object with manipulative standard units and with these rulers helps students connect their experiences and ideas. As they build and use these tools, they develop the ideas of length-unit iteration, correct alignment (with a ruler), and the zero-point concept (the idea that the zero of the ruler indicates one endpoint of a length). These are reinforced as children compare the results of measuring to compare to objects with the results of directly comparing these objects.

Similarly, discussions might frequently focus on "What are you counting?" with the answer being "length-units" or "centimeters" or the like. This is especially important because counting discrete items often convinces students that the size of things counted does not matter (there could be exactly 10 toys, even if they are different sizes). In contrast, for measurement, unit size is critical, so teachers are advised to plan experiences and reflections on the use of other units and length-units in various discrete counting and measurement contexts. Given that counting discrete items often correctly teaches students that the length-unit size does not matter, so teachers are advised to plan experiences and reflections on the use of units in various discrete counting and measurement contexts. For example, a teacher might challenge students to consider a fictitious student's measurement in which he lined up three large and four small blocks and claimed a path was "seven blocks long." Students can discuss whether he is correct or not.

Second graders also learn the concept of the inverse relationship between the size of the unit of length and the number of units required to cover a specific length or distance.^{2.MD.2} For example, it will take more centimeter lengths to cover a certain distance than inch lengths because inches are the larger unit. Initially, students may not appreciate the need for identical units. Previously described work with manipulative units of standard measure (e.g., 1 inch or 1 cm), along with related use of rulers and consistent discussion, will help children learn both the concepts and procedures of linear measurement. Thus, second grade students can learn that the larger the unit, the fewer number of units in a given measurement (as was illustrated on p. 9). That is, for measurements of a given length there is an inverse relationship between the size of the unit of measure and the number of those units. This is the time that measuring and reflecting on measuring the same object with different units, both standard and nonstandard, is likely to be most productive (see the discussion of this issue in the Grade 1 section on length). Results of measuring with different nonstandard length-units can be explicitly compared. Students also can use the concept of unit to make



2.MD.2 Measure the length of an object twice, using length units of different lengths for the two measurements; describe how the two measurements relate to the size of the unit chosen.

inferences about the relative sizes of objects; for example, if object A is 10 regular paperclips long and object B is 10 jumbo paperclips long, the number of units is the same, but the units have different sizes, so the lengths of A and B are different.

Second graders also learn to combine and compare lengths using arithmetic operations. That is, they can add two lengths to obtain the length of the whole and subtract one length from another to find out the difference in lengths.^{2.MD.4} For example, they can use a simple unit ruler or put a length of connecting cubes together to measure first one modeling clay “snake,” then another, to find the total of their lengths. The snakes can be laid along a line, allowing students to compare the measurement of that length with the sum of the two measurements. Second graders also begin to apply the concept of length in less obvious cases, such as the width of a circle, the length and width of a rectangle, the diagonal of a quadrilateral, or the height of a pyramid. As an arithmetic example, students might measure all the sides of a table with unmarked (foot) rulers to measure how much ribbon they would need to decorate the perimeter of the table.^{2.MD.5} They learn to measure two objects and subtract the smaller measurement from the larger to find how much longer one object is than the other.

Second graders can also learn to represent and solve numerical problems about length using tape or number-bond diagrams. (See p. 16 of the Operations and Algebraic Thinking Progression for discussion of when and how these diagrams are used in Grade 1.) Students might solve two-step numerical problems at different levels of sophistication (see p. 18 of the Operations and Algebraic Thinking Progression for similar two-step problems involving discrete objects). Conversely, “missing measurements” problems about length may be presented with diagrams.

These understandings are essential in supporting work with number line diagrams.^{2.MD.6} That is, to use a number line diagram to understand number and number operations, students need to understand that number line diagrams have specific conventions: the use of a single position to represent a whole number and the use of marks to indicate those positions. They need to understand that a number line diagram is like a ruler in that consecutive whole numbers are 1 unit apart, thus they need to consider the distances between positions and segments when identifying missing numbers. These understandings underlie students’ successful use of number line diagrams. Students think of a number line diagram as a measurement model and use strategies relating to distance, proximity of numbers, and reference points.

After experience with measuring, second graders learn to estimate lengths.^{2.MD.3} Real-world applications of length often involve estimation. Skilled estimators move fluently back and forth between written or verbal length measurements and representations of their corresponding magnitudes on a *mental ruler* (also called the “mental number line”). Although having real-world “benchmarks” is useful

2.MD.4 Measure to determine how much longer one object is than another, expressing the length difference in terms of a standard length unit.

2.MD.5 Use addition and subtraction within 100 to solve word problems involving lengths that are given in the same units, e.g., by using drawings (such as drawings of rulers) and equations with a symbol for the unknown number to represent the problem.

Missing measurements problems

Different solution methods for “A girl had a 43 cm section of a necklace and another section that was 8 cm shorter than the first. How long the necklace would be if she combined the two sections?” ^{2.MD.5}

Missing measurements problems

These problems might be presented in the context of turtle geometry. Students work on paper to figure out how far the Logo turtle would have to travel to *finish* drawing the house (the remainder of the right side, and the bottom). They then type in Logo commands (e.g., for the rectangle, forward 40 right 90 fd 100 rt 90 fd 20 fd 20 rt 90 fd 100) to check their calculations (MP5).

2.MD.6 Represent whole numbers as lengths from 0 on a number line diagram with equally spaced points corresponding to the numbers 0, 1, 2, . . . , and represent whole-number sums and differences within 100 on a number line diagram.

2.MD.3 Estimate lengths using units of inches, feet, centimeters, and meters.

(e.g., a meter is about the distance from the floor to the top of a door-knob), instruction should also help children build understandings of scales and concepts of measurement into their estimation competencies. Although “guess and check” experiences can be useful, research suggests explicit teaching of estimation strategies (such as iteration of a mental image of the unit or comparison with a known measurement) and prompting students to learn reference or benchmark lengths (e.g., an inch-long piece of gum, a 6-inch dollar bill), order points along a continuum, and build up mental rulers.

Length measurement should also be used in other domains of mathematics, as well as in other subjects, such as science, and connections should be made where possible. For example, a line plot scale is just a ruler, usually with a non-standard unit of length. Teachers can ask students to discuss relationships they see between rulers and line plot scales. Data using length measures might be graphed (see example on pp. 8–9 of the Measurement Data Progression). Students could also graph the results of many students measuring the same object as precisely as possible (even involving halves or fourths of a unit) and discuss what the “real” measurement of the object might be. Emphasis on students solving real measurement problems, and, in so doing, building and iterating units, as well as units of units, helps students development strong concepts and skills. When conducted in this way, measurement tools and procedures become tools for mathematics and tools for thinking about mathematics.

Area and volume: Foundations To learn area (and, later, volume) concepts and skills meaningfully in later grades, students need to develop the ability known as *spatial structuring*. Students need to be able to see a rectangular region as decomposable into rows and columns of squares. This competence is discussed in detail in the Geometry Progression, but is mentioned here for two reasons. First, such spatial structuring precedes meaningful mathematical use of the structures, such as determining area or volume. Second, Grade 2 work in multiplication involves work with rectangular arrays,^{2.G.2} and this work is an ideal context in which to simultaneously develop both arithmetical and spatial structuring foundations for later work with area.

2.G.2 Partition a rectangle into rows and columns of same-size squares and count to find the total number of them.

Grade 3

Perimeter Third graders focus on solving real-world and mathematical problems involving perimeters of polygons.^{3.MD.8} A perimeter is the boundary of a two-dimensional shape. For a polygon, the length of the perimeter is the sum of the lengths of the sides. Initially, it is useful to have sides marked with unit length marks, allowing students to count the unit lengths. Later, the lengths of the sides can be labeled with numerals. As with all length tasks, students need to count the length-units and not the end-points. Next, students learn to mark off unit lengths with a ruler and label the length of each side of the polygon. For rectangles, parallelograms, and regular polygons, students can discuss and justify faster ways to find the perimeter length than just adding all of the lengths (MP3). Rectangles and parallelograms have opposite sides of equal length, so students can double the lengths of adjacent sides and add those numbers or add lengths of two adjacent sides and double that number. A regular polygon has all sides of equal length, so its perimeter length is the product of one side length and the number of sides.

Perimeter problems for rectangles and parallelograms often give only the lengths of two adjacent sides or only show numbers for these sides in a drawing of the shape. The common error is to add just those two numbers. Having students first label the lengths of the other two sides as a reminder is helpful.

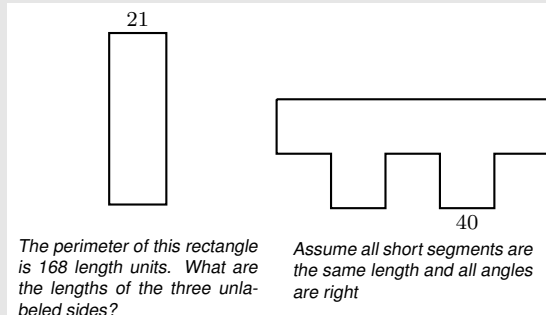
Students then find unknown side lengths in more difficult “missing measurements” problems and other types of perimeter problems.^{3.MD.8}

Children learn to subdivide length-units. Making one’s own ruler and marking halves and other partitions of the unit may be helpful in this regard. For example, children could fold a unit in halves, mark the fold as a half, and then continue to do so, to build fourths and eighths, discussing issues that arise. Such activities relate to fractions on the number line.^{3.NF.2} Labeling all of the fractions can help students understand rulers marked with halves and fourths but not labeled with these fractions. Students also measure lengths using rulers marked with halves and fourths of an inch.^{3.MD.4} They show these data by making a line plot, where the horizontal scale is marked off in appropriate units—whole numbers, halves, or quarters (see the Measurement Data Progression, p. 10).

Understand concepts of area and relate area to multiplication and to addition Third graders focus on learning area. Students learn formulas to compute area, with those formulas based on, and summarizing, a firm conceptual foundation about what area is. Students need to learn to conceptualize area as the amount of two-dimensional space in a bounded region and to measure it by choosing a unit of area, often a square. A two-dimensional geometric figure that is covered by a certain number of squares without gaps

3.MD.8 Solve real world and mathematical problems involving perimeters of polygons, including finding the perimeter given the side lengths, finding an unknown side length, and exhibiting rectangles with the same perimeter and different areas or with the same area and different perimeters.

Missing measurements and other perimeter problems



Compare these problems with the “missing measurements” problems of Grade 2.

Another type of perimeter problem is to draw a robot on squared grid paper that meets specific criteria. All the robot’s body parts must be rectangles. The perimeter of the head might be 36 length-units, the body, 72; each arm, 24; and each leg, 72. Students are asked to provide a convincing argument that their robots meet these criteria (MP3). Next, students are asked to figure out the area of each of their body parts (in square units). These are discussed, with students led to reflect on the different areas that may be produced with rectangles of the same perimeter. These types of problems can be also presented as turtle geometry problems. Students create the commands on paper and then give their commands to the Logo turtle to check their calculations. For turtle length units, the perimeter of the head might be 300 length-units, the body, 600; each arm, 400; and each leg, 640.

3.NF.2 Understand a fraction as a number on the number line; represent fractions on a number line diagram.

3.MD.4 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 off in appropriate units—whole numbers, halves, or quarters.

or overlaps can be said to have an area of that number of square units.^{3.MD.5}

Activities such as those in the Geometry Progression teach students to compose and decompose geometric regions. To begin an explicit focus on area, teachers might then ask students which of three rectangles covers the most area. Students may first solve the problem with decomposition (cutting and/or folding) and re-composition, and eventually analyses with area-units, by covering each with unit squares (tiles).^{3.MD.5, 3.MD.6} Discussions should clearly distinguish the attribute of area from other attributes, notably length.

Students might then find the areas of other rectangles. As previously stated, students can be taught to multiply length measurements to find the area of a rectangular region. But, in order that they make sense of these quantities (MP2), they first learn to interpret measurement of rectangular regions as a multiplicative relationship of the number of square units in a row and the number of rows.^{3.MD.7a} This relies on the development of spatial structuring.^{MP7} To build from spatial structuring to understanding the number of area-units as the product of number of units in a row and number of rows, students might draw rectangular arrays of squares and learn to determine the number of squares in each row with increasingly sophisticated strategies, such as skip-counting the number in each row and eventually multiplying the number in each row by the number of rows (MP8). They learn to partition a rectangle into identical squares by anticipating the final structure and forming the array by drawing line segments to form rows and columns. They use skip counting and multiplication to determine the number of squares in the array.

Many activities that involve seeing and making arrays of squares to form a rectangle might be needed to build robust conceptions of a rectangular area structured into squares. One such activity is illustrated in the margin. In this progression, less sophisticated activities of this sort were suggested for earlier grades so that Grade 3 students begin with some experience.

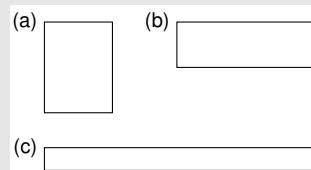
Students learn to understand and explain why multiplying the side lengths of a rectangle yields the same measurement of area as counting the number of tiles (with the same unit length) that fill the rectangle's interior (MP3).^{3.MD.7a} For example, students might explain that one length tells how many unit squares in a row and the other length tells how many rows there are.

Students might then solve numerous problems that involve rectangles of different dimensions (e.g., designing a house with rooms that fit specific area criteria) to practice using multiplication to compute areas.^{3.MD.7b} The areas involved should not all be rectangular, but decomposable into rectangles (e.g., an "L-shaped" room).^{3.MD.7d}

Students also might solve problems such as finding all the rectangular regions with whole-number side lengths that have an area of 12 area-units, doing this later for larger rectangles (e.g., enclosing 24, 48, or 72 area-units), making sketches rather than drawing each

3.MD.5 Recognize area as an attribute of plane figures and understand concepts of area measurement.

Which rectangle covers the most area?



These rectangles are formed from unit squares (tiles students have used) although students are not informed of this or the rectangle's dimensions: (a) 4 by 3, (b) 2 by 6, and (c) 1 row of 12. Activity from Lehrer, et al., 1998, "Developing understanding of geometry and space in the primary grades," in R. Lehrer & D. Chazan (Eds.), *Designing Learning Environments for Developing Understanding of Geometry and Space*, Lawrence Erlbaum Associates.

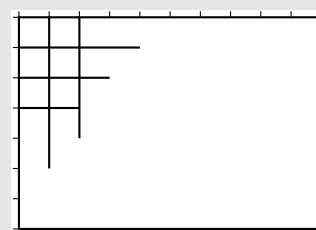
3.MD.5 Recognize area as an attribute of plane figures and understand concepts of area measurement.

3.MD.6 Measure areas by counting unit squares (square cm, square m, square in, square ft, and improvised units).

3.MD.7a Find the area of a rectangle with whole-number side lengths by tiling it, and show that the area is the same as would be found by multiplying the side lengths.

MP7 See the Geometry Progression

Incomplete array



To determine the area of this rectangular region, students might be encouraged to construct a row, corresponding to the indicated positions, then repeating that row to fill the region. Cutouts of strips of rows can help the needed spatial structuring and reduce the time needed to show a rectangle as rows or columns of squares. Drawing all of the squares can also be helpful, but it is slow for larger rectangles. Drawing the unit lengths on the opposite sides can help students see that joining opposite unit end-points will create the needed unit square grid.

3.MD.7b Multiply side lengths to find areas of rectangles with whole-number side lengths in the context of solving real world and mathematical problems, and represent whole-number products as rectangular areas in mathematical reasoning.

3.MD.7d Recognize area as additive. Find areas of rectilinear figures by decomposing them into non-overlapping rectangles and adding the areas of the non-overlapping parts, applying this technique to solve real world problems.

square. They learn to justify their belief they have found all possible solutions (MP3).

Similarly using concrete objects or drawings, and their competence with composition and decomposition of shapes, spatial structuring, and addition of area measurements, students learn to investigate arithmetic properties using area models. For example, they learn to rotate rectangular arrays physically and mentally, understanding that their areas are preserved under rotation, and thus, for example, $4 \times 7 = 7 \times 4$, illustrating the commutative property of multiplication.^{3.MD.7c} They also learn to understand and explain that the area of a rectangular region of, for example, 12 length-units by 5 length-units can be found either by multiplying 12×5 , or by adding two products, e.g., 10×5 and 2×5 , illustrating the distributive property.

Recognize perimeter as an attribute of plane figures and distinguish between linear and area measures

With strong and distinct concepts of both perimeter and area established, students can work on problems to differentiate their measures. For example, they can find and sketch rectangles with the same perimeter and different areas or with the same area and different perimeters and justify their claims (MP3).^{3.MD.8} Differentiating perimeter from area is facilitated by having students draw congruent rectangles and measure, mark off, and label the unit lengths all around the perimeter on one rectangle, then do the same on the other rectangle but also draw the square units. This enables students to see the units involved in length and area and find patterns in finding the lengths and areas of non-square and square rectangles (MP7). Students can continue to describe and show the units involved in perimeter and area after they no longer need these .

Problem solving involving measurement and estimation of intervals of time, liquid volumes, and masses of objects

Students in Grade 3 learn to solve a variety of problems involving measurement and such attributes as length and area, liquid volume, mass, and time.^{3.MD.1, 3.MD.2} Many such problems support the Grade 3 emphasis on multiplication (see Table 1) and the mathematical practices of making sense of problems (MP1) and representing them with equations, drawings, or diagrams (MP4). Such work will involve units of mass such as the kilogram.

3.MD.7c Use tiling to show in a concrete case that the area of a rectangle with whole-number side lengths a and $b + c$ is the sum of $a \times b$ and $a \times c$. Use area models to represent the distributive property in mathematical reasoning.

3.MD.8 Solve real world and mathematical problems involving perimeters of polygons, including finding the perimeter given the side lengths, finding an unknown side length, and exhibiting rectangles with the same perimeter and different areas or with the same area and different perimeters.

3.MD.1 Tell and write time to the nearest minute and measure time intervals in minutes. Solve word problems involving addition and subtraction of time intervals in minutes, e.g., by representing the problem on a number line diagram.

3.MD.2 Measure and estimate liquid volumes and masses of objects using standard units of grams (g), kilograms (kg), and liters (l).² Add, subtract, multiply, or divide to solve one-step word problems involving masses or volumes that are given in the same units, e.g., by using drawings (such as a beaker with a measurement scale) to represent the problem.³

Table 1: Multiplication and division situations for measurement

| | Unknown Product $A \times B = \square$ | Group Size Unknown $A \times \square = C$ and $C \div A = \square$ | Number of Groups Unknown $\square \times B = C$ and $C \div B = \square$ |
|--|--|---|--|
| Grouped Objects (Units of Units) | You need A lengths of string, each B inches long. How much string will you need altogether? | You have C inches of string, which you will cut into A equal pieces. How long will each piece of string be? | You have C inches of string, which you will cut into pieces that are B inches long. How many pieces of string will you have? |
| Arrays of Objects (Spatial Structuring) | What is the area of a A cm by B cm rectangle? | A rectangle has area C square centimeters. If one side is A cm long, how long is a side next to it? | A rectangle has area C square centimeters. If one side is B cm long, how long is a side next to it? |
| Compare | A rubber band is B cm long. How long will the rubber band be when it is stretched to be A times as long? | A rubber band is stretched to be C cm long and that is A times as long as it was at first. How long was the rubber band at first? | A rubber band was B cm long at first. Now it is stretched to be C cm long. How many times as long is the rubber band now as it was at first? |

Adapted from box 2-4 of *Mathematics Learning in Early Childhood: Paths Toward Excellence and Equity*, National Research Council, 2009, pp. 32–33. Note that Grade 3 work does not include Compare problems with “times as much,” see the Operations and Algebraic Thinking Progression, Table 3, also p. 29.

A few words on volume are relevant. Compared to the work in area, volume introduces more complexity, not only in adding a third dimension and thus presenting a significant challenge to students’ spatial structuring, but also in the materials whose volumes are measured. These materials may be solid or fluid, so their volumes are generally measured with one of two methods, e.g., “packing” a right rectangular prism with cubic units or “filling” a shape such as a right circular cylinder. Liquid measurement, for many third graders, may be limited to a one-dimensional unit structure (i.e., simple iterative counting of height that is not processed as three-dimensional). Thus, third graders can learn to measure with liquid volume and to solve problems requiring the use of the four arithmetic operations, when liquid volumes are given in the same units throughout each problem. Because liquid measurement can be represented with one-dimensional scales, problems may be presented with drawings or diagrams, such as measurements on a beaker with a measurement scale in milliliters.

Grade 4

In Grade 4, students build on competencies in measurement and in building and relating units and units of units that they have developed in number, geometry, and geometric measurement.

Solve problems involving measurement and conversion of measurements from a larger unit to a smaller unit Fourth graders learn the relative sizes of measurement units within a system of measurement^{4.MD.1} including:

length: meter (m), kilometer (km), centimeter (cm), millimeter (mm); *volume:* liter (l), milliliter (ml, 1 cubic centimeter of water; a liter, then, is 1000 ml);

mass: gram (g, about the weight of a cc of water), kilogram (kg); *time:* hour (hr), minute (min), second (sec).

For example, students develop benchmarks and mental images about a meter (e.g., about the height of a tall chair) and a kilometer (e.g., the length of 10 football fields including the end zones, or the distance a person might walk in about 12 minutes), and they also understand that “kilo” means a thousand, so 3000 m is equivalent to 3 km.

Expressing larger measurements in smaller units within the metric system is an opportunity to reinforce notions of place value. There are prefixes for multiples of the basic unit (meter or gram), although only a few (kilo-, centi-, and milli-) are in common use. Tables such as the one in the margin indicate the meanings of the prefixes by showing them in terms of the basic unit (in this case, meters). Such tables are an opportunity to develop or reinforce place value concepts and skills in measurement activities.

Relating units within the metric system is another opportunity to think about place value. For example, students might make a table that shows measurements of the same lengths in centimeters and meters.

Relating units within the traditional system provides an opportunity to engage in mathematical practices, especially “look for and make use of structure” (MP7) and “look for and express regularity in repeated reasoning” (MP8). For example, students might make a table that shows measurements of the same lengths in feet and inches.

Students also combine competencies from different domains as they solve measurement problems using all four arithmetic operations, addition, subtraction, multiplication, and division (see examples in Table 1).^{4.MD.2} For example, “How many liters of juice does the class need to have at least 35 cups if each cup takes 225 ml?” Students may use tape or number line diagrams for solving such problems (MP1).

4.MD.1 Know relative sizes of measurement units within one system of units including km, m, cm; kg, g; lb, oz.; l, ml; hr, min, sec. Within a single system of measurement, express measurements in a larger unit in terms of a smaller unit. Record measurement equivalents in a two-column table.

| Super- or subordinate unit | Length in terms of basic unit |
|----------------------------|--------------------------------------|
| kilometer | 10^3 or 1000 meters |
| hectometer | 10^2 or 100 meters |
| decameter | 10^1 or 10 meters |
| meter | 1 meter |
| decimeter | 10^{-1} or $\frac{1}{10}$ meters |
| centimeter | 10^{-2} or $\frac{1}{100}$ meters |
| millimeter | 10^{-3} or $\frac{1}{1000}$ meters |

Note the similarity to the structure of base-ten units and U.S. currency (see illustrations on p. 12 of the Number and Operations in Base Ten Progression).

Centimeter and meter equivalences

| cm | m |
|------|---|
| 100 | 1 |
| 200 | 2 |
| 300 | 3 |
| 500 | |
| 1000 | |

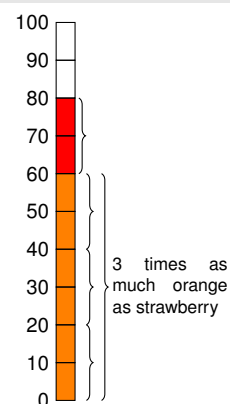
Foot and inch equivalences

| feet | inches |
|------|--------|
| 0 | 0 |
| 1 | 12 |
| 2 | 24 |
| 3 | |
| | |

4.MD.2 Use the four operations to solve word problems involving distances, intervals of time, liquid volumes, masses of objects, and money, including problems involving simple fractions or decimals, and problems that require expressing measurements given in a larger unit in terms of a smaller unit. Represent measurement quantities using diagrams such as number line diagrams that feature a measurement scale.

Using tape diagrams to solve word problems

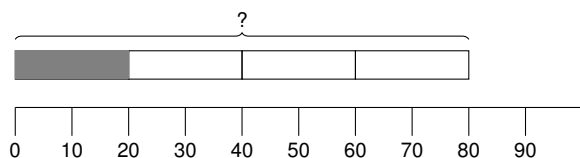
Lisa put two flavors of soda in a glass. There were 80 ml of soda in all. She put three times as much orange drink as strawberry. How many ml of orange did she put in?



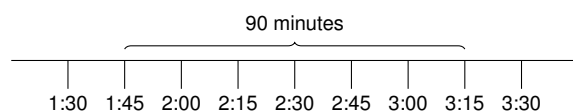
In this diagram, quantities are represented on a measurement scale.

Using number line diagrams to solve word problems

Juan spent $\frac{1}{4}$ of his money on a game. The game cost \$20. How much money did he have at first?



What time does Marla have to leave to be at her friend's house by a quarter after 3 if the trip takes 90 minutes?



Using a number line diagram to represent time is easier if students think of digital clocks rather than round clocks. In the latter case, placing the numbers on the number line involves considering movements of the hour and minute hands.

Students learn to consider perimeter and area of rectangles, begun in Grade 3, more abstractly (MP2). Based on work in previous grades with multiplication, spatially structuring arrays, and area, they abstract the formula for the area of a rectangle $A = l \times w$.

Students generate and discuss advantages and disadvantages of various formulas for the perimeter length of a rectangle that is l units by w units. Giving verbal summaries of these formulas is also helpful. For example, a verbal summary of the basic formula, $A = l + w + l + w$, is "add the lengths of all four sides." Specific numerical instances of other formulas or mental calculations for the perimeter of a rectangle can be seen as examples of the properties of operations, e.g., $2l + 2w = 2(l + w)$ illustrates the distributive property.

Perimeter problems often give only one length and one width, thus remembering the basic formula can help to prevent the usual error of only adding one length and one width. The formula $P = 2(l + w)$ emphasizes the step of multiplying the total of the given lengths by 2. Students can make a transition from showing all length units along the sides of a rectangle or all area units within (as in Grade 3, p. 18) by drawing a rectangle showing just parts of these as a reminder of which kind of unit is being used. Writing all of the lengths around a rectangle can also be useful. Discussions of formulas such as $P = 2l + 2w$, can note that unlike area formulas, perimeter formulas combine length measurements to yield a length measurement.

Such abstraction and use of formulas underscores the importance of distinguishing between area and perimeter in Grade 3^{3.MD.8} and maintaining the distinction in Grade 4 and later grades, where rectangle perimeter and area problems may get more complex and problem solving can benefit from knowing or being able to rapidly remind oneself of how to find an area or perimeter. By repeatedly reasoning about how to calculate areas and perimeters of rectangles, students can come to see area and perimeter formulas as summaries of all such calculations (MP8).

- The formula is a generalization of the understanding, that, given a unit of length, a rectangle whose sides have length w units and l units, can be partitioned into w rows of unit squares with l squares in each row. The product $l \times w$ gives the number of unit squares in the partition, thus the area measurement is $l \times w$ square units. These square units are derived from the length unit.

- For example, $P = 2l + 2w$ has two multiplications and one addition, but $P = 2(l + w)$, which has one addition and one multiplication, involves fewer calculations. The latter formula is also useful when generating all possible rectangles with a given perimeter. The length and width vary across all possible pairs whose sum is half of the perimeter (e.g., for a perimeter of 20, the length and width are all of the pairs of numbers with sum 10).

3.MD.8 Solve real world and mathematical problems involving perimeters of polygons, including finding the perimeter given the side lengths, finding an unknown side length, and exhibiting rectangles with the same perimeter and different areas or with the same area and different perimeters.

Students learn to apply these understandings and formulas to the solution of real-world and mathematical problems.^{4.MD.3} For example, they might be asked, “A rectangular garden has an area of 80 square feet. It is 5 feet wide. How long is the garden?” Here, specifying the area and the width, creates an unknown factor problem (see Table 1). Similarly, students could solve perimeter problems that give the perimeter and the length of one side and ask the length of the adjacent side. Students could be challenged to solve multi-step problems such as the following. “A plan for a house includes rectangular room with an area of 60 square meters and a perimeter of 32 meters. What are the length and the width of the room?”

In Grade 4 and beyond, the mental visual images for perimeter and area from Grade 3 can support students in problem solving with these concepts. When engaging in the mathematical practice of reasoning abstractly and quantitatively (MP2) in work with area and perimeter, students think of the situation and perhaps make a drawing. Then they recreate the “formula” with specific numbers and one unknown number as a situation equation for this particular numerical situation. • “Apply the formula” does not mean write down a memorized formula and put in known values because at Grade 4 students do not evaluate expressions (they begin this type of work in Grade 6). In Grade 4, working with perimeter and area of rectangles is still grounded in specific visualizations and numbers. These numbers can now be any of the numbers used in Grade 4 (for addition and subtraction for perimeter and for multiplication and division for area).^{4.NBT.4, 4.NF.3d, 4.OA.4} By repeatedly reasoning about constructing situation equations for perimeter and area involving specific numbers and an unknown number, students will build a foundation for applying area, perimeter, and other formulas by substituting specific values for the variables in later grades.

Understand concepts of angle and measure angles Angle measure is a “turning point” in the study of geometry. Students often find angles and angle measure to be difficult concepts to learn, but that learning allows them to engage in interesting and important mathematics. An *angle* is the union of two rays, a and b , with the same initial point P . The rays can be made to coincide by rotating one to the other about P ; this rotation determines the size of the angle between a and b . The rays are sometimes called the *sides* of the angles.

Another way of saying this is that each ray determines a direction and the angle size measures the change from one direction to the other. (This illustrates how angle measure is related to the concepts of parallel and perpendicular lines in Grade 4 geometry.) A clockwise rotation is considered positive in surveying or turtle geometry; but a counterclockwise rotation is considered positive in Euclidean geometry. Angles are measured with reference to a circle with its center at the common endpoint of the rays, by considering

4.MD.3 Apply the area and perimeter formulas for rectangles in real world and mathematical problems.

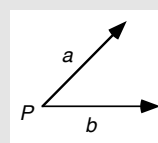
• “Situation equation” refers to the idea that the student constructs an equation as a representation of a situation rather than identifying the situation as an example of a familiar equation.

4.NBT.4 Fluently add and subtract multi-digit whole numbers using the standard algorithm.

4.NF.3d Solve word problems involving addition and subtraction of fractions referring to the same whole and having like denominators, e.g., by using visual fraction models and equations to represent the problem.

4.OA.4 Find all factor pairs for a whole number in the range 1–100. Recognize that a whole number is a multiple of each of its factors. Determine whether a given whole number in the range 1–100 is a multiple of a given one-digit number. Determine whether a given whole number in the range 1–100 is prime or composite.

An angle



P is called the *vertex* of the angle and the rays a and b are called the *arms*.

the fraction of the circular arc between the points where the two rays intersect the circle. An angle that turns through $\frac{1}{360}$ of a circle is called a "one-degree angle," and degrees are the unit used to measure angles in elementary school. A full rotation is thus 360° .

Two angles are called *complementary* if their measurements have the sum of 90° . Two angles are called *supplementary* if their measurements have the sum of 180° . Two angles with the same vertex that overlap only at a boundary (i.e., share a side) are called *adjacent angles*.

Like length, area, and volume, angle measure is additive: The sum of the measurements of *adjacent angles* is the measurement of the angle formed by their union. This leads to other important properties. If a right angle is decomposed into two adjacent angles, the sum is 90° , thus they are complementary. Two adjacent angles that compose a "straight angle" of 180° must be supplementary. In some situations (see margin), such properties allow logical progressions of statements (MP3).

As with all measurable attributes, students must first recognize the attribute of angle measure, and distinguish it from other attributes. This may not appear too difficult, as the measure of angles and rotations appears to knowledgeable adults as quite different than attributes such as length and area. However, the unique nature of angle size leads many students to initially confuse angle measure with other, more familiar, attributes. Even in contexts designed to evoke a dynamic image of turning, such as hinges or doors, many students use the length between the endpoints, thus teachers find it useful to repeatedly discuss such cognitive "traps."

As with other concepts (e.g., see the Geometry Progression), students need varied examples and explicit discussions to avoid learning limited ideas about measuring angles (e.g., misconceptions that a right angle is an angle that points to the right, or two right angles represented with different orientations are not equal in measure). If examples and tasks are not varied, students can develop incomplete and inaccurate notions. For example, some come to associate all slanted lines with 45° measures and horizontal and vertical lines with measures of 90° . Others believe angles can be "read off" a protractor in "standard" position, that is, a base is horizontal, even if neither arm of the angle is horizontal. Measuring and then sketching many angles with no horizontal or vertical arms,^{4.MD.6} perhaps initially using circular 360° protractors, can help students avoid such limited conceptions.

As with length, area, and volume, children need to understand equal partitioning and unit iteration to understand angle and turn measure. Whether defined as more statically as the measure of the figure formed by the intersection of two rays or as turning, having a given angle measure involves a relationship between components of plane figures and therefore is a *property* (see the Overview in the Geometry Progression).^{4.G.2}

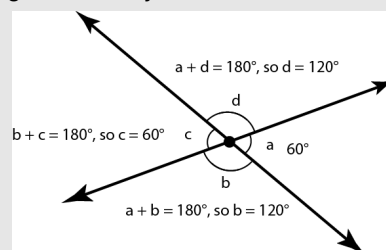
Given the complexity of angles and angle measure, it is unsur-

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An angle

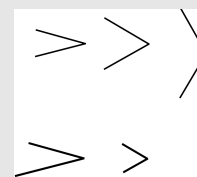
| name | measurement |
|----------------|-------------------------------------|
| right angle | 90° |
| straight angle | 180° |
| acute angle | between 0 and 90° |
| obtuse angle | between 90° and 180° |
| reflex angle | between 180° and 360° |

Angles created by the intersection of two lines



When two lines intersect, they form four angles. If the measurement of one is known (e.g., angle a is 60°), the measurement of the other three can be determined.

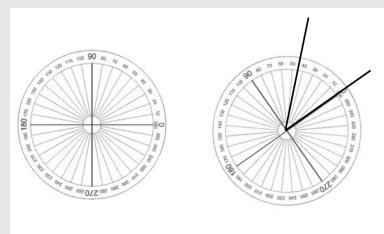
Two representations of three angles



Initially, some students may correctly compare angle sizes only if all the line segments are the same length (as shown in the top row). If the lengths of the line segments are different (as shown in the bottom row), these students base their judgments on the lengths of the segments, the distances between their endpoints, or even the area of the triangles determined by the drawn arms. They believe that the angles in the bottom row decrease in size from left to right, although they have, respectively, the same angle measurements as those in the top row.

4.MD.6 Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.

A 360° protractor and its use



The figure on the right shows a protractor being used to measure a 45° angle. The protractor is placed so that one side of the angle lies on the line corresponding to 0° on the protractor and the other side of the angle is located by a clockwise rotation from that line.

4.G.2 Classify two-dimensional figures based on the presence or absence of parallel or perpendicular lines, or the presence or absence of angles of a specified size. Recognize right triangles as a category, and identify right triangles.

prising that students in the early and elementary grades often form separate concepts of angles as figures and turns, and may have separate notions for different turn contexts (e.g., unlimited rotation as a fan vs. a hinge) and for various “bends.”

However, students can develop more accurate and useful angle and angle measure concepts if presented with angles in a variety of situations. They learn to find the common features of superficially different situations such as turns in navigation, slopes, bends, corners, and openings. With guidance, they learn to represent an angle in any of these contexts as two rays, even when both rays are not explicitly represented in the context; for example, the horizontal or vertical in situations that involve slope (e.g., roads or ramps), or the angle determined by looking up from the horizon to a tree-or mountain-top. Eventually they abstract the common attributes of the situations as angles (which are represented with rays and a vertex, MP4) and angle measurements (MP2). To accomplish the latter, students integrate turns, and a general, dynamic understanding of angle measure-as-rotation, into their understandings of angles-as-objects. Computer manipulatives and tools can help children bring such a dynamic concept of angle measure to an explicit level of awareness. For example, dynamic geometry environments can provide multiple linked representations, such as a screen drawing that students can “drag” which is connected to a numerical representation of angle size. Games based on similar notions are particularly effective when students manipulate not the arms of the angle itself, but a representation of rotation (a small circular diagram with radii that, when manipulated, change the size of the target angle turned).

Students with an accurate conception of angle can recognize that angle measure is *additive*.^{4.MD.7} As with length, area, and volume, when an angle is decomposed into non-overlapping parts, the angle measure of the whole is the sum of the angle measures of the parts. Students can then solve interesting and challenging addition and subtraction problems to find the measurements of unknown angles on a diagram in real world and mathematical problems. For example, they can find the measurements of angles formed a pair of intersecting lines, as illustrated above, or given a diagram showing the measurement of one angle, find the measurement of its complement. They can use a protractor to check, not to check their reasoning, but to ensure that they develop full understanding of the mathematics and mental images for important benchmark angles (e.g., 30° , 45° , 60° , and 90°).

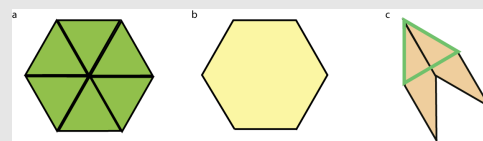
Such reasoning can be challenged with many situations as illustrated in the margin.

Similar activities can be done with drawings of shapes using right angles and half of a right angle to develop the important benchmarks of 90° and 45° .

Missing measures can also be done in the turtle geometry context, building on the previous work. Note that unguided use of Logo’s turtle geometry does not necessary develop strong angle

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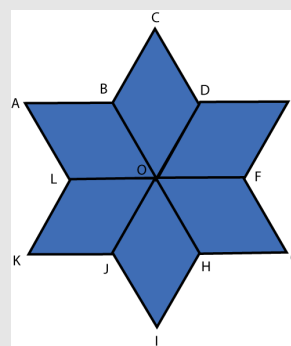
Determining angles in pattern blocks



Students might determine all the angles in the common “pattern block” shape set based on equilateral triangles. Placing six equilateral triangles so that they share a common vertex (as shown in part a), students can figure out that because the sum of the angles at this vertex is 360° , each angle which shares this vertex must have measure 60° . Because they are congruent, all the angles of the equilateral triangles must have measure 60° (again, to ensure they develop a firm foundation, students can verify these for themselves with a protractor). Because each angle of the regular hexagon (part b) is composed of two angles from equilateral triangles, the hexagon’s angles each measure 120° . Similarly, in a pattern block set, two of the smaller angles from tan rhombi compose an equilateral triangle’s angle, so each of the smaller rhombus angles has measure 30° .

4.MD.7 Recognize angle measure as additive. When an angle is decomposed into non-overlapping parts, the angle measure of the whole is the sum of the angle measures of the parts. Solve addition and subtraction problems to find unknown angles on a diagram in real world and mathematical problems, e.g., by using an equation with a symbol for the unknown angle measure.

Determining angle measurements



Students might be asked to determine the measurements of the following angles:

$\angle BOD$
 $\angle BOF$
 $\angle ODE$
 $\angle CDE$
 $\angle CDJ$
 $\angle BHG$

concepts. However, if teachers emphasize mathematical tasks and, within those tasks, the difference between the angle of rotation the turtle makes (in a polygon, the external angle) and the angle formed (internal angle) and integrates the two, students can develop accurate and comprehensive understandings of angle measure. For example, what series of commands would produce a square? How many degrees would the turtle turn? What is the measure of the resulting angle? What would be the commands for an equilateral triangle? How many degrees would the turtle turn? What is the measure of the resulting angle? Such questions help to connect what are often initially isolated ideas about angle conceptions.

These understandings support students in finding all the missing length and angle measures in situations such as the examples in the margin (compare to the missing measures problems Grade 2 and Grade 3).

Missing measures: Length (top) and length and angle (turn)

180

Assume equilateral triangle

Assume regular hexagon

Assume all segments in "steps" are the same length.

Students are asked to determine the missing lengths. They might first work on paper to figure out how far the Logo turtle would have to travel to *finish* drawing the house, then type in Logo commands to verify their reasoning and calculations.

Grade 5

Convert like measurement units within a given measurement system

In Grade 5, students extend their abilities from Grade 4 to express measurements in larger or smaller units within a measurement system.^{4.MD.1, 5.MD.1} This is an excellent opportunity to reinforce notions of place value for whole numbers and decimals, and connection between fractions and decimals (e.g., $2\frac{1}{2}$ meters can be expressed as 2.5 meters or 250 centimeters). For example, building on the table from Grade 4, Grade 5 students might complete a table of equivalent measurements in feet and inches.

Grade 5 students also learn and use such conversions in solving multi-step, real world problems (see example in the margin).

Understand concepts of volume and relate volume to multiplication and to addition

The major emphasis for measurement in Grade 5 is volume. Volume not only introduces a third dimension and thus a significant challenge to students' spatial structuring, but also complexity in the nature of the materials measured. That is, solid units are "packed," such as cubes in a three-dimensional array, whereas a liquid "fills" three-dimensional space, taking the shape of the container. As noted earlier (see Overview, also Grades 1 and 3), the unit structure for liquid measurement may be psychologically one-dimensional for some students.

"Packing" volume is more difficult than iterating a unit to measure length and measuring area by tiling. Students learn about a unit of volume, such as a cube with a side length of 1 unit, called a unit cube.^{5.MD.3} They pack cubes (without gaps) into right rectangular prisms and count the cubes to determine the volume or build right rectangular prisms from cubes and see the layers as they build.^{5.MD.4} They can use the results to compare the volume of right rectangular prisms that have different dimensions. Such experiences enable students to extend their spatial structuring from two to three dimensions (see the Geometry Progression). That is, they learn to both mentally decompose and recompose a right rectangular prism built from cubes into layers, each of which is composed of rows and columns. That is, given the prism, they have to be able to decompose it, understanding that it can be partitioned into layers, and each layer partitioned into rows, and each row into cubes. They also have to be able to compose such as structure, multiplicatively, back into higher units. That is, they eventually learn to conceptualize a layer as a unit that itself is composed of units of units—rows, each row composed of individual cubes—and they iterate that structure. Thus, they might predict the number of cubes that will be needed to fill a box given the net of the box.

Another complexity of volume is the connection between "packing" and "filling." Often, for example, students will respond that a box can be filled with 24 centimeter cubes, or build a structure of 24 cubes, and still think of the 24 as individual, often discrete, not

4.MD.1 Know relative sizes of measurement units within one system of units including km, m, cm; kg, g; lb, oz.; l, ml; hr, min, sec. Within a single system of measurement, express measurements in a larger unit in terms of a smaller unit. Record measurement equivalents in a two-column table.

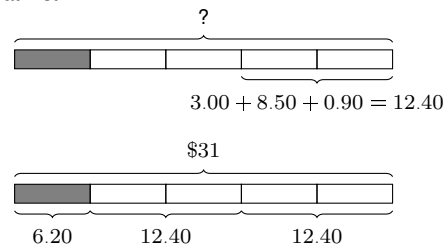
5.MD.1 Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.

| Feet | Inches |
|------|--------|
| 0 | 0 |
| | 1 |
| | 2 |
| | 3 |
| | |
| | |

In Grade 6, this table can be discussed in terms of ratios and proportional relationships (see the Ratio and Proportion Progression). In Grade 5, however, the main focus is on arriving at the measurements that generate the table.

Multi-step problem with unit conversion

Kumi spent a fifth of her money on lunch. She then spent half of what remained. She bought a card game for \$3, a book for \$8.50, and candy for 90 cents. How much money did she have at first?

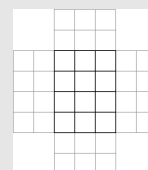


Students can use tape diagrams to represent problems that involve conversion of units, drawing diagrams of important features and relationships (MP1).

5.MD.3 Recognize volume as an attribute of solid figures and understand concepts of volume measurement.

5.MD.4 Measure volumes by counting unit cubes, using cubic cm, cubic in, cubic ft, and improvised units.

Net for five faces of a right rectangular prism



Students are given a net and asked to predict the number of cubes required to fill the container formed by the net. In such tasks, students may initially count single cubes or repeatedly add the number of cubes in a row to determine the number in each layer, and repeatedly add the number in each layer to find the total number of unit cubes. In folding the net to make the shape, students can see how the side rectangles fit together and determine the number of layers.

necessarily *units of volume*. They may, for example, not respond confidently and correctly when asked to fill a graduated cylinder marked in cubic centimeters with the amount of liquid that would fill the box. That is, they have not yet connected their ideas about filling volume with those concerning packing volume. Students learn to move between these conceptions, e.g., using the same container, both filling (from a graduated cylinder marked in ml or cc) and packing (with cubes that are each 1 cm^3). Comparing and discussing the volume-units and what they represent can help students learn a general, complete, and interconnected conceptualization of volume as filling three-dimensional space.

Students then learn to determine the volumes of several right rectangular prisms, using cubic centimeters, cubic inches, and cubic feet. With guidance, they learn to increasingly apply multiplicative reasoning to determine volumes, looking for and making use of structure (MP7). That is, they understand that multiplying the length times the width of a right rectangular prism can be viewed as determining how many cubes would be in each layer if the prism were packed with or built up from unit cubes.^{5.MD.5a} They also learn that the height of the prism tells how many layers would fit in the prism. That is, they understand that volume is a derived attribute that, once a length unit is specified, can be computed as the product of three length measurements or as the product of one area and one length measurement.

Then, students can learn the formulas $V = l \times w \times h$ and $V = B \times h$ for right rectangular prisms as efficient methods for computing volume, maintaining the connection between these methods and their previous work with computing the number of unit cubes that pack a right rectangular prism.^{5.MD.5b} They use these competencies to find the volumes of right rectangular prisms with edges whose lengths are whole numbers and solve real-world and mathematical problems involving such prisms.

Students also recognize that volume is additive (see Overview) and they find the total volume of solid figures composed of two right rectangular prisms.^{5.MD.5c} For example, students might design a science station for the ocean floor that is composed of several rooms that are right rectangular prisms and that meet a set criterion specifying the total volume of the station. They draw their station (e.g., using an isometric grid, MP7) and justify how their design meets the criterion (MP1).

5.MD.5a Find the volume of a right rectangular prism with whole-number side lengths by packing it with unit cubes, and show that the volume is the same as would be found by multiplying the edge lengths, equivalently by multiplying the height by the area of the base. Represent threefold whole-number products as volumes, e.g., to represent the associative property of multiplication.

5.MD.5b Apply the formulas $V = l \times w \times h$ and $V = b \times h$ for rectangular prisms to find volumes of right rectangular prisms with whole-number edge lengths in the context of solving real world and mathematical problems.

5.MD.5c Recognize volume as additive. Find volumes of solid figures composed of two non-overlapping right rectangular prisms by adding the volumes of the non-overlapping parts, applying this technique to solve real world problems.

Where the Geometric Measurement Progression is heading

Connection to Geometry In Grade 6, students build on their understanding of length, area, and volume measurement, learning to how to compute areas of right triangles and other special figures and volumes of right rectangular prisms that do not have measurements given in whole numbers. To do this, they use dissection arguments. These rely on the understanding that area and volume measures are additive, together with decomposition of plane and solid shapes (see the K–5 Geometry Progression) into shapes whose measurements students already know how to compute (MP1, MP7). In Grade 7, they use their understanding of length and area in learning and using formulas for the circumference and area of circles. In Grade 8, they use their understanding of volume in learning and using formulas for the volumes of cones, cylinders, and spheres. In high school, students learn formulas for volumes of pyramids and revisit the formulas from Grades 7 and 8, explaining them with dissection arguments, Cavalieri’s principle, and informal limit arguments.

Connection to the Number System In Grade 6, understanding of length-units and spatial structuring comes into play as students learn to plot points in the coordinate plane.

Connection to Ratio and Proportion Students use their knowledge of measurement and units of measurement in Grades 6–8, coming to see conversions between two units of measurement as describing proportional relationships.