Inspect for Accuracy and Precision

Print:

Quality Control Math - Inspect for Accuracy and Precision

Industry Sector: Advanced Manufacturing
Content Area: Mathematics
Core Topic: Decimals, fractions and percents

Expand All | Collapse All

Common Core State Standards

Content Standards

CCSS.Math.Content.6.NS.B.3 Fluently add, subtract, multiply, and divide multi-digit decimals using the standard algorithm for each operation.
CCSS.Math.Content.5.NBT.A.3 Read, write, and compare decimals to thousandths.

CCSS.Math.Content.5.NBT.A.3a Read and write decimals to thousandths using base-ten numerals, number names, and expanded form, e.g., 347.392 = 3 × 100 + 4 × 10 + 7 × 1 + 3 × (1/10) + 9 × (1/100) + 2 × (1/1000).
CCSS.Math.Content.5.NBT.A.3b Compare two decimals to thousandths based on meanings of the digits in each place, using >, =, and

CCSS.Math.Content.5.NBT.B.7 Add, subtract, multiply, and divide decimals to hundredths, using concrete models or drawings and strategies based on place value, properties of operations, and/or the relationship between addition and subtraction; relate the strategy to a written method and explain the reasoning used.
CCSS.Math.Content.6.NS.C.7b Write, interpret, and explain statements of order for rational numbers in real-world contexts. For example, write -3°C > -7°C to express the fact that -3°C is warmer than -7°C.

Practice Standards

CCSS.Math.Practice.MP4 Model with mathematics.
Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace. In early grades, this might be as simple as writing an addition equation to describe a situation. In middle grades, a student might apply proportional reasoning to plan a school event or analyze a problem in the community. By high school, a student might use geometry to solve a design problem or use a function to describe how one quantity of interest depends on another. Mathematically proficient students who can apply what they know are comfortable making assumptions and approximations to simplify a complicated situation, realizing that these may need revision later. They are able to identify important quantities in a practical situation and map their relationships using such tools as

diagrams, two-way tables, graphs, flowcharts and formulas. They can analyze those relationships mathematically to draw conclusions. They routinely interpret their mathematical results in the context of the situation and reflect on whether the results make sense, possibly improving the model if it has not served its purpose.

CCSS.Math.Practice.MP6 Attend to precision.

Mathematically proficient students try to communicate precisely to others. They try to use clear definitions in discussion with others and in their own reasoning. They state the meaning of the symbols they choose, including using the equal sign consistently and appropriately. They are careful about specifying units of measure, and labeling axes to clarify the correspondence with quantities in a problem. They calculate accurately and efficiently, express numerical answers with a degree of precision appropriate for the problem context. In the elementary grades, students give carefully formulated explanations to each other. By the time they reach high school they have learned to examine claims and make explicit use of definitions.

Adult Basic Education Standards

Content Standards

Mathematics Standards Level C More than any other, Level C provides the foundation for all future mathematical studies. Fluency with multidigit whole and decimal numbers as well as calculations with fractions (and the relationships between them) carry the most weight at this level. This extends to working with the concept of ratio and rates, addition and subtraction of fractions, and understanding why the procedures for multiplying and dividing fractions make sense. While the greatest emphasis is still on standards for numbers and operations, attention to algebra and geometry increases considerably in Level C. Reading, writing, and interpreting expressions and equations and generating patterns in numbers and shapes provide a conceptual foundation for functions. In addition, analyzing geometric properties, such as parallelism, perpendicularity, and symmetry, and developing and finding volumes of right rectangular prisms take precedence. Level C also emphasizes sampling techniques and data collection through statistical questioning; to previous standards about data, it adds the understanding of measures of center and spread and display of collected data with line plots.

Perform operations with multi-digit whole numbers and with decimals to hundredths.

5.NBT.5 Fluently multiply multi-digit whole numbers using the standard algorithm.
5.NBT.6 Find whole-number quotients of whole numbers with up to four-digit dividends and two-digit divisors, using strategies based on place value, the properties of operations, and/or the relationship between multiplication and division. Illustrate and explain the calculation by using equations, rectangular arrays, and/or area models.
5.NBT.7 Add, subtract, multiply, and divide decimals to hundredths, using concrete models or drawings and strategies based on place value, properties of operations, and/or the relationship between addition and subtraction; relate the strategy to a written method and explain the reasoning used.
6.NS.7b Write, interpret, and explain statements of order for rational numbers in real–world contexts. For example, write -3°C > -7°C to express the fact that -3°C is warmer than -7°C.

Practice Standards

MP.4 Model with mathematics

Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace. In early grades, this might be as simple as writing an addition equation to describe a situation. In middle grades, a student might apply proportional reasoning to plan a school event or analyze a problem in the community. By high school, a student might use geometry to solve a design problem or use a function to describe how one quantity of interest depends on another. Mathematically proficient students who can apply what they know are comfortable making assumptions and approximations to simplify a complicated situation, realizing that these may need revision later. They are able to identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas. They can analyze those relationships mathematically to draw conclusions. They routinely interpret their mathematical results in the context of the situation and reflect on whether the results make sense, possibly improving the model if it has not served its purpose.

MP.6 Attend to precision.
Mathematically proficient students try to communicate precisely to others. They try to use clear definitions in discussion with others and in their own reasoning. They state the meaning of the symbols they choose, including using the equal sign consistently and appropriately. They are careful about specifying units of measure, and labeling axes to clarify the correspondence with quantities in a problem. They calculate accurately and efficiently, express numerical answers with a degree of precision appropriate for the problem context. Less experienced students give carefully formulated explanations to each other. By the time they reach high school they have learned to examine claims and make explicit use of definitions.

Industry Overview

Today's Manufacturing Workplace

A manufacturing renaissance is occurring in the United States. The United States is the largest manufacturing economy in the world, producing 21 percent of the goods manufactured across the globe. In addition to the 12 million Americans working directly in the manufacturing industry, manufacturing supports more than 6.5 million other jobs, thus accounting for nearly 17 percent of all private sector jobs in the United States. In 2010, the average U.S. manufacturing worker earned $77,186, including pay and benefits (the average in all industries was $56,436).[1]

While manufacturing jobs in Massachusetts have declined, as they have nationally, manufacturing is still a critical industry in this state and provides opportunities for good, high-paying jobs. In the Greater Boston area, most of the manufacturing jobs are in computer and electronics companies, and much of the state relies on manufacturing positions in these and other very high-tech areas, such as aerospace and biotechnology.[2]

Advanced manufacturing involves the use of computers and technology in the manufacture of products. While not all manufacturing companies use technological innovations in developing their products or processes, the competitive advantage of the United States in the manufacture of goods relies on technological innovations. This means that today's manufacturing workplace is usually highly technical, which accounts for the high-paying positions many workers in this field receive in compensation for their work. It also means that today's advanced manufacturing workplace is very different from many people's conceptions of factories and mills as dark, dirty, and unsafe. Today's advanced manufacturing facilities are usually bright, clean, and very safe, and the emphasis is on working efficiently—with as little waste as possible.

In the advanced manufacturing industry, there has been a marked shift from the traditional role of line workers to workers who demonstrate creativity and innovation. Innovation is a hallmark of the U.S. manufacturing industry, and key to maintaining its position in the global market since products can often be produced at a lower cost in developing countries. Critical-thinking, problem solving and reasoning are important components of the innovation process. Today's manufacturing workers are expected to formulate solutions to problems using critical thinking and reasoning skills while working independently and/or in teams.

1. http://www.nam.org/~/media/AF4039988F9241C09218152A709CD06D.ashx
2. http://www.bostonglobe.com/business/2012/05/08/high-end-factory-jobs-boston-paying-high-wages/3gZuNc6GywDGKoYNP2hnaO/story.html?camp=pm

Careers in Advanced Manufacturing

The manufacturing sector includes jobs related to planning, managing, and performing the processing of materials into intermediate or final products and related activities such as production planning and control, maintenance, and engineering. Thus, this industry includes not only those people who actually produce the manufactured goods, but also managers, maintenance staff, scientists and researchers, analysts, administrative personnel, and IT personnel.

Career Pathways

The manufacturing industry includes six career pathways:

- Production is the construction and assembly of parts and final products. People in these positions work in factories and mills, with machines, to make or assemble parts, construct components of parts (such as plastics), and print materials. Occupations in this pathway range from production helpers who move parts and materials around the factory, to numerical control machine operators who run the computer-controlled machines that modify metal and plastic to create products, to manufacturing production technicians who oversee production.

- Manufacturing production process development occupations are involved in designing products and manufacturing processes. People in these occupations work with production workers to set up the machines and processes to develop new products. These occupations include engineers and production managers.

- Maintenance, installation and repair workers take care of products after they've been sold and delivered to customers—they install the products, perform maintenance on machines, tools, and equipment so that they work properly, and repair systems that are not performing adequately. Workers in this pathway include automotive technicians, automotive electronics installers, building maintenance workers, industrial electronics repairers, industrial machinery mechanics, millwrights, and small engine mechanics.

- Quality assurance is provided by quality control inspectors and technicians, who ensure that products both meet design standards and are of high quality.

- Logistics and inventory control workers ensure that those working in Production have the materials they need to complete their work. Workers in these occupations inventory materials and products, move materials to the line, and pack and ship finished products. Thus, they include production and planning clerks, and operators of moving machinery such as cranes and forklifts, and packers.

- Health, safety and environmental assurance occupations are focused on keeping the workplace safe by ensuring that workers are using equipment safely and that manufacturing processes are as safe as they can be. The also conduct investigations and conduct inspections.

Mathematics and Communication Skills Needed in Advanced Manufacturing

Mathematics and communication are key skills needed for success in today's high-performance advanced manufacturing workplaces. Mathematics is used in the advanced manufacturing industry to measure the amounts and sizes of materials and parts, create "recipes" used to manufacture man-made materials, and analyze data. Data analysis is critical at many levels of a manufacturing organization in order to ensure quality and to continuously improve both quality and processes. Today's manufacturing industry must operate extremely efficiently and produce very high-quality products in order to maintain competitiveness. Many front-line workers are involved in collecting data and working to improve quality and efficiency. Thus, in addition to basic mathematical calculations (which rarely involve simple whole numbers), workers are engaged in mathematical reasoning and solving problems using a variety of mathematical tools.

To succeed and move up the ladder in today's advanced manufacturing workplace, workers need reading skills to understand technical concepts, vocabulary, and to bring together information needed for a particular situation; to locate, organize, and document written information from various sources needed by co-workers and customers; and to locate written information needed by co-workers and customers. They need to use correct grammar, punctuation and terminology to write and edit documents and to develop and deliver formal and informal presentations using appropriate media to engage and inform audiences. In addition, they need to interpret verbal and nonverbal behaviors to enhance communication with co-workers and clients/participants; apply active listening skills to obtain and clarify information; and interpret and use information in tables, charts, and figures to support written and oral communications. They also must communicate with co-workers and customers using technology tools. As they move up the corporate ladder they will need to explain written organizational policies, rules and procedures to help employees perform their jobs.

Career Opportunities in Advanced Manufacturing with Education from Community Colleges

Massachusetts Community Colleges play an important role in preparing the state's citizens to take advantage of the career opportunities available in advanced manufacturing. Degree and certificate programs prepare students to enter advanced manufacturing occupations, including:

- production occupations, including people who work as assemblers (such as airplane assemblers), machine operators, machinists, systems operators, CNC machine tool operators, machine setters, laminators/fabricators, metal and plastic workers, packers, molders, semiconductor processing operators, welders and solderers, tool and die makers, and other production workers;

- manufacturing production process development occupations, including numerical control tool programmers who write the programs that control machine tools and industrial production managers who plan and oversee production;

- maintenance, installation and repair occupations include automotive, electronics, and biotechnology technicians, industrial machinery mechanics, and millwrights (who install and maintain heavy equipment);

- quality assurance occupations including quality control technicians and inspectors.

Recent Career Opportunities in Massachusetts

The following is a sample of advanced manufacturing job listings in Massachusetts that require associate's degree or certificate:

- Manufacturing Engineering Technician, Randstad Corporation, Framingham, MA, [show]
- Quality Control Technician, QD Vision, Lexington, MA [show]
- Manufacturing Technican, Hologic, Marlborough, MA [show]

Employment Outlook for Advanced Manufacturing

Advanced manufacturing continues to be a high-growth industry, given the knowledge capital in the United States. However, the work in this industry is increasingly technical and requires far fewer workers as more tasks are automated. Entry-level positions in this industry require the same skills that only a select group of highly-experienced and well-paid workers once had. Unfortunately manufacturers find it difficult to fill these high-skill positions. A 2011 survey found that there is a persistent skills gap between the skills that are needed in the today's manufacturing workplace and the skills that candidates bring to the workforce.

Most of the advanced manufacturing companies in Massachusetts are small to mid-sized operations that employ smaller numbers of workers and rely on computer-operated machinery for production. While the numbers of workers are smaller than in the past, the more highly-skilled nature of the work means that these are high-paying jobs and provide workers with opportunities to grow through training and education and to be part of the effort to innovate.

Resources:

Advanced Manufacturing Industry

- National Council for Advanced Manufacturing
- Advanced Manufacturing
- Brookings: "Why Does Manufacturing Matter? Which Manufacturing Matters?" (2012)
- National Association of Manufacturers: "A Manufacturing Renaissance: Four Goals for Economic Growth" (2012)

Advanced Manufacturing Industry Outlook Information

- Bureau of Labor Statistics: Manufacturing Industry at a Glance
- Massachusetts Labor Market Data
- Massachusetts Career Information System

Careers in Advanced Manufacturing

- Massachusetts Career Information System
- Manufacturing Career Opportunities
- Manufacturing Career Pathways
- Industry Competency Model for Advanced Manufacturing shows the skills and knowledge needed to work in this industry
- National Association of State Directors of Career Technical Education Consortium's Common Career Technical Core
- National Association of State Directors of Career Technical Education Consortium's Knowledge and Skills: Manufacturing
- O*NET
- WorkKeys Occupational Profiles
- Manufacturing's Missing Generation
- A Career in Toolmaking or Machining Technologies: The Right Choice for Students, Community, & Country

Workplace Scenario (8th Grade Level)

You are a Quality Control Technician. You work at a small manufacturing company. Your company produces plastic parts. QCT is an important job. It ensures that all products that reach the public are safe. You are responsible for measuring and testing parts. You also do visual inspections. This ensures the parts meet the customer's specifications. You work closely with the Operators molding the part. You must ensure that a high quality standard is met.

For new products, you review the drawings and specifications. You then write an inspection plan. The inspection plan is stapled to the part drawings. It is hung in the shop for the manufacturing team to see. The inspection plan is organized by part number. It provides the range of acceptable dimensions for each part. Some variation occurs in all manufacturing. A part may be designed to be 2 centimeters wide. The actual measurements can be a bit smaller or larger. This is due to natural varying conditions in manufacturing. Tolerance is used to control the variation in size. The tolerance is specified by the designer of the part. You apply the tolerance to the dimensions in your plan. That way the acceptable size range for each part is defined. Your plan provides time intervals for measuring parts. You record the results.

You work with the operator on production runs. You perform first piece inspection using specific tools. You reference the inspection plan. Then you check that the part complies with the customer's request. Sometimes the part is the wrong size. You then work with the operator. Together you analyze the problem. You might need to adjust the machinery. There may be an issue with the material mix. You continue to monitor the production run. If necessary, you perform regular inspections.

To do your job, you must make precise measurements. You regularly perform basic operations. You also calculate decimals, fractions, and percents. You read and interpret engineering drawings. This helps you understand the dimensions and tolerances. You also use various devices to measure parts. This must be done with a high level of accuracy. You compare the measurements with the range of acceptable sizes. This helps you see if the part complies with the plan.

Workplace Scenario (High School Level)

You are a Quality Control Technician at a small manufacturing company that produces plastic parts for a variety of products. This is an important job that ensures that all products that reach the public work well and are safe. You are responsible for measuring and testing parts, as well as visually inspecting them, to ensure they meet the specifications required by the customer. You work closely with the Operators molding the part to ensure that the required quality standard is met.

For new products, you review the engineering drawings and specifications, and write an inspection plan. The inspection plan is stapled to the part drawings and hung in the shop for the manufacturing team to reference. The inspection plan is organized by part number. It provides the corresponding dimensions and range of acceptable dimensions for each part. Some variation occurs in all manufacturing. While a part may be designed to be 2 centimeters wide, the actual measurements can be a bit smaller or larger. This is due to the natural varying conditions in manufacturing. Tolerance is used to control the variation in size and the tolerance is specified by the designer of the part. You apply the tolerance to the critical dimensions in your plan so that the acceptable size range for each part is clearly defined. Your plan also provides time intervals for measuring parts and spaces to record the results.

At the start of a production run, you work with the operator to perform first piece inspection using specific measuring tools. Using the inspection plan, you check that the part complies with the specifications and standards required by the customer. If there is a variance between the part's measurements and the job specifications, you work with the operator to analyze the problem. This may require that you adjust the machinery or material mix so that the finished product aligns with the specifications. You continue to monitor the production run. If necessary, you perform regular inspections as scheduled in the inspection plan.

To do your job, you must work precisely and accurately with measurement. You regularly perform basic operations and multi-step calculations with decimals, fractions, and percents. You read and interpret engineering drawings to understand the critical dimensions and tolerances. You also must use various devices to measure parts with a high level of accuracy and precision. You compare the measurements with the range of acceptable sizes to see whether or not the part complies with the plan.

Core instructional context

In advanced manufacturing, attention to precision and accuracy are important to the safety and quality of the products produced. These professionals are fluent computing multi-digit numbers, decimals, and percentages, and understanding at a glance whether or not a number falls inside or outside a range of numbers. In addition to procedural fluency, a strong conceptual understanding of this math is equally important; just plugging numbers into formulas instead of understanding what is being calculated and why can lead to mistakes with potentially major consequences.

A job as a Quality Control Inspector, as well as most other jobs in advanced manufacturing, requires the ability to read engineering plans and drawings to identify critical dimensions of parts, and understand how to apply tolerance to calculate ranges of acceptable sizes. Additionally, knowing how to organize numerous calculations into charts and using the charts to make decisions is a real world application of modeling with mathematics. This skill is needed for most jobs in the advanced manufacturing field.

These math skills are transferable to personal lives, as well. Knowing how to read and follow plans, as well as make calculations with multi-digit numbers, fractions, and decimals, is useful for assembling furniture at home, following a sewing pattern, and woodworking.

Worked Examples

You work for the Lego company as a Quality Control Inspector. The Lego company is famous for their very low tolerances in their manufacturing, just ±0.002 mm. To reach these low tolerances, their quality control and inspection processes are very rigorous. From Wikipedia, "Human inspectors check the output of the mold, to eliminate significant variations in colour or thickness. According to the Lego Group, about eighteen bricks out of every million fail to meet the standard required." As a Quality Control Inspector, you measure one Lego every hour during a production run to make sure that the size is acceptable. You want to create some charts to help you quickly determine whether or not the Lego you are measuring passes inspection.

1. Look at the part drawing of two Lego bricks. Click on image to enlarge. Two Lego Bricks
2. Create an Inspection Chart for the yellow Lego using the specified tolerance of ±0.002 mm. Read the part drawing to identify the measurements in the chart below and calculate the minimum and maximum acceptable sizes. *Note: P refers to the measurement between the center of one knob to the center of the next knob. The other dimensions reference P so that the Lego bricks fit together properly. For students, P is only important as the "basic measurement" that all other measurements use in some way.*

   Inspection Chart: Acceptable Size of Yellow Lego

Part of Lego	Dimension	Minimum allowed size	Maximum allowed size
Knob: diameter			
Knob: height			
Base: height			
Base: width			

Answer:

Part of Lego	Dimension	Minimum allowed size	Maximum allowed size
Knob: diameter	5.0 mm	5.0 – .002 = 4.998 mm	5.0 + .002 = 5.002 mm
Knob: height	1.7 mm	1.7 – .002 = 1.698 mm	1.7 + .002 = 1.702 mm
Base: height	7.8 mm	7.8 – .002 = 7.798 mm	7.8 + .002 = 7.802 mm
Base: width	9.6 mm	9.6 – .002 = 9.598 mm	9.6 + .002 = 9.602 mm

3. (small group) Create an Inspection Chart for the red Lego using the same part drawing. This time, you'll need to first identify the critical dimensions (parts of the Lego) you'll use in your chart, as well as the minimum and maximum sizes for each part. If a measurement is listed on an engineering drawing, it is considered a critical dimension. Click on image to enlarge. Two Lego

    a. According to the part drawing, how many critical dimensions of the red Lego do you need to inspect?
    Answer: There are seven dimensions (parts) of the red Lego to inspect.
    b. Create chart.
    Answer:

Part of Lego	Dimension	Minimum allowed size	Maximum allowed size
Distance between knobs	3.0 mm	3.0 – .002 = 2.98 mm	3.0 + .002 = 3.002 mm
P or distance between the centers of two knobs	8.0 mm	8.0 – .002 = 7.98 mm	8.0 + .002 = 8.002 mm
Knob: diameter	5.0 mm	75.0 – .002 = 4.998 mm	5.0 + .002 = 5.002 mm
Knob: height	1.7 mm	1.7 – .002 = 1.698 mm	1.7 + .002 = 1.702 mm
Base: width	7.8 mm	7.8 – .002 = 7.798 mm	7.8 + .002 = 7.802 mm
Base: length	15.8 mm	15.8 – .002 = 15.798 mm	15.8 + .002 = 15.802 mm
Base: height	3.2 mm	3.2 – .002 = 3.198 mm	3.2 + .002 = 3.202 mm

    c. The minimum and maximum allowed sizes can be expressed symbolically. For example, the distance between the knobs could be expressed as:

2.98 mm ≤distance between knobs ≤ 3.002 mm

Or using the word "to" to express the range (Note: Engineers don't use a long hyphen in plans because it can get mistaken for a subtraction sign):

2.98 mm to 3.002 mm

How might you modify the chart to express the minimum and maximum allowed sizes as a range instead of a column for each number?

Answer: Answers will vary; one possible idea is to add a column called "Acceptable range."

d. Why is the length of the base of the red Lego NOT two times the length (width) of the yellow Lego? Discuss with your group.

Answer: Answers will vary. The length of the red Lego base is 15.8, while the length of the yellow Lego base is 7.8 mm. While the length of two yellow bricks, side by side, will be the same length as the red brick, there is the smallest amount of space (.2 mm or .1 mm on each side) between those two yellow bricks. This space is referred to as the "play" and is similar to tolerance. This "play" helps the bricks fit together but not too tightly; if the Lego bricks fit together too tightly, they are difficult to pull apart.

Contextualized learning activities

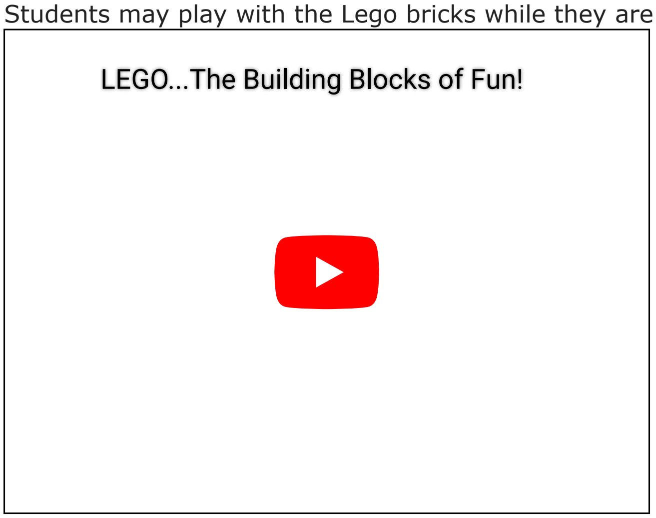
Read the Scenario

Ask students to read the scenario in this module. Have students look for unfamiliar words or concepts and write them on the board. Deciding whether or not a measurement of a part passes inspection has to do with tolerance. The hands-on activity below is designed to help students understand the concept of tolerance so that they may fully engage with the math in this module.

Understanding Tolerance: Hands-on Activity and Discussion

Materials: Lego bricks, enough for several per student

1. Give each student several Lego bricks of various sizes. Ask them to play with them and think about how they are constructed, particularly the dimensions.
2. Show video (5:30) from Lego plant if students are new to how plastic parts are manufactured. Students may play with the Lego bricks while they are watching the video.



3. Discuss what the students notice about the dimensions. Help students articulate that every Lego fits with every Lego ever made, and that they are manufactured to highly precise specifications.
4. The Quality Control Inspector cares a lot about how the Lego bricks are sized. Some variation is allowed—this is called the tolerance. Tolerance is used to control the variation in size that exists for all manufactured parts. When designing a part, the engineer/designer will specify the

dimensions of the part and the allowed tolerance, or variation from those dimensions that is allowed. The variation or tolerance allowed depends on the part and what it is supposed to do.

5. For example, a plastic part might have a length of 5.25 mm, with a tolerance ±0.10 mm. The ± symbol means to add and subtract that number from the specified measurement. To find the maximum length of the part that is acceptable in our example, add .10 mm to the length, so 5.25 + .10 = 5.35 mm. To find the minimum length of the part that is acceptable, subtract .10 mm from the length, so 5.25 – .10 = 5.15 mm.
6. Predict the tolerance of Lego bricks in mm. Discuss students' predictions and ask them to justify their answers. Guide students to understand that a very low tolerance is key to precision; all Lego bricks, no matter when they were manufactured, must fit together perfectly every single time.
7. The Lego company is legendary in the plastics manufacturing world for their incredibly low tolerance of just .002 mm (roughly the width of a thin human hair). From Lego Wiki:

   > Bricks, beams, axles, mini figures, and all other elements in the Lego system are manufactured to an exacting degree of tolerance. When snapped together, pieces must have just the right amount of "clutch power"; they must stay together until pulled apart. They cannot be too easy to pull apart, or the resulting constructions would be unstable; they also cannot be too difficult to pull apart, since the disassembly of one creation in order to build another is part of the Lego appeal. In order for pieces to have just the right "clutch power", Lego elements are manufactured within a tolerance of 2 μm or .002 mm.

8. Imagine the tolerance that would be specified to manufacture a child's plastic bucket for the beach. How do you predict that tolerance compares to Lego's tolerance? Guide students to understand that Lego manufacturing is highly precise and the measurements of the product must be very accurate whereas plastic bucket manufacturing has a high tolerance, or is much less precise. Low tolerance means very precise and high tolerance means less precise.

Worked Examples

Work through the Worked Example problems in the "Core instructional context" section; problems 1 and 2 can be done as a full class and problem 3 provides an opportunity for students to practice what they've learned in a small group. These problems should be worked *without* calculators to help students with their fluency with addition and subtraction with decimals.

Contextualized Problems (2)

Problem 1
Your company has won the contract to produce a complex assembly (multiple parts) for a client that sells bicycle, ski, and kayak racks that mount to the tops of cars. The first production run will be for the parts for a bicycle rack. You review the drawings from the engineer to create the inspection plan. You need to create a chart that lists the minimum and maximum allowed sizes for each critical dimension. Engineers specify the tolerances for ranges of measurements in their plans. The first page of the engineering plan provides the information about tolerances and the actual drawing labels each critical dimension by letter, i.e., A, B, C and so on. Use the tolerance for each measurement range to identify the minimum and maximum allowed sizes for each critical dimension for the chart in the inspection plan. *Note: You may continue to work with this manufacturing scenario in some of the problems in the Creating Quotes module.*

Information about Tolerenaces from First Page of Engineering Plan

UNLESS OTHERWISE SPECIFIED:
1. DIMENSIONS ARE IN MM
2. TOLERANCES

0.00 TO 3.00 ±0.08
3.00 TO 6.00 ±0.10
6.00 TO 18.00 ±0.13
18.00 TO 30.00 ±0.15
30.00 TO 50.00 ±0.18
50.00 TO 80.00 ±0.23
80.00 TO 117.50 ±0.28

117.50 TO 180.00 ±0.33
180.00 TO 250.00 ±0.36
250.00 TO 315.00 ±0.38
315.00 TO 400.00 ±0.46
400.00 TO 500.00 ±0.51

a. Before you create the chart, you study the tolerances specified for the parts on the first page of the engineering plan. What do you notice happens to the tolerance as the dimensions increase? Express your idea with words instead of numbers.

   Answer: As the dimensions increase, the tolerance increases. This means that bigger parts are allowed more variation in size than smaller part.

b. In your inspection plan, you specify which testing equipment will be used to perform the measurements. To measure the dimensions, you use digital calipers. Your shop has a variety of digital calipers, each with different accuracy ratings. Which digital caliper should you specify in your testing plan and why?

   digital caliper

   Titan caliper: accuracy rating of .001 mm
   Acme Digital caliper: accuracy rating .02 mm
   General Hardware caliper: accuracy rating of .05 mm
   Northeastern Industrial caliper: accuracy rating of .10 mm

   Answer: General General Hardware caliper. The accuracy of the caliper must be as good or better than the lowest tolerance. With accuracy of .05 mm, this will satisfy the lowest tolerance requirement of .08 mm. Some students may also choose the Titan or Acme caliper; those both work, but their accuracy rating exceeds what is needed for the specifications for this job.

c. **Measurement Inspection Plan: 2Lee Bike Rack Assembly**

Part (Critical Dimension)	**Dimension**	**Minimum allowed size**	**Maximum allowed size**
A	5.5 mm		
B	315.2 mm		
C	19.0 mm		
D	52.3 mm		
E	89.2 mm		
F	453.5 mm		
G	289.4 mm		
H	2.0 mm		
I	42.7 mm		

Answer:

Measurement Inspection Plan: 2Lee Bike Rack Assembly

Part (Critical Dimension)	**Dimension**	**Minimum allowed size**	**Maximum allowed size**
A	5.5 mm	5.5 – .10 = 5.40 mm	5.5 + .10 = 5.60 mm
B	315.2 mm	315.2 – .46 = 314.74 mm	315.2 + .46 = 315.66 mm

C	19.0 mm	19.0 – .15 = 18.85 mm	19 + .15 = 19.15 mm
D	52.3 mm	52.3 – .23 = 52.07 mm	52.3 + .23 = 52.53 mm
E	89.2 mm	89.2 – .28 = 88.92 mm	89.2 + .28 = 89.48 mm
F	453.5 mm	453.5 – .51 = 452.99 mm	453.5 + .51 = 454.01 mm
G	289.4 mm	289.4 – .38 = 289.02 mm	289.4 + .38 = 289.78 mm
H	2.0 mm	2.0 – .08 = 1.92 mm	2.0 + .08 = 2.08 mm
I	42.7 mm	42.7 – .18 = 42.52 mm	42.7 + .18 = 42.88 mm

Problem 2

a. You determine that the bicycle rack parts should be inspected every hour for safety reasons. The assembly must be of very high quality because the parts hold bicycles to the tops of cars that may be driving high speeds on the highway. At 9:30 a.m., you have to leave the shop floor and ask another inspector to fill in for you, measuring the critical dimensions of the parts every hour. When you get back at 12:30 p.m., you review the Measurement Inspection Sheet and see a few issues. One of the issues makes you very unhappy with your colleague. What problems do you see? Which is the worst and why?

Part	**Critical Dimension Measurements per Hour**					
	10 a.m.	**11 a.m.**	**Noon**	**1 p.m.**	**2 p.m.**	**3 p.m.**
A	5.42 mm	5.51 mm	5.53 mm			
B	315.10 mm	315.70 mm	315.62 mm			
C	19.20 mm	19.21 mm	19.22 mm			
D	52.10 mm	52.17 mm	52.28 mm			
E	89.24 mm	89.36 mm	89.21 mm			
F	453.51 mm	453.74 mm	453.98 mm			
G	289.19 mm	289.50 mm	289.62 mm			
H	2.05 mm	1.92 mm	1.91 mm			
I	42.580 mm	42.52 mm	42.76 mm			

Answer: You see several problems: Part B failed at 11 am; Part C failed at 10 am, 11 am, and noon; Part H failed at noon. The issues around Part C are the worst. Your colleague allowed the part to keep being produced after it failed the inspection at 10 a.m. The entire 3 hour run of Part C must be rejected and that is a much more expensive mistake than if he had stopped the run after the 10 am inspection. Note: *Students will need to consult the chart they completed for the previous problem and apply those measurements to make decisions in this problem./p>*

b. You talk with your colleague and he tells you that he finds it difficult to quickly identify problems with your charts. For each measurement, he had to look between two different charts and it was easy to make mistakes. He has a fair point. How could you redo the Critical Dimension Measurements per Hour inspection chart to make it easier to use? Sketch your idea.

Answer: Answers will vary. One possible chart expresses the tolerance as a range and includes that data in the chart:

Part	Acceptable Range for Dimensions	Critical Dimension Measurements per Hour					
		10 a.m.	11 a.m.	Noon	1 p.m.	2 p.m.	3 p.m.
A	5.40 mm to 5.60 mm						
B	314.74 mm to 315.66 mm						
C	18.85 mm to 19.15 mm						
D	52.07 mm to 52.53 mm						
E	88.92 mm to 89.48 mm						
F	452.99 mm to 454.01 mm						
G	289.02 mm to 289.78 mm						
H	1.92 mm to 2.08 mm						
I	42.52 mm to 42.88 mm						

Contextualized test items

You examine the engineering plan for a part. Note: The diameter symbol symbol in drafting means diameter.

part drawing testtolerance

1. 1. What are the critical dimensions for this part? Label each dimension with a name, and include the measurement and the units.

   Answer: There are two critical dimensions on this part.

   - Dimension A or Outer Ring: .440 inches
   - Dimension B or Thru Hole: .122 inches

2. Using the tolerances provided, what are the maximum and minimum allowable sizes for each critical dimension? Be sure to include the correct units for the measurement.

   Answer:
   Dimension A: Min .435 inches and Max .445 inches br /> Dimension B: Min .117 inches and Max .127 inches

3. Given the tolerances specified by the engineer, why do you think the diameter of the outer ring is labeled .440 instead of .44?

   Answer: According to the tolerances, three digits have a lower tolerance than two digits. Therefore, this measurement needs to have less variation than it would if it was listed as .44.

4. Which of the following tolerances demands the most precision in the manufacturing process?

   A. ±0.08
   B. ±0.22
   C. ±0.220
   D. ±0.42

   Answer: A

Contextualized project

Create an Inspection Plan Using Real Engineering Drawings (group project)
OpenBeam, a "low cost, open-source extruded aluminum construction system," is a real product comprised of aluminum rails, plastic brackets, and screws. This product has been used to make 3D printers, support structures for cameras, and is frequently used by students who compete in robotics competitions. The designer of the product has put all of the engineering drawings and specifications into the public domain with a Creative Commons license so that anyone may produce it.

1. As a class, learn about OpenBeam from the Intro page of their website. Watch the video embedded on the page to see how one designer used the system.
2. Go to Thingiverse.com and look at the five different plastic brackets in the OpenBeam product. The two flat blue pieces are made of metal, so only look at the plastic brackets.
3. Divide students into five teams and give each team the engineering plan for a bracket. If each team has at least one computer, they may download the engineering plan. If the students do not have computers to use in class, download and print each plan for them. To download:
    - Click on the image of the bracket.
    - Click on the blue "Download This Thing" button to see a list of files to download.
    - The correct file to use for this project is first file on the list with a gear icon.
4. Ask each team to review the engineering plan as a Quality Control Inspector and create an inspection plan. Students should work together to find the tolerances and the critical dimensions for the bracket, and calculate the maximum and minimum sizes for each dimension. For extra credit, students may include additional information that seems relevant for the inspector to include in the plan (e.g., cleanliness, part identification marking, packaging); look for students to create some kind of chart or process to inspect these items. This extra credit part of the project gives students additional practice reading and interpreting plans. *Note: Teams should work independently on this project, without your support, to interpret the plans.*
5. Teams can either submit their inspection plans in writing or present them to the class.

Additional or extension activities, multimedia, readings and/or resources

Extension: OpenBeam Kickstarter Campaign (group or individual)

Note: If students find the context of the OpenBeam project engaging, this extension activity offers additional practice applying operations to understand real-world situations.

OpenBeam had a successful Kickstarter campaign in 2013. Ask students to review the Kickstarter page and calculate how much money was raised at each of the funding levels. Ask students to graph the data, using a graph of their choice.

Please contact ETLO to report any broken links or other problems with this page.

Massachusetts Community Colleges and Workforce Development Transformation Agenda (MCCWDTA) is 100% funded by a $20 million grant from the U.S. Department of Labor, Employment & Training Administration TAACCCT. Grant Agreement #TC-22505-11-60-A-25.