CENTER FOR CURRICULUM REDESIGN

Draft Manufacturing Standards

Standards design philosophy: These standards are designed to produce students who can manufacture objects by a wide variety of fabrication techniques, look at an object and know how it was made, operate safely in an industrial environment, operate computer-aided design and computer-aided manufacturing systems, construct a small flexible manufacturing system, and optimize entire manufacturing facilities for cost, throughput and quality through the application of Six Sigma and Lean Manufacturing principles.

Subjects	Topics	Standards	Grades 6-8 Benchmarks (pre-Manufacturing: Industrial Arts/Shop and Drafting)	Grades 9-12 Benchmarks (Manufacturing)
Raw Materials Processing	Primary Manufacturing	CCR-MFG PM 1. Understand how raw materials are made and used.	CCR-MFG PM 6-8, 1.1. Understand all manufactured objects come from pre-processed raw materials, which in turn come from natural resources. CCR-MFG PM 6-8, 1.2. Research and document the pre-processing steps (i.e., primary manufacturing) associated with household items of their choice (e.g., cotton to fabric, oil and plant products to plastic; trees to lumber; wheat to flour; plants to paper). CCR-MFG PM 6-8, 1.3. Understand that the difference between "natural" and "synthetic" or "natural" vs. "Human-made" is one of degree that all "natural" products bought in stores have some degree of processing (e.g., apples are automatically harvested and sprayed with wax before sale). CCR-MFG PM 6-8, 1.4. Explain the relative advantages and disadvantages of using bronze, iron, steel, and aluminum to make objects. CCR-MFG PM 6-8, 1.5. Understand how the major materials enabling the rise of civilization - wood, bronze, iron, steel, aluminum and silicon - are made, starting from the mining or harvesting of natural resources. CCR-MFG PM 6-8, 1.6. Understand the technical challenges that resulted in humans making products of wood before bronze before iron before steel before aluminum before silicon (e.g., temperature required for processing).	
	Raw Materials and Society		CCR-MFG PM 6-8, 1.7. Understand why major manufacturing facilities are often located near water (e.g., water for cooling, energy, waste effluent, transportation) and thus why coastal regions have historically had high population densities. CCR-MFG PM 6-8, 1.8. Describe some historical technologies that the availability of wood, bronze, iron, steel, aluminum, and silicon each made possible, and how the lives of citizens and the history of nations changed as a result. CCR-MFG PM 6-8, 1.9. Choose a rare material and list several products that could not be made where access to that material to disappear.	
	Raw Material Properties and Manufacturability		CCR-MFG PM 6-8, 1.10. Differentiate woods, metals, ceramics, glasses, and polymers by sight and touch. CCR-MFG PM 6-8, 1.11. Understand how the different material properties of wood vs. metal vs. ceramic vs. glass vs. polymer affect their manufacturability (e.g., metals can be easily bent and squeezed into tubes but wood cannot; glass can easily be cast but can break on machining).	
Manufacturing Objects	Manufacturing Techniques	CCR-MFG OBJ 2. Understand specific manufacturing processes.	CCR-MFG OBJ 6-8, 2.1. Understand there are multiple manufacturing techniques and recognize them by sight, such as casting, forming, cutting, machining, joining, and finishing.	CCR-MFG OBJ 9-12, 2.1. Demonstrate and explain different types of welding and when they are used (e.g., stick/shielded metal arc welding, tungsten inert gas/gas tungsten arc, gas metal arc, spot welding, solid state welding). CCR-MFG OBJ 9-12, 2.2. Explain the typical reasons welds fail (e.g., hydrogen embrittlement, porosity, trapped oxides or dirt) and how to avoid them (e.g., purer gas, complete heating, slow cooling, careful cleaning).
	Casting		CCR-MFG OBJ 6-8, 2.2. Understand how cast metals are made (e.g., batch casting into molds, continuous casting, lost wax casting). CCR-MFG OBJ 6-8, 2.3. Discuss the similarities and differences between batch, continuous, and custom manufacturing processes. CCR-MFG OBJ 6-8, 2.4. Understand how cast polymers are made (e.g., compression molding, injection molding, vacuum molding). CCR-MFG OBJ 6-8, 2.5. Use a casting operation. CCR-MFG OBJ 6-8, 2.6. Understand typical visual features, strengths, and weaknesses of objects made by casting.	
	3D Printing/Additive Manufacturing		CCR-MFG OBJ 6-8, 2.7. Understand 3D printing/additive manufacturing. CCR-MFG OBJ 6-8, 2.8. Use a 3D printing/additive manufacturing operation. CCR-MFG OBJ 6-8, 2.9. Describe how 3D printing/additive manufacturing is often used for rapid prototyping of custom objects. CCR-MFG OBJ 6-8, 2.10. Understand typical visual features (e.g., enclosed internal holes), strengths, and weaknesses of objects made by 3D printing/additive manufacturing.	
	Forming		CCR-MFG OBJ 6-8, 2.11. Understand rolling, drawing, extrusion, stamping, and powder processing. CCR-MFG OBJ 6-8, 2.12. Use at least one forming operation. CCR-MFG OBJ 6-8, 2.13. Understand that heat treatment after fabrication (i.e., heating at a certain rate, holding for a certain time at temperature, cooling at a specific rate) can radically change how strong or tough an material or object is. CCR-MFG OBJ 6-8, 2.14. Understand tempering is a form of heat treatment, often used with steel or glass that consists of quenching (i.e., cooling) at a fast rate from high temperature at which point the material is brittle, followed by reheating to a moderate temperature at which point the material is strong but no longer brittle. CCR-MFG OBJ 6-8, 2.15. Understand typical visual features, strengths, and weaknesses of objects made by different forming techniques.	
	Cutting		CCR-MFG OBJ 6-8, 2.16. Understand manual (i.e., saw, chisel, shear, snip, punch) and powered (i.e., abrasive water jet, laser, plasma) processes for cutting. CCR-MFG OBJ 6-8, 2.17. Use one or more cutting operations and explain how each cutting operation is different.	
	Machining		CCR-MFG OBJ 6-8, 2.18. Understand the processes of milling, turning (i.e., lathe work), grinding, and electro machining. CCR-MFG OBJ 6-8, 2.19. Use at least one machining process. CCR-MFG OBJ 6-8, 2.20. Recognize machined objects by sight (e.g., by the presence of sharp edges).	
	Joining		CCR-MFG OBJ 6-8, 2.21. Demonstrate a variety of joining techniques. [CAN-QU CP 1-6, 3.5. (Modified).] CCR-MFG OBJ 6-8, 2.22. Understand the differences between welding (including soldering and brazing), gluing, and mechanical fastening and when each is used. CCR-MFG OBJ 6-8, 2.23. Explain the difference between soldering, brazing, and welding (e.g., difference in joining temperature, joint strength, and materials used). CCR-MFG OBJ 6-8, 2.24. Describe situations for which each of the joining technologies (i.e., welding, gluing, mechanical fastening) is preferable to each of the others.	
	Finishing		CCR-MFG OBJ 6-8, 2.25. Demonstrate finishing procedures (e.g., deburring, sanding, buffing, staining, cleaning, painting, bleaching.) (Grade 6). [CAN-QU CP 1-6, 3.6.]	
	Measuring		CCR-MFG OBJ 6-8, 2.26. Use measuring devices and gauges (e.g., calipers, rulers, protractors, radius gauges, timers, scales). CCR-MFG OBJ 6-8, 2.27. Convert between English and metric measures. CCR-MFG OBJ 6-8, 2.28. Use product quantity and time measures to calculate the rate of a manufacturing process (e.g., parts/hr.). CCR-MFG OBJ 6-8, 2.29. Understand the concept of accuracy and how it is influenced by the measurement unit (i.e., accuracy is limited by the smallest measurement unit used).	
	Recycling		CCR-MFG OBJ 6-8, 2.30. Understand the basics of plastic recycling and why plastics typically need to be separated before they are recycled. CCR-MFG OBJ 6-8, 2.31. Understand the basics of metal recycling. CCR-MFG OBJ 6-8, 2.32. Understand different types of manufacturing waste (e.g., solvents used in cleaning or degreasing operations; sludges and wastewaters from treatment and production processes; some pesticides and some pharmaceutical products become hazardous waste when discarded) and how each is disposed or recycled. CCR-MFG OBJ 6-8, 2.33. Compare the prices local recyclers will pay for scrap metal and explain why consumers get paid substantially more for dropping off aluminum cans compared to steel cans.	
	Designing for Manufacturability		CCR-MFG OBJ 6-8, 2.34. Identify and explain object features that make manufacturing easy or difficult (e.g., sharp corners, thin connectors, internal holes, high melting point materials, brittle materials, materials with lower coefficients of thermal expansion than the dies used to form them). CCR-MFG OBJ 6-8, 2.35. Identify and explain the shapes that are easily manufactured through subtractive processes (i.e., cutting, milling) and which require additive processes (i.e., 3D printing, additive manufacturing) (e.g., enclosed holes require additive manufacturing). CCR-MFG OBJ 6-8, 2.36. Analyze a variety of household objects to propose the sequence of manufacturing processes used to create them. CCR-MFG OBJ 6-8, 2.37. Demonstrate and explain the use of jigs and fixtures to ensure reproducibility in cutting, machining, and joining operations.	
Drafting	Mechanical Drawings	CCR-MFG DR 3. Read, understand, and create technical drawings of manufactured objects.	CCR-MFG DR 6-8, 3.1. Associate a drawing with a combination of geometric lines (e.g., the drawing of a rounded corner of a table is an arc joined to two sides of a right triangle). [CAN-QU LIN 7-8, 4.1.] CCR-MFG DR 6-8, 3.2. Name basic lines in a drawing (i.e., visible contour, hidden contour, center, extension, dimension lines). [CAN-QU LIN 7-8, 4.2.] CCR-MFG DR 6-8, 3.3. Associate the basic lines in a drawing with the contours and details of a simple part. [CAN-QU LIN 7-8, 4.3.] CCR-MFG DR 6-8, 3.4. Associate the types of projection with their use (e.g., multi-view and isometric projections). [CAN-QU LIN 7-8, 4.4.] CCR-MFG DR 6-8, 3.5. Interpret drawings representing parts in multi-view orthogonal projection. [CAN-QU LIN 7-8, 4.5.] CCR-MFG DR 6-8, 3.6. Draw simple shapes in multi-view orthogonal projection. [CAN-QU LIN 7-8, 4.6.] CCR-MFG DR 6-8, 3.7. Represent different types of motion related to the operation of an object using the appropriate symbols (e.g., rectilinear translation, rotation, helical). [CAN-QU REP 9-10, 3.2.] CCR-MFG DR 6-8, 3.8. Create mechanical drawings to scale, including common features, such as internal and external dimension lines (i.e., both linear and radial), extension lines and leaders, center lines, internal holes, section lines, cross-hatching, and legends.	
	Construction diagrams		CCR-MFG DR 6-8, 3.9. Explain the assembly of a technical object using a provided construction diagram. [CAN-QU CON 7-8, 2.1.] CCR-MFG DR 6-8, 3.10. Draw a construction diagram to illustrate the assembly of an object. [CAN-QU CON 7-8, 2.3.]	

Manufacturing	Definition, Mass Production	CCR-MFG MFG 4. Understand and be able to explain manufacturing and its related processes and systems.		CCR-MFG MFG 9-12, 4.1. Understand and explain that manufacturing is the making of goods on a large scale, using tools and machines. CCR-MFG MFG 9-12, 4.2. Explain that mass production means making the same product repeatedly. CCR-MFG MFG 9-12, 4.3. Understand step-by-step instructions are used to manufacture an object. CCR-MFG MFG 9-12, 4.4. Understand the meaning of "durable goods" (i.e., manufactured objects intended to last 3 or more years). CCR-MFG MFG 9-12, 4.5. Understand that manufacturing products and manufacturing processes are intentionally designed.
	Manufacturing Facilities			CCR-MFG MFG 9-12, 4.6. Understand features common to all manufacturing enterprises using the manufacturing enterprise wheel. [PLTW-MFG HM 9-12, 1.B2. (modified)]. CCR-MFG MFG 9-12, 4.7. Understand and describe the reasons why teamwork is a core element in all manufacturing processes (i.e., division of labor allows more efficient production). CCR-MFG MFG 9-12, 4.8. Research the number of employees required for a typical manufacturing processing facility, and explain how this has changed over time. CCR-MFG MFG 9-12, 4.9. Understand the way information is used as a resource that enables manufacturing (e.g., information on how to make products; information on lessons learned from prior experiences; information provided by monitoring sensors). CCR-MFG MFG 9-12, 4.10. Explain where companies get the money to build manufacturing plants (e.g., corporate bonds) and how much typical plants cost. CCR-MFG MFG 9-12, 4.11. Understand how manufacturing facilities acquire the land they use (e.g., eminent domain, purchase, acquisition) and the concept of zoning regulations.
	Inputs Outputs, Feedback			CCR-MFG MFG 9-12, 4.12. Understand all manufacturing systems have inputs, processes, outputs, and at times, feedback. CCR-MFG MFG 9-12, 4.13. Emulate a simple manufacturing process, making multiple copies of a multi-part object (e.g., paper airplane or Lego toy) from raw materials according to a hypothetical customer order. CCR-MFG MFG 9-12, 4.14. Identify the inputs and outputs of the emulated manufacturing process.
Quality Control	Reliability and Reproducibility	CCR-MFG QC 5. Understand methods for achieving quality control.	CCR-MFG QC 6-8, 5.1. Describe issues that arise in mass producing objects (e.g., preventing defects, maintaining consistent quality, reducing cost of production, increasing production rate, preventing adverse events from impacting production), even once it is known how to perfectly make a single copy. CCR-MFG QC 6-8, 5.2. Understand that manufacturing problems and many other types of problems can be solved by asking and answering a series of questions in order (e.g., 1. What's the problem? 2. How do we know? 3. What are some of the root causes? 4. What treatment can be applied? 5. Can we set up a system to ensure the treatment results are always going to be in the range of what we're looking for?). CCR-MFG QC 6-8, 5.3. Identify a problem and use this problem-solving approach to solve it.	CCR-MFG QC 9-12, 5.1. Understand the concepts of reliability and reproducibility.
	Accuracy, Precision, Tolerances			CCR-MFG QC 9-12, 5.2. Understand the concepts of tolerance, accuracy and precision. CCR-MFG QC 9-12, 5.3. Identify and demonstrate by measuring with calipers, micrometers, scales, or other instruments, if a manufactured object is within tolerance. CCR-MFG QC 9-12, 5.4. Demonstrate and explain how the dimensions of a die or mold relate to the dimensions of an object manufactured by the die or mould. CCR-MFG QC 9-12, 5.5. Draw diagrams of provided parts that specify tolerances.
	Inspection, Quality Control			CCR-MFG QC 9-12, 5.6. Understand the concept of acceptance sampling and the role of sample size. CCR-MFG QC 9-12, 5.7. Apply binomial expansions to calculate the probability of finding a bad part in a batch of parts, and then compare the calculations with the results obtained by sampling parts from the batch. (Grade 10) CCR-MFG QC 9-12, 5.8. Using statistical concepts of the normal distribution and standard deviations, measure a sample of objects from a batch of objects and determine whether the batch as a whole adheres to the tolerances guaranteed to a hypothetical customer. (Grade 9) CCR-MFG QC 9-12, 5.9. Understand when binomial distributions vs. normal distributions are used as the underlying mathematics in sampling problems (e.g., difference between predicting the likelihood of a binary (yes/no) outcome vs. a continuous outcome that could have a range of values). (Grade 10) CCR-MFG QC 9-12, 5.10. Understand and explain how statistics is used in designing and running manufacturing operations.
	Quality Assurance			CCR-MFG QC 9-12, 5.11. Understand the practical differences between inspection and quality assurance as approaches to quality control. CCR-MFG QC 9-12, 5.12. Understand the role that sensors play in quality assurance.
	Continuous Quality Improvement			CCR-MFG QC 9-12, 5.13. Understand and explain the concept of continuous quality improvement. CCR-MFG QC 9-12, 5.14. Use a process control chart to graph the variation in manufactured objects over time. CCR-MFG QC 9-12, 5.15. Determine if a manufacturing process can be iterated, and then iterate the manufacturing process to progressively reduce product variation.
	Six Sigma			CCR-MFG QC 9-12, 5.16. Understand where the term "Six Sigma" comes from (e.g., 3.4 defects per million opportunities, i.e., Six Standard deviations fit between the mean and the acceptable process/product limit). CCR-MFG QC 9-12, 5.17. Understand and explain the steps that make up the Six Sigma process for improving a defective system (i.e., define what's the problem; measure to know how to know; analyze what are some of the root causes; improve what treatment can be applied; control the set up of a system to ensure the treatment results are always going to be in the range of what was identified. CCR-MFG QC 9-12, 5.18. Explain and demonstrate when Six Sigma is used in manufacturing. CCR-MFG QC 9-12, 5.19. Identify a defective system in its environment (e.g., school) and use a Six Sigma approach to fix it (e.g., reducing cafeteria waste; improving classroom air quality; reducing the percent of students who turn in homework late; reducing the time needed for teachers to develop lessons; making more efficient use of the school's bus fleet). CCR-MFG QC 9-12, 5.20. Identify and demonstrate the steps that make up the Six Sigma process for designing a new system as opposed to fixing an existing one (e.g., define, measure, analyze, design, verify).
Industrial Safety	Power vs. Energy	CCR-MFG SAF 6. Understand industrial safety and demonstrate the use of safety equipment and procedures.	CCR-MFG SAF 6-8, 6.1. Understand the relationship between energy and power. CCR-MFG SAF 6-8, 6.2. Convert power between English and SI units. CCR-MFG SAF 6-8, 6.3. Understand where energy is used in manufacturing processes (e.g., electricity to drive machines; water wheels to turn flour mills; fire to melt raw materials; human energy to pump bellows).	CCR-MFG SAF 9-12, 6.1. Prerequisite - and repeat as needed - benchmarks CCR-MFG SAF 6-8, 1.1 through 1.15.
	Electrical Safety, Lockout and Tagout		CCR-MFG SAF 6-8, 6.4. Understand that safety risk increases as the energy or power associated with equipment use increases. CCR-MFG SAF 6-8, 6.5. Explain and provide examples of high vs. low energy situations that are not related to powered equipment (e.g., mechanical, chemical, thermal, and gravitational). CCR-MFG SAF 6-8, 6.6. Experimenting and demonstrate approaching higher energy situations with higher levels of caution and greater deployment of safety procedures.	
			CCR-MFG SAF 6-8, 6.7. Explain the levels of AC and DC current that are lethal and compare these to the currents used by or with household and industrial devices. CCR-MFG SAF 6-8, 6.8. Describe situations or arrangements of objects that could result in a short circuit through the human body. [CCR-EE ES 6-8, 3.2.] CCR-MFG SAF 6-8, 6.9. Describe how the combination of electricity and water is potentially lethal. CCR-MFG SAF 6-8, 6.10. Describe and demonstrate electrical fire precautions and response procedures. [CCR-EE ES 6-8, 3.5.] CCR-MFG SAF 6-8, 6.11. Understand and use the concept of equipment isolation and demonstrate the lock, tag, and try method for rendering energized equipment safe to work on.	
	Chemical Safety		CCR-MFG SAF 6-8, 6.12. Demonstrate how to find and read a manufacturing safety data sheet. CCR-MFG SAF 6-8, 6.13. Explain the common household and industrial chemicals that are potentially lethal in combination (e.g., ammonia and bleach (toxic gas); ethyl alcohol and hydrochloric acid (explosive); methanol and sulfuric acid (severely toxic); phosphoric acid and any alcohol (nerve poison); hydrogen peroxide and acid (violent reaction); cyanide compounds and any acid (deadly gas); perchloric acid and any alcohol, acetone, plastic or other organic (very explosive); chromic acid and any alcohol, acetone, plastic or organic (explosive)).	
	OSHA		CCR-MFG SAF 6-8, 6.14. Research applicable OSHA regulations and explain their meaning as they relate to a provided industrial working scenario.	
	Fire Safety		CCR-MFG SAF 6-8, 6.15. Explain different kinds of fires (e.g., grease, electrical) and the correct method for extinguishing each. CCR-MFG SAF 6-8, 6.16. Use, and know where to find, a fire extinguisher.	
	Safety Equipment		CCR-MFG SAF 6-8, 6.17. Understand how to use and where to find personal safety equipment (e.g., safety goggles, hardhats, steel-toed boots, insulating mats and boots, chemical-resistant gloves, fire-resistant aprons and clothing, acid and base storage containers). CCR-MFG SAF 6-8, 6.18. Describe how to set up a work environment and how to equip personnel with necessary safety equipment and related safety precautions given a hypothetical industrial work task with a related safety equipment catalog.	
Industrial Power	Electrical, Pneumatic, Hydraulic, and Mechanical	CCR-MFG IP 7. Understand industrial power.		CCR-MFG IP 9-12, 7.1. Understand electrical, pneumatic, hydraulic, mechanical, and motion-based (i.e., kinetic) energy and power. CCR-MFG IP 9-12, 7.2. Understand how industrial power is generated by at least one local power company. CCR-MFG IP 9-12, 7.3. Understand fluid power is inversely proportional to the area upon which the force is being applied. [PLTW-MFG PWR 9-12, 8.A2.] CCR-MFG IP 9-12, 7.4. Solve problems involving electrical, fluid (pneumatic or hydraulic), and mechanical power. [PLTW-MFG PWR 9-12, 8.B2. (modified)] CCR-MFG IP 9-12, 7.5. Calculate torque and use it to calculate power. [PLTW-MFG PWR 9-12, 8.B4.] CCR-MFG IP 9-12, 7.6. Construct a system to convert pneumatic power into mechanical power. (e.g., robot arm). [PLTW-MFG PWR 9-12, 8.B6.]
Manufacturing Process Diagrams	Flowcharts	CCR-MFG MP 8. Diagram manufacturing processes.		CCR-MFG MP 9-12, 8.1. Identify basic flowcharting symbols and explain each function. CCR-MFG MP 9-12, 8.2. Flowchart the operation of an object (e.g., car, microwave, oven, washing machine), illustrating all inputs, outputs, and conditions. CCR-MFG MP 9-12, 8.3. Make an object or product, and then flowchart its manufacturing process. CCR-MFG MP 9-12, 8.4. Use flowcharting for other engineering problems (e.g., transportation, structural, or communication systems) creating a model of the inputs, processes, outputs, and feedback among components. [7.MS-ETS3-5(MA). (Modified).]
	Process Flow Design			CCR-MFG MP 9-12, 8.5. Understand the process flow design can have a major impact on overall production time and thus product profit by play acting the steps in a flowchart, rearranging those steps, and then play-acting the revised process.

Computer-Aided Design and Manufacturing	Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM)	CCR-MFG CAD 9. Understand and use computers to design and manufacture objects.		CCR-MFG CAD 9-12, 9.1. Create part drawings using computer-aided design. CCR-MFG CAD 9-12, 9.2. Interpret G&M codes used with computer numerically controlled equipment. [PLTW-MFG PD 9-12, 6.B4. (modified)] CCR-MFG CAD 9-12, 9.3. Transfer the drawings made in CAD to a CAM program. [PLTW-MFG PD 9-12, 6.B5.] CCR-MFG CAD 9-12, 9.4. Create numerical code using a CAM program. [PLTW-MFG PD 9-12, 6.B6.] CCR-MFG CAD 9-12, 9.5. Verify the creation of a part using simulation software. [PLTW-MFG PD 9-12, 6.B7.] CCR-MFG CAD 9-12, 9.6. Create parts using machines while following specific instructions. [PLTW-MFG PD 9-12, 6.B8. (modified)] CCR-MFG CAD 9-12, 9.7. Create a product via computer using knowledge of CAD-CAM manufacturing processes: [PLTW-MFG PD 9-12, 6.B9. (modified)]
Production Manufacturing	Production Processes and Tradeoffs	CCR-MFG PRD 10. Design a manufacturing process and use it in a production setting.		CCR-MFG PRD 9-12, 10.1. List the consequences and tradeoffs associated with choosing one manufacturing process over another, including environmental impacts, raw material availability, product lifecycle, cost, schedule, equipment availability, maintenance requirements, product quality and properties, interchangeability of parts, obsolescence, potential warranty implications, and hazards or risks. CCR-MFG PRD 9-12, 10.2. Design and develop a fabrication sequence, and use it in a manufacturing or production setting to satisfy a defined need or want, within specified requirements.
Manufacturing Systems	Flexible Manufacturing	CCR-MFG CIM 11. Understand flexible and computer-integrated manufacturing		CCR-MFG CIM 9-12, 11.1. Explain that a flexible manufacturing system (FMS) is one that can adapt to a wide variety of products, typically through the use of interchangeable parts. CCR-MFG CIM 9-12, 11.2. Understand the two features of a flexible manufacturing system (i.e., machine flexibility, routing flexibility). CCR-MFG CIM 9-12, 11.3. Understand the three components of most industrial FMS (e.g., work machines, typically automated CNC machines; a material handling system; a central control computer). CCR-MFG CIM 9-12, 11.4. Understand the term "programmable logic controller" (PLC) and recognize that CNC machines are one type of programmable logic controller.
	Computer-Integrated Manufacturing			CCR-MFG CIM 9-12, 11.5. Understand that computer-integrated-manufacturing can be used to describe an FMS when at least two computers are exchanging information and, more typically, when the entire production process is controlled by computers exchanging sensors and data flow with factory equipment and systems. CCR-MFG CIM 9-12, 11.6. Explain that a CIM can include almost all parts of the manufacturing process including the manufacturing equipment, the handling equipment, the purchasing system, the inventory control system, the accounting system, and the design system. CCR-MFG CIM 9-12, 11.7. Compare the use of a control system in Flexible vs. Computer-integrated manufacturing.
	Making a Flexible Manufacturing System			CCR-MFG CIM 9-12, 11.8. Model and create a program to control an automated system. [PLTW-MFG CS 9-12, 2.B5.] CCR-MFG CIM 9-12, 11.9. Design a manufacturing system that contains at least two automated components (e.g., marble sorter separating by size, then density; dough stamper followed by scrap dough remover). [PLTW-MFG MA 9-12, 11.B3. (modified)] CCR-MFG CIM 9-12, 11.10. Complete the construction of each individual component of a miniature FMS and verify that each component works. [PLTW-MFG MA 9-12, 11.B4.] CCR-MFG CIM 9-12, 11.11. Assemble components into a working miniature FMS. [PLTW-MFG MA 9-12, 11.B5.] CCR-MFG CIM 9-12, 11.12. Refine each component of a miniature working FMS to improve the total process flow and cycle time. [PLTW-MFG MA 9-12, 11.B6.] CCR-MFG CIM 9-12, 11.13. Research working manufacturing line in the real world and identify places where robotics are used or could be used.
Optimizing Manufacturing Systems	Lean Manufacturing	CCR-MFG LM 12. Understand and explain ways of optimizing a manufacturing system to reduce the time and cost of production while improving product quality and customer satisfaction.		CCR-MFG LM 9-12, 12.1. Understand and explain logistics (i.e., the coordination of complex operations involving many people, facilities, or supplies). CCR-MFG LM 9-12, 12.2. Understand that lean manufacturing is a logistics optimization strategy. CCR-MFG LM 9-12, 12.3. Describe the primary theme associated with lean manufacturing (i.e., demand-based flow manufacturing) and typical benefits (e.g., decreased production time, lower inventory, lower cost). CCR-MFG LM 9-12, 12.4. Understand and explain the components of lean manufacturing (e.g., just-in-time, takt time (pull flow), Heijunka, Jidoka, man-machine separation, standard working, Kaizen).
	Just-in-Time			CCR-MFG LM 9-12, 12.5. Describe the just-in-time concept, how it relates to surplus inventory, and why just-in-time approaches often result in lower production time and costs.
	Takt Time (Pull-Flow)			CCR-MFG LM 9-12, 12.6. Describe and distinguish the concepts of lead time, cycle time, and takt time.
	Work Cells			CCR-MFG LM 9-12, 12.7. Understand the concept of a workcell and how the physical layout of equipment can minimize time and effort associated with human motion and component transportation.
	Heijunka			CCR-MFG LM 9-12, 12.8. Understand the concept of Heijunka. CCR-MFG LM 9-12, 12.9. Calculate the production rate and inventory size that will allow the manufacturing system to always meet customer demand while carrying a minimum inventory (Heijunka) when given a typical schedule of fluctuating customer demand, a range of production rates that could be used, and a fixed shipping schedule.
	Production Line Balancing			CCR-MFG LM 9-12, 12.10. Understand and explain the concept of production line balancing and ways to achieve it (e.g., labor balancing, equipment balancing, preventative maintenance).
	Standardized Work			CCR-MFG LM 9-12, 12.11. Understand the concept of standardized work and its components (e.g., takt time, work sequence, standard in-process inventory). CCR-MFG LM 9-12, 12.12. Identify from a set of forms (e.g., standardized job instruction sheet, standardized work combination table, and standardized work chart for a simulated manufacturing process) the steps in the manufacturing process that need to be improved.
	Jidoka			CCR-MFG LM 9-12, 12.13. Understand the concept of Jidoka and describe what happens if a machine is not able to sense when a defective product is produced and stop automatically (i.e., defective product piles up and/or extra humans need to be hired to watch for defective product and turn the machine off).
	Man-Machine Separation			CCR-MFG LM 9-12, 12.14. Understand the concept of human-machine separation (i.e., workflow should be designed so machines do all the repetitive steps and a human does the steps requiring intelligence (e.g., no human should be babysitting a machine)) and explain examples from daily life where the principle is and is not followed.
	Kaizen			CCR-MFG LM 9-12, 12.15. Experience Kaizen as a formal process of suggesting, implementing, and testing continuous aligned small improvements to a production process that are acted out each day over a period of time. CCR-MFG LM 9-12, 12.16. Measure the impact Kaizen has had on the time and cost of a real or play-acted manufacturing process.
	System Optimization			CCR-MFG LM 9-12, 12.17. Calculate the baseline production time per finished part (i.e., Takt) for a multistep manufacturing process in which each step is controlled (e.g., a single person or team hands off a partially finished product to the next person in the line). CCR-MFG LM 9-12, 12.18. Calculate the Takt after the manufacturing process experiences involve disruptive variables (e.g., customer change orders, inventory shortages, difference in the rates at which components or subassemblies are produced, changes in physical separation between manufacturing machines or stations, equipment changeovers, personnel changeovers). CCR-MFG LM 9-12, 12.19. Improve a production line's response to each disruptive variable by refining factors (e.g., personnel duties, inventory, operating procedures, equipment tasks, process sequence, physical layout, and maintenance schedule) and remeasure the response and explain why the response cannot be improved. CCR-MFG LM 9-12, 12.20. Document the measured improvement (if any) that was achieved for each disruptive variable.
Design of Experiments (ENRICHMENT)	Definition	CCR-MFG DE Enrich. Understand and know methods for isolating manufacturing problems.	**ENRICHMENT THAT CAN BE INTRODUCED OR COVERED WITH EITHER GRADES 6-8 OR 9-12. Therefore, the benchmark numbering reflects either grade band.**	
			CCR-MFG DE Enrich 6-8, 9-12, E1.1. Understand that Design of Experiments (DoE) is typically used to isolate problems in a manufacturing process when many possible variables could be the source of the problem. CCR-MFG DE Enrich 6-8, 9-12, E1.2. Understand that DoE is a procedure used to reduce the potentially very large number of experiments needed to isolate the problem down to a manageable number.	
	Variable Definition			
			CCR-MFG DE Enrich 6-8, 9-12, E1.4. Design and develop a measure for the outcome of interest (e.g., specific width of the dark brown center region, being able to insert and extract a toothpick without collecting liquid residue).	
	Full Factorial Experimental Designs		CCR-MFG DE Enrich 6-8, 9-12, E1.5. Determine and explain the binary variations to each variable that might influence the outcome (e.g., higher temperature/lower temperature; faster cooling rate/slower cooling rate) and code them (e.g., +1,-1 or +,-) into a full factorial matrix.	
			CCR-MFG DE Enrich 6-8, 9-12, E1.6. Understand the definition of a full factorial matrix (i.e., all possible combinations of all variables) and be able to describe the experiments it implies (e.g., in experiment #1, the brownies are cooked at a higher temperature, with a fast cooling rate, in a metal pan, with slightly more flour than the recipe states).	
	Partial Factorial Experimental Designs		CCR-MFG DE Enrich 6-8, 9-12, E1.7. Determine and explain why the number of required experiments were reduce when reformulating the problem into a partial factorial matrix and allowing some interaction terms to be coded as new variables. CCR-MFG DE Enrich 6-8, 9-12, E1.8. Understand the caveats associated with reducing the required number of experiments (e.g., the ability to detect actual variable interactions is lost).	
	Analyzing Results		CCR-MFG DE Enrich 6-8, 9-12, E1.9. Design, develop, and conduct the experiments defined by the partial factorial matrix, summarize the averages of all positive and negative conditions for each variable, and determine which of the many variables have the most significant effect on the outcome of interest. CCR-MFG DE Enrich 6-8, 9-12, E1.10. Document results and include reflections of what was learned regarding DoE.	