Let the Chips Fall Where They May

Middle School and High School Geometry

DRAFT

SCALE K-12

SCalable Asymmetric Lifecycle Engagement

PURDUE UNIVERSITY

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Cover Information

Unit Title: Let the Chips Fall Where They May

Grade Level Range: Middle School and High School Geometry

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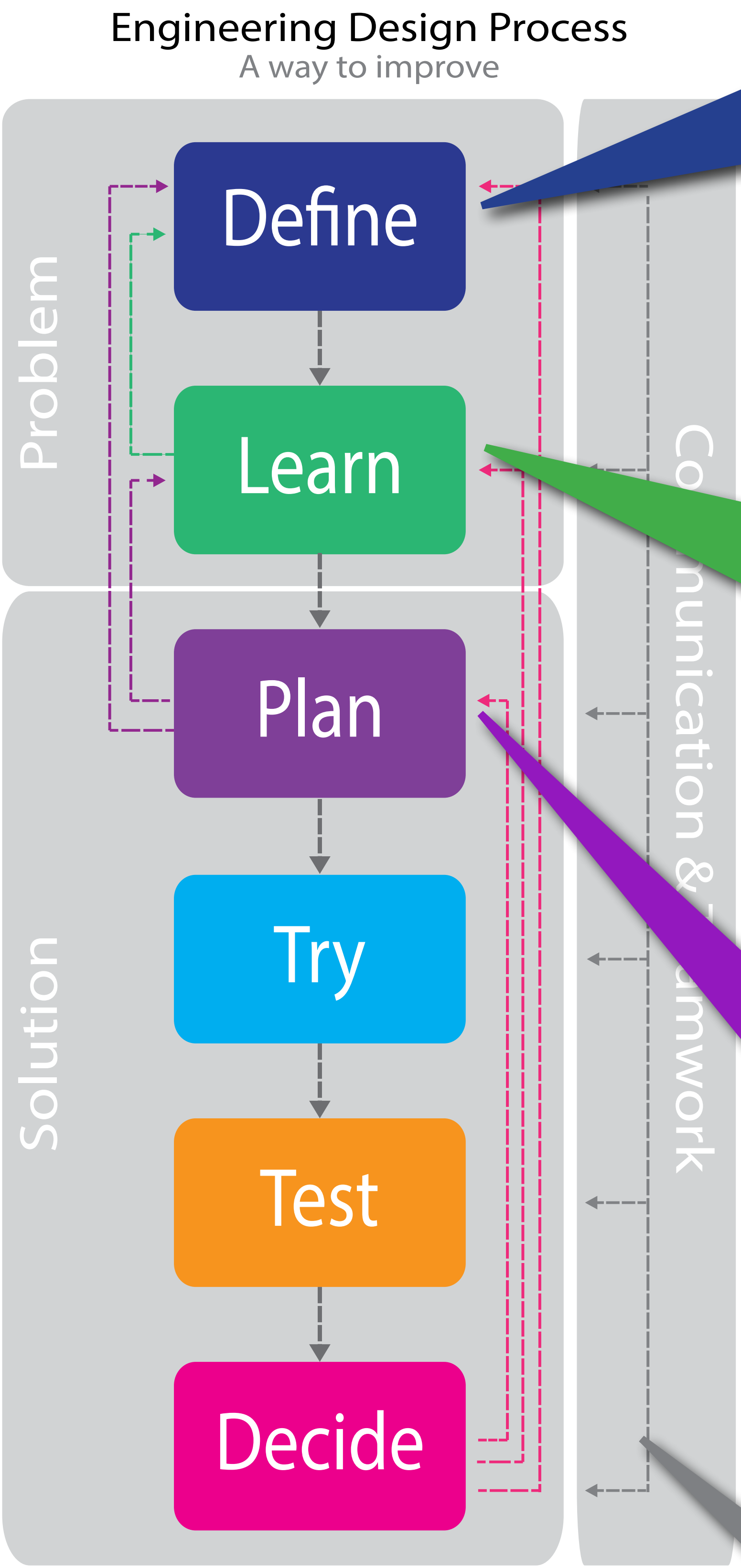
Overview: Engineering Design Process



DEFINE THE PROBLEM

- Who is the **client**?
- What does the client need?
- Why does the client need it?
- Who is the **end user**?
- Why might the end user want it?
- What are the **criteria** (requirements) and **constraints** (limits) of the solution?

Problem Scoping:
WHO needs **WHAT** because **WHY**

LEARN ABOUT THE PROBLEM

- What kind of background knowledge is needed?
  - What science/math knowledge will be needed?
  - What materials will be needed?
- What has already been done to solve the problem?
- What products fill a similar need?
- How should we measure success and improvement?

PLAN A SOLUTION

- Continue to specify the criteria/ constraints
- Generate ideas of possible solutions
- Develop multiple solution paths
- Consider **constraints**, **criteria**, and **trade-offs** (criteria that compete with one another)
- Choose a solution to try
- Develop plans (blueprints, schematics, cost sheets, storyboards, notebook pages, etc.)

COMMUNICATION

- Communicate the solution clearly and make sure it is easily understandable
- Use **evidence** to support why the client should use your solution

TRY A SOLUTION

- Put the plan into action
- Consider risks and how to optimize work
- Use criteria/constraints and consider trade-offs from the problem/plan to build a **prototype** (a testable representation of a solution), **model**, or **product**

TEST A SOLUTION

- Consider testable questions or hypotheses
- Develop experiments or rubrics to determine if the solution is meeting the stated criteria, constraints, and needs
- Collect and analyze data

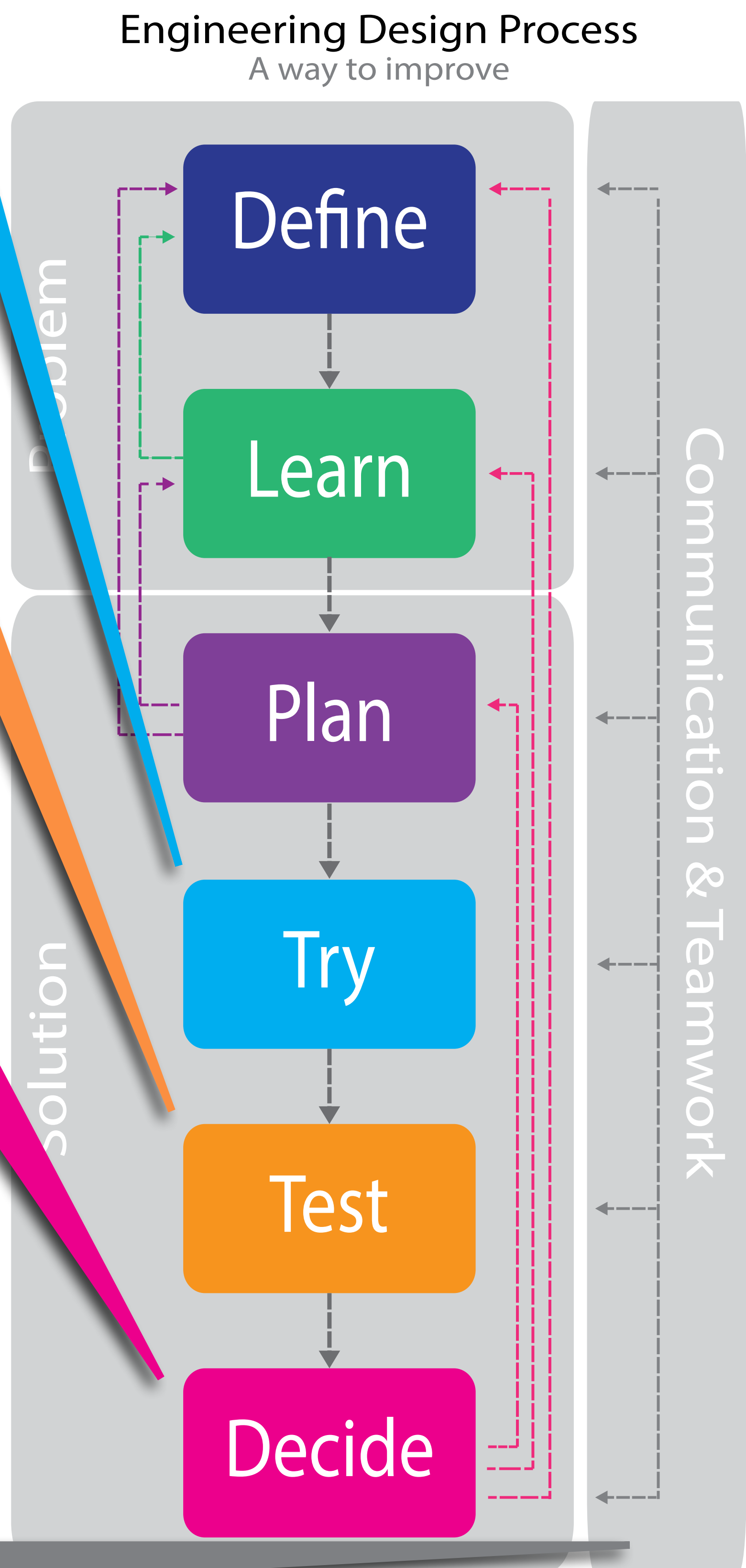
DECIDE IF THE SOLUTION IS GOOD ENOUGH

- Are users able to use the design to help with the problem?
- Does the design meet the criteria and constraints?
- How could the design be improved based on test results and feedback from the client/user?

Iterative nature of design: Always consider which step should be next!

TEAMWORK

- Discuss in teams how the solution meets the criteria and needs of the client
- Consider different viewpoints from each teammate



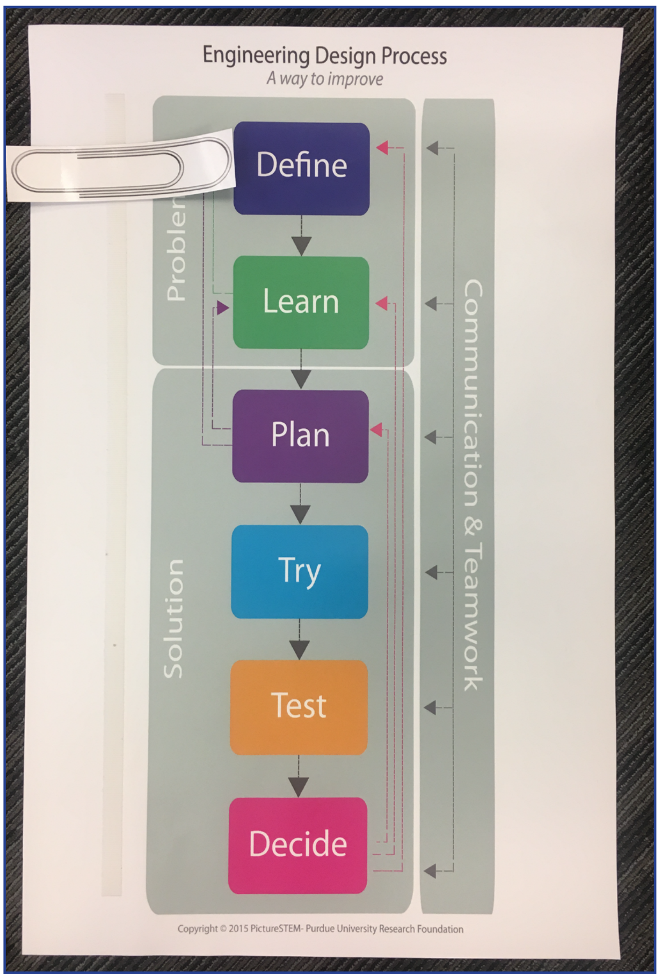
Overview: How to make EDP sliders

How to create the poster

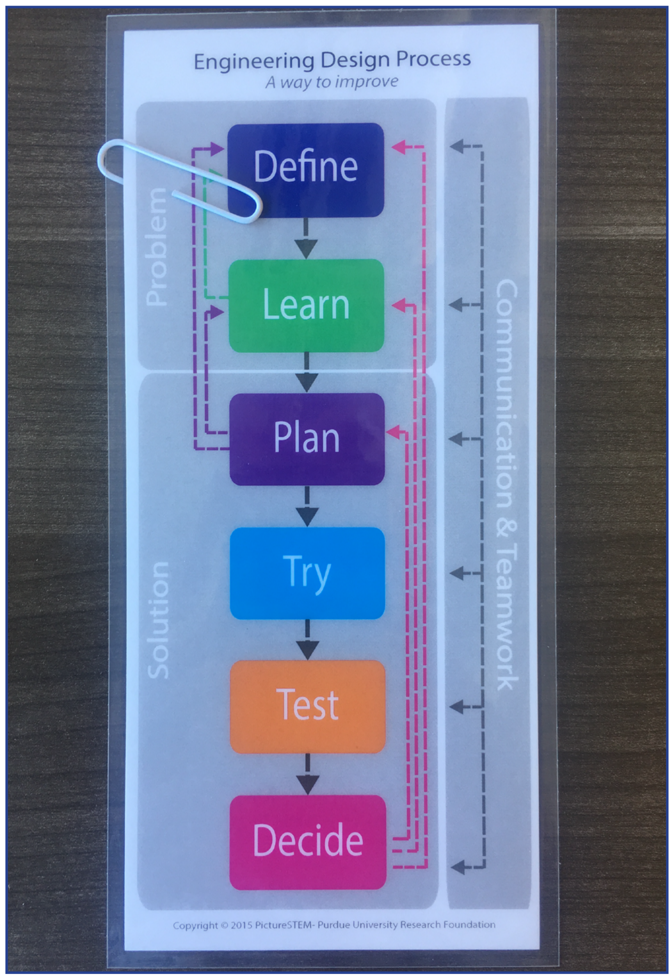
1. Download the high-quality PictureSTEM Slider Poster and the paper clip images from PictureSTEM.org.
2. Print the poster and the paper clip on poster-sized paper and cut to size. High-gloss or semi-gloss paper is the best choice.
3. Use self-sticking Velcro on the back of the paper clip and down the side of the poster so that the paper clip can be placed to point at all 6 sections of the slider.

How to create individual sliders

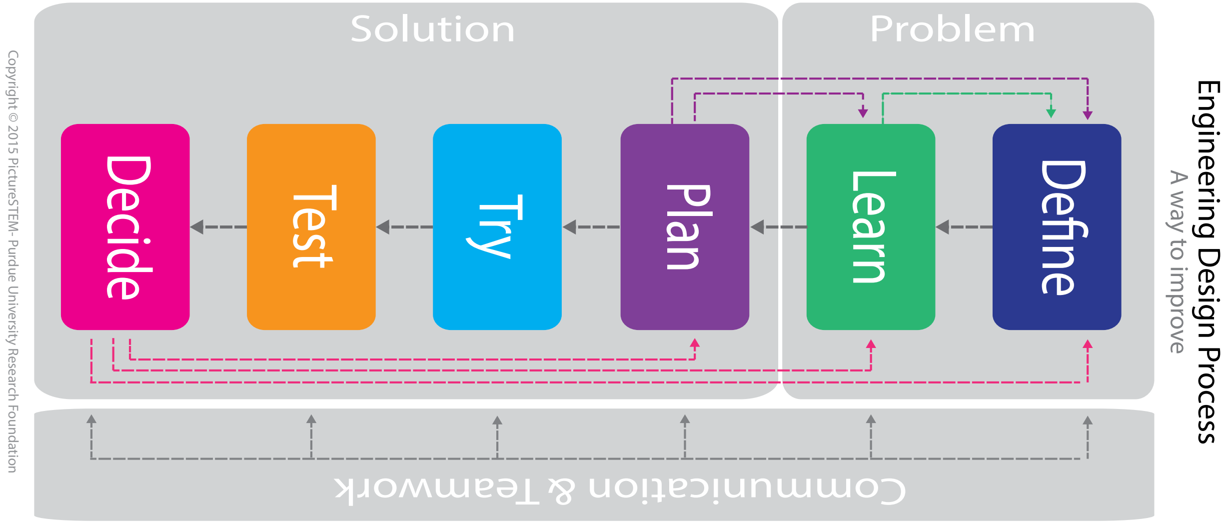
1. Print the sliders on the opposite page - enough for one slider per student in your class.
2. Cut the sliders apart.
3. Laminate the sliders individually.
4. Use a jumbo paper clip as the pointer for each slider.



Poster



Individual slider


Engineering Design Process
A way to improve
Problem
Solution
Define
Learn
Plan
Try
Test
Decide
Communication & Teamwork
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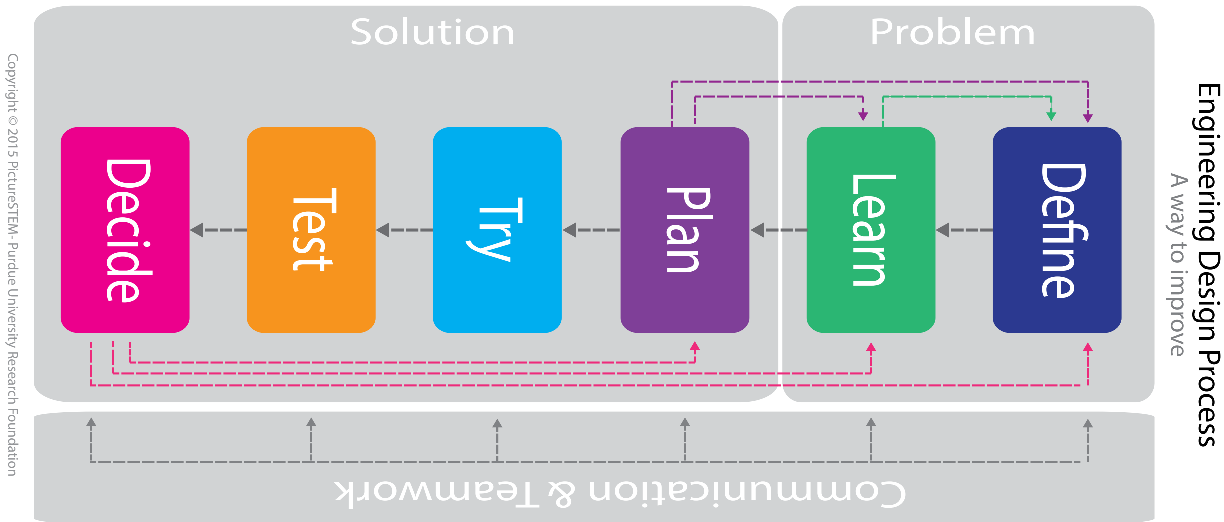
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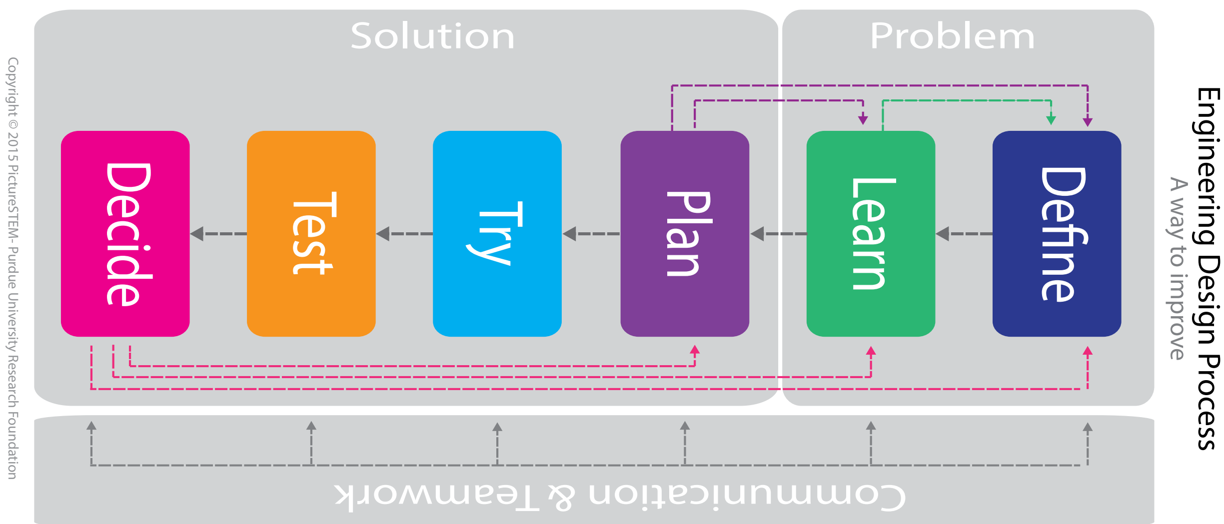
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Unit Overview

Grade Levels: Middle School and High School Geometry

Approximate Time Needed to Complete Unit: Approximately 10 50-minute class periods

Unit Summary

Geti Games is experiencing a surge in demand for a new gaming controller, and the existing process used by their suppliers for manufacturing microchips is not able to keep up. Skylar Geti, the CEO of Geti Games, is asking the student engineers for help to understand the microchip manufacturing process while assessing whether to bring the manufacturing process in-house. Students are tasked with calculating silicon wafer waste, silicon wafer production, silicon boule waste, and ultimately designing an efficient process to layout a silicon wafer. In teams, students will used evidence-based reasoning to select a process to recommend to the client, and will test and evaluate the design selected using a decision criteria matrix. Finally, students will communicate their solution, justifying it with evidence.

Subject Connections

Science Connections	Technology and Engineering Connections	Mathematics Connections
Material Science, finite resources, infinite resources, purification, yield (theoretical, actual)	Engineering Design Process Manufacturing Engineering Microelectronics	Area, volume, circumference, ratio, percentage, cylinder, cone, sphere, hemisphere

Standards

NGSS Standards - HS-ETS1 Engineering Design

- HS ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

2023 Indiana Academic Standards: Mathematics - Geometry

- PS.1: Make sense of problems and persevere in solving them.
- PS.2: Reason abstractly and quantitatively.
- PS.3: Construct viable arguments and critique the reasoning of others.
- PS.4: Model with mathematics.
- PS.5: Use appropriate tools strategically.
- PS.6: Attend to Precision
- G.QP.4 Compute perimeters and areas of regular and irregular polygons to solve real-world and other mathematical problems. (E)
- G.CI.1 Define, identify, and use relationships among the following: radius, diameter, arc, measure of an arc, chord, secant, tangent, congruent circles, and concentric circles.
- G.CI.3 Solve real-world and other mathematical problems that involve finding measures of circumference, areas of circles and sectors, and arc lengths and related angles (central, inscribed, and intersections of secants and tangents). (E)
- G.TS.4 Solve real-world and other mathematical problems involving volume and surface area of prisms, cylinders, cones, spheres, and pyramids, including problems that involve composite solids and algebraic expressions. (E)
- G.TS.5 Apply geometric methods to create and solve design problems. (E)

Indiana Academic Standards: Mathematics Grade 8

- PS.1: Make sense of problems and persevere in solving them.
- PS.2: Reason abstractly and quantitatively.
- PS.3: Construct viable arguments and critique the reasoning of others.
- PS.4: Model with mathematics.
- PS.5: Use appropriate tools strategically.
- PS.6: Attend to Precision
- 8.NS.4 Solve real-world problems with rational numbers by using multiple operations. (E)
- 8.GM.2 Solve real-world and other mathematical problems involving volume of cones, spheres, and pyramids and surface area of spheres. (E)
- 8.GM.3 Apply the Pythagorean Theorem to determine unknown side lengths in right triangles in real-world and other mathematical problems in two dimensions. (E)

Indiana Academic Standards: Mathematics Grade 7

- PS.1: Make sense of problems and persevere in solving them.
- PS.2: Reason abstractly and quantitatively.
- PS.3: Construct viable arguments and critique the reasoning of others.
- PS.4: Model with mathematics.
- PS.5: Use appropriate tools strategically.
- PS.6: Attend to Precision

- 7.NS.7 Compute fluently with rational numbers using an algorithmic approach. (E)
- 7.AF.1 Apply the properties of operations (e.g., identity, inverse, commutative, associative, distributive properties) to create equivalent linear expressions, including situations that involve factoring out a common number (e.g., given 2x - 10, create an equivalent expression 2(x - 5)). Justify each step in the process. (E)
- 7.AF.2 Solve real-world problems with rational numbers by using one or two operations. (E)
- 7.GM.2 Understand the formulas for area and circumference of a circle and use them to solve real-world and other mathematical problems; give an informal derivation of the relationship between circumference and area of a circle.
- 7.GM.3 Solve real-world and other mathematical problems involving volume of cylinders and three-dimensional objects composed of right rectangular prisms. (E)

Indiana Academic Standards: Mathematics Grade 6

- PS.1: Make sense of problems and persevere in solving them.
- PS.2: Reason abstractly and quantitatively.
- PS.3: Construct viable arguments and critique the reasoning of others.
- PS.4: Model with mathematics.
- PS.5: Use appropriate tools strategically.
- PS.6: Attend to Precision
- 6.NS.4 Solve real-world problems with positive fractions and decimals by using one or two operations. (E)
- 6.RP.2 Understand the concept of a unit rate and use terms related to rate in the context of a ratio relationship.
- 6.RP.4 Solve real-world and other mathematical problems involving rates and ratios using models and strategies such as reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations. (E)
- 6.AF.1 Define and use multiple variables when writing expressions to represent real-world and other mathematical problems, and evaluate them for given values. (E)
- 6.GM.3 Find the area of complex shapes composed of polygons by composing or decomposing into simple shapes; apply this technique to solve real-world and other mathematical problems.
- 6.GM.4 Find the volume of a right rectangular prism with fractional edge lengths using unit cubes of the appropriate unit fraction edge lengths (e.g., using technology or concrete materials) and show that the volume is the same as would be found by multiplying the edge lengths of the prism. Apply the formulas V = lwh and V = Bh to find volumes of right rectangular prisms with fractional edge lengths to solve real-world and other mathematical problems. (E)

Lesson 1: Die Hard

Students are introduced to the client and a first-level problem which will serve as the context within which students can learn about microchip manufacturing. Here students will critique the client's model with a hands-on demonstration and with geometric calculations. Students will learn about the Engineering Design Process and take part in iterative class and group discussions to identify criteria, constraints, and knowledge gaps needed to successfully solve the client's challenge.

Lesson 2: Waste Not, Want Not

In this lesson, students will work with the client's response which contains a new model, which has also been identified as problematic in that it has too much waste. Students will calculate waste using area of circles, rectangles, and simple volume ideas first on a specific example, then as a class to develop a model for the calculation of waste.

Lesson 3: The Elemental Difference

Students will learn about resource abundance and how readily available silicon is to be used to manufacture wafers. Students will research the abundance and geographic location of the sand used to make silicon. They will compare finite and infinite resources and discuss why this is important for the engineering design challenge.

Lesson 4: To Yield or Not to Yield

In this lesson, students will learn about the purification process that takes place to extract silicon from sand. They will complete calculations to learn about the percent yield of silicon from sand. Students will then play a game to experience being part of the microelectronics industry while trading money and resources.

Lesson 5: A Watched Pot Never… Boules???

Silicon is made into boules in order to create wafers which are then cut into die. In this lesson, students will focus on understanding how to model the volume of a boule, which is a composite 3-D figure or shape. They will also consider where the waste from the manufacturing process of boule to wafer comes from. As a class, the students will develop a simple model to determine wafer yield from a boule.

Lesson 6: Is Your Wafer in Chip Shape?

The client shares the root of the problem that needs to be solved in order help the end user increase productivity in the microchip manufacturing process. Here students will learn about the wafer dicing process used to cut a silicon wafer into dies. Students will learn how to scope the problem, identify criteria, constraints, and knowledge gaps needed to successfully solve the client's challenge. Students will generate individual process design ideas and then collaborate as a team, arriving at a final design by consensus. Students will use evidence-based reasoning to defend their design decisions.

Lesson 7: Ready to Roll the Die!

In this lesson, students will test and evaluate their process designs with a specific request from the client. Students will prepare presentations as a team to share their design and results with the class. Students will review the results of their designs using the decision matrix prior to providing a final recommendation to the client.

Unit Planner

Lesson	Time Needed	Objectives	Materials	Duplication Master
1. Die Hard	Two 50-minute class-periods	Students will be able to: • Identify the problem from a client. • Identify issues with a given mathematical model. • Understand why the area of die on a wafer cannot equal the area of the circle wafer.	**Per Classroom:** 1 Engineering Design Process (EDP) poster, chart paper, sample silicon wafer **Per Group:** 1 cm area tiles (about 350 per group), transparent rulers marked in inches and cm (with marks for mm), scissors **Per Student:** EDP slider and paper clip, Laptop/ Chromebook/Tablet, Engineering notebook, Pencils and erasers	**Duplication Masters** 1.A Content Pre-Assessment 1.B Client Letter 1.C 200 mm Wafer Model **Educator Resources** 1.D Reply to Client Template 1.E Content Pre-Assessment Key
2. Waste Not, Want Not	One 50-minute class-period	Students will be able to: • Identify the problem from a client. • Calculate waste based on area and volume. • Develop a generalized model for wasted material on a wafer.	**Per Classroom:** 1 Engineering Design Process (EDP) poster, chart paper **Per Group:** transparent rulers marked in inches and cm (with marks for mm) **Per Student:** EDP slider and paper clip, Laptop/ Chromebook/Tablet, Engineering notebook, Pencils and erasers	**Duplication Masters** 2.A Client Response 2.B Die on Wafer

Lesson	Time Needed	Objectives	Materials	Duplication Master
3. The Elemental Difference	One 50-minute class-period	Students will be able to: • Discover which elements make wafers. • Understand the difference between finite/ infinite resources.	**Per Classroom:** 1 Engineering Design Process (EDP) poster, Element sample box, silicon samples **Per Student:** EDP slider and paper clip, Laptop/ Chromebook/Tablet, Engineering notebook, Pencils and erasers, Calculator, Gloves to handle materials	**Duplication Masters** 3.A Client Memo 3.B Resource Abundance 3.C Resource Abundance Calculations **Educator Resources** 3.D Resource Abundance KEY
4. To Yield or Not to Yield	One 50-minute class-period	Students will be able to: • Calculate yield through purification process.	**Per Classroom:** 1 Engineering Design Process (EDP) poster **Per Student:** EDP slider and paper clip, Laptop/ Chromebook/Tablet, Engineering notebook, Pencils and erasers, Calculator	**Duplication Masters** 4.A Client Memo 4.B Silicon Yield 4.C Microelectronics Resources Game Pieces 4.D Microelectronics Resources Game Instructions 4.E Microelectronics Resources Game Instructions **Educator Resources** 4.F Silicon Yield KEY

Unit Planner

Lesson	Time Needed	Objectives	Materials	Duplication Master
5. A Watched Pot Never … Boules?	One 50-minute class-period	Students will be able to: • Understand that silicon boules are grown to specifications in order to be sliced to create wafers with the least amount of waste. • Decompose 3-D models of boules to calculate volume and determine wafer yield.	**Per Classroom:** 1 Engineering Design Process (EDP) poster, playdough, string of various widths, ruler **Per Group:** Variety of 3D models representative of boules, Variety of thin circular disks representative of wafers **Per Student:** EDP slider and paper clip, Laptop/ Chromebook/Tablet, Engineering notebook, transparent rulers marked in inches and cm (with marks for mm), Pencils and erasers, Calculator, PowerPoint slides	**Duplication Masters** 5.A Client Response **Educator Resources** 5.B Boule Shapes 5.C Kerf Loss Demonstration

Lesson	Time Needed	Objectives	Materials	Duplication Master
6. Is Your Wafer in Chip Shape?	Three 50-minute class-periods	Students will be able to: • Define the problem including client and end user needs • Identify and explain criteria and constraints • Identify background knowledge needed to develop a solution • Design a process to layout a silicon wafer that supports rectangular die of many different sizes and any of the standard size silicon wafer diameters (i.e., 50 mm, 100 mm, 150 mm, 200 mm), when given constraints of spacing (vertical and horizontal) and handling space. • Use evidence-based reasoning to defend design decisions	**Per Classroom:** 1 Engineering Design Process (EDP) poster, chart paper **Per Student:** EDP slider and paper clip, Laptop/Chromebook/Tablet, Engineering notebook, transparent rulers marked in inches and cm (with marks for mm), Pencils and erasers, Calculator	**Duplication Masters** 6.A Client Letter – Scoping the Problem 6.B Client Response [*Word document template*] 6.C Client Letter – Process Design Requirements 6.D Brainstorming Worksheet 6.E Evidence-Based Reasoning Worksheet 6.F Design Sketching **Educator Resources** 6.G Problem Scoping Questions and Answers 6.H Problem Scoping Prompts 6.I Evidence-Based Reasoning Poster

Unit Planner

Lesson	Time Needed	Objectives	Materials	Duplication Master
7. Ready to Roll the Die!	One 50-minute class-period	Students will be able to: • Implement a design while working together within a design team • Analyze the performance of their design • Communicate science, technology, engineering and mathematics ideas through presentation and written communication • Compare their design's performance with the performance of their peer's designs	**Per Classroom:** 1 Engineering Design Process (EDP) poster, chart paper **Per Student:** EDP slider and paper clip, Laptop/ Chromebook/Tablet, Engineering notebook, transparent rulers marked in inches and cm (with marks for mm), Pencils and erasers, Calculator	**Duplication Masters** 7.A Decision Matrix Rubric 7.B Decision Matrix Activity 7.C (Optional) Class Report to the Client 7.D Content Post-Assessment **Educator Resources** 7.E Content Post-Assessment KEY

Master Material List

	Unit Materials	Lessons Where Material is Used
Per Classroom	• 1 Engineering Design Process (EDP) poster* • Digital technologies to display videos, simulations and other online resources (I.e. computer/laptop; interactive whiteboard or other projector* • Chart paper • Element sample box • Silicon samples	• All • All • 1, 2, 6, 7 • 3
Per Group (assume 3 students per group)	• 1 cm area tiles (about 350 per group), rulers marked with inches and cm (with marks for mm), • Scissors* • Variety of 3D models representative of boules* • Variety of this circular discs representative of wafers*	• 1 • 1 • 5 • 5
Per Student	• EDP slider and paper clip* • Laptop/Chromebook/Tablet* • Engineering notebook* • Pencils and erasers* • Calculator • PowerPoint slides • Gloves to handle materials	• All • All • All • All • 3,4,5,6,7 • 5

* Required materials not included in the kit

Unit Background

Introduction

This unit models engineering teamwork, practices, and the engineering design process.

Teamwork

Students should be teamed strategically and may or may not be assigned jobs within their team. When forming student teams, consider academic, language, and social needs. In place of strategic teaming, a random teaming can be substituted. Students will work in teams of 3 or 4 throughout the unit. Effective teamwork is essential in this unit, just like in engineering. The teams will operate as consulting engineers with each team specializing in a specific measuring device eventually working together as a class to address the client's problem.

Career Connections

Students will be introduced to new STEM content potentially for the first time. There are many career opportunities that align with the content in this unit. Please plan to highlight these as you see fit and encourage students to think about how these topics align with their personal and future interests.

Engineering Design Process

NOTE: If students are familiar with the engineering design process (EDP) before beginning the unit, the teacher can skip this (EDP) introduction.

The engineering design process (EDP) is an iterative, systematic process used to guide the development of solutions to engineering problems. There is no single engineering design process, just like there is no one scientific method. However, the various engineering design processes have similar components. The engineering design process (EDP) involves understanding the problem, learning background information necessary to solve the problem, planning, trying, testing the solution, making changes based on the tests, and communicating their ideas. Students will use an engineering design process slider throughout the unit to help them understand where they are in the design process. For more information about the steps of the engineering design process presented in this unit, see the front matter section at the front of the unit.

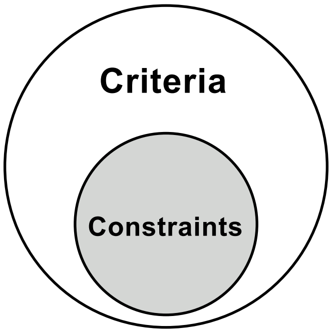
Some common misconceptions about engineering

- Engineers do not have to learn anything new when they are working on a project. **In reality**: Engineers need to continually learn throughout their lives.
- Engineers come up with solutions that are just "good enough" and do not take risks. **In reality**: Engineers strive to create the best solution possible through optimization. It is normal to experience failure when solving engineering problems.

- Engineers work alone to solve a design problem. **In reality**: Engineers collaborate with people in different disciplines and fields to best solve a problem. Engineering problems often require a wide range of content knowledge.

Some common misconceptions about the EDP

- The engineering design process is linear, and you never need to go back to previous phases. **In reality:** The EDP is a cyclical process that requires many iterations.
- Once the project is done, it is considered complete and not revisited. **In reality:** The engineering design process is never really "done" and it is revisited so engineers can improve projects and make changes.



Criteria and Constraints

One difficulty that students might experience is distinguishing between criteria and constraints. Criteria are the things required for a successful design, or the goals of the designed solutions. They help engineers decide whether the solution has solved the problem. Another way of thinking about criteria are that they are anything that the client and the engineers will use to judge the quality of a solution. Constraints are a specific type of criteria; they are those criteria that limit design possibilities, or the ways that problem can be solved. If constraints are not met, the design solution is by default not a viable solution to the problem. The relationship between criteria and constraints is represented in the figure. It may be helpful to post the definitions with the figure somewhere in the classroom for future reference.

Problem Scoping

<u>Define</u> the problem and <u>learn</u> about the problem combine to make Problem Scoping. In this stage, students will be first introduced to the engineering problem through a client letter and then be given a chance to ask questions to the client to receive more information about the problem. The problem statements given in the client memos purposefully do not provide all the information necessary to solve the problem. Students are tasked with generating questions about the problem to try to fill in this missing information. Based on all information from the client, students will then define the problem in terms of: what the problem is and why it is important, who are the client and end users, what are the criteria and constraints, and what other information they may need to learn about in order to solve the problem. This process of generating ideas and questions for the client is an important skill on its own both in engineering and in other fields, but it also helps to ensure that the students fully understand the problem and their task in the engineering design challenge.

Solution Generation

The Solution Generation section of the engineering design process includes <u>plan</u> the solution, <u>try</u> out the plan of the solution, <u>test</u> the solution, and <u>decide</u> whether the solution is good enough. When engineers are generating solutions, they will use iteration as a means to continually improve their solution, reflect back on the problem definition and what they have learned about the problem, and consider criteria, constraints, and trade-offs. Trade-offs involve having to make compromises about which criteria to emphasize because they compete with one another in terms of making the solution effective. For example, cost could be a trade-off for durability.

Engineering Notebook

Throughout the unit students will be recording information in an engineering notebook, and they will need the notebook immediately in Lesson 1. The engineering notebook is set of documents which includes writing prompts, black space to take notes or upload pictures of work, and copies of the duplication masters that are listed in each lesson. The engineering notebook can be offered electronically or on paper and can be adapted to your classroom needs. Students' engineering notebooks will support their communication of ideas and should be used consistently throughout the unit.

Vocabulary

Students will be introduced to many new mathematics and engineering vocabulary terms throughout the unit. It may be helpful to create a vocabulary section in their notebook with term definition and memory clue. Additionally, the class could maintain a word wall.

Term	Definition	Lesson introduced
microchip	computer chip or integrated circuit that is used for processing and storing information in electronic devices	1
substrate	semi-conductive material used to make integrated circuits	1
silicon	common mineral used to make the substrate for microchips	1
boule	single crystal ingot (a bar or rod of material) that is produced for further processing; boules for microchip production are generally made of silicon	1
wafer	thin slice of substrate; wafers are cut from a boule	1
die	square or rectangle of substrate cut from a wafer that is the foundation for a microchip	1
abundance	how readily available a material is, or having extra material available	3
finite resource	resources we only have so much of; we will eventually run out of a finite resource	3

infinite resource	resources we will never run out of; we will never run out of a infinite resource	3
percent	percent = part/whole x 100	3
purification	the process of removing undesired material from your raw materials	4
yield	the amount of desired material you get from a process; theoretical yield is the highest possible yield and assumes a perfect process, and actual yield is the real-life yield that is lower than the theoretical due to losses during the process	4
percent yield	a comparison of the actual yield of a process to the theoretical yield in a perfectly executed process	4
mole	the base unit for the amount of substance in atoms or molecules.1 mol = 6.022 x 1023 units of the substance; for example, 1 mol of silicon contains 6.022 x 1023 silicon atoms, which has a mass of 28.09 grams. The abbreviation is “mol”	4
Si	the chemical symbol for silicon on the periodic table; pronounce each letter (“S-I”)	4
SiO2	the chemical symbol for silicon dioxide; this is the molecule that makes up the sand that becomes silicon for wafers; pronounce each letter and number (“S-I-O-2”)	4
Cu	chemical symbol of copper, a metal used in microelectronics	4
Co	chemical symbol of cobalt, a metal used in microelectronics	4
kerf loss	amount of material lost during a cutting process. Instinctively, the kerf loss would seem to follow a pattern of greater material lost as the abrasive size and width of the cutting blade increases	5
problem scoping	defining the problem and learning about the problem	6
criteria	features of the solution that the client wants	6
constraints	a specific type of criteria; the criteria that limit design possibilities or ways that the problem can be solved	6
evidence-based reasoning	supporting a solution or recommendation with scientific analysis and/or data	6
design matrix	a tool used to compare, assess, and prioritize a set of options based on weighted criteria	7

LESSON ONE:

Lesson Objectives

Students will be able to:

- Identify the problem from a client.
- Identify issues with a given mathematical model.
- Understand why the area of die on a wafer cannot equal the area of the circle wafer.

Time Required

Two 50-minute lessons

Standards Addressed

HS ETS1-1, G.QP.4, G.CI.1, G.CI.3, G.TS.4, G.TS.5
8.NS.4, 8.GM.2, 8.GM.3
7.NS.7, 7.AF.1, 7.AF.2, 7.GM.2, 7.GM.3
6.NS.4, 6.AF.1, 6.GM.3, 6.GM.4
PS.1: Make sense of problems and persevere in solving them
PS.3: Construct viable arguments and critique the reasoning of others
PS.4: Model with mathematics
PS 5: Use appropriate tools strategically
PS.6: Attend to Precision

Key Terms

Client, engineering design process, criteria, constraints, microelectronics, wafer, microchip

Lesson Summary

Students are introduced to the client and a first-level problem that will serve as the context within which students can learn about microchip manufacturing. Here students will critique the client's model with a hands-on demonstration and with geometric calculations. Students will learn about the Engineering Design Process and take part in iterative class and group discussions to identify criteria, constraints, and knowledge gaps needed to successfully solve the client's challenge.

Background

Engineering Design Process

Read the Unit Background to understand the engineering terms and concepts used in this unit.

Engineering Design Process Sliders

Assemble the Engineering Design Process Sliders and post the EDP poster in the classroom (see the front matter for how to assemble them). If your students do not want to use the sliders, simply hanging the poster achieves the same result. Make sure you and your students can refer to the EDP sliders and/or poster throughout the unit.

Teamwork

Determine student teams of three or four. Students should remain on the same team for the duration of the unit. See the Unit Background for more information about making teams.

Sample wafers for demonstration

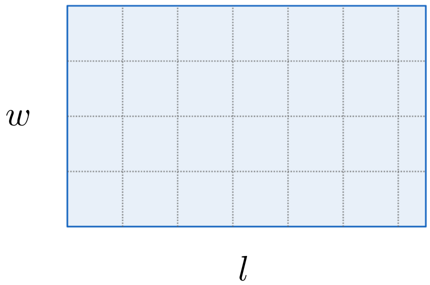
Consider ordering sample silicon wafers. Waferworld.com has a selection of wafers that can be ordered and delivered. Delivery time varies from 1 week to 10 weeks, so please plan accordingly. Cost can range from $300 on up. (https://www.waferworld.com/product-search)

Area definitions and formulas

Area is the amount of space inside a 2-D shape. It can be represented as the number of unit squares that fit inside the shape. Use definitions and formulas that are grade-level appropriate; consider your students' knowledge of pi.

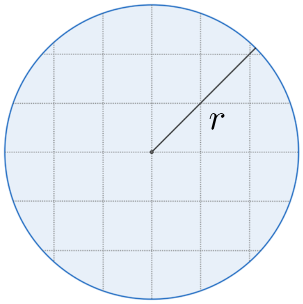
Rectangle

$$A = lw$$



Circle

$$A = \pi r^2$$



Vocabulary

microchip	computer chip or integrated circuit that is used for processing and storing information in electronic devices
substrate	semi-conductive material used to make integrated circuits
silicon	common mineral used to make the substrate for microchips
boule	single crystal ingot (a bar or rod of material) that is produced for further processing; boules for microchip production are generally made of silicon
wafer	thin slice of substrate; wafers are cut from a boule
die	square or rectangle of substrate cut from a wafer that is the foundation for a microchip

Before the Activity

Printouts

This lesson uses these duplication masters in the following quantities.

- ☐ 1.A Content Pre-Assessment — 1 per student
- ☐ 1.B Client Letter — 1 per student
- ☐ 1.C 200mm Wafer Model — 1 per team

Lesson Materials

Per classroom

- EDP Poster
- Chart paper
- Sample Silicon Wafer (Optional)

Per team

- 1 cm area tiles (about 350 per group)
- Transparent rulers marked in inches and cm (with marks for mm)
- Scissors

Per student

- EDP slider and paperclip
- Laptop/Chromebook/ Tablet
- Engineering notebook
- Pencils and erasers

Duplication Masters

1.A Content Pre-Assessment

1.B Client Letter

1.C 200 mm Wafer Model

Educator Resources

1.D Reply to Client Template

1.E Content Pre-Assessment Key

Assessment

Pre-Activity Assessment

Use students' answers to 1.A Content Pre-Assessment as baseline data about the students' current level of understanding and background knowledge.

Activity Embedded Assessment

Observe students' discussions and written responses to 1.C 200 mm Wafer Model. Check students' brainstorming lists to see if they can identify the content they will be expected to master by the end of the unit.

Post-Activity Assessment

Assess students' verbal reflections to the client's problem and engineering design process to determine if they fully understand the concepts. If the 1.D Reply to Client paragraph was written, evaluate how students responded to the client and inquired about the problem.

Other preparation

- ☐ Check the YouTube video to ensure it will play in your classroom: How Are Microchips Made? (https://youtu.be/g8Qav3vIv9s)
- ☐ (Optional) Prepare a review of circle area and circumference
- ☐ (Optional) Prepare the pre-assessment activity in the form of a survey, kahoot, etc. using the questions on 1.A Content Pre-Assessment

Classroom Instruction

Introduction

1. **Complete the pre-assessment activity.** The students will participate in a more formal pre-assessment to assess their current level of knowledge and understanding regarding topics related to area, volume, microelectronics, and the engineering design process. Using the questions on the *1.A Content Pre-Assessment*, distribute hard copies or have students respond to a digital version of the survey. Make sure to tell students that this is just to assess any prior knowledge, so it is okay to not know the answers.
2. **Read Client Letter 1.** Hand out a copy of the letter 1.B Client Letter to each student.
3. **Review prior knowledge.** Lead a discussion with the class in which students are able to share their prior knowledge on the topics of engineering and the concepts of area and volume (don't go into formulas – get at what the students think area and volume are). Prompts may include the following: *What do engineers do? What kinds of industries do engineers work in? What is area? What is volume? Why are area and volume useful? What are microchips? What are wafers?*
4. **Set up engineering notebooks. Say:** *Engineers use notebooks to document their design process and keep notes. We will also be using Engineering Notebooks throughout our engineering challenge. Each day, you'll use the digital notebooks to take notes and record what you are learning. In addition, there are questions that you'll be asked to answer.* NOTE: You can have your students type in their notebooks in two different colors – one for thoughts and prompts that are individual and one for

thoughts and prompts that they discuss in their teams. This will help both you assess, and the students recognize, where ideas came from. You also may want to have students start a Table of Contents page.

5. **Introduction to wafers and microchips.** Ask students if they have ever seen a wafer or microchip (tying into the content of the letter). Show them an example of blank wafer. Have them record a definition of wafer in their notebooks. Also show some devices and point out the microchips on them, making sure that they notice the rectangular and square shapes (NOTE: Many microcontrollers – such as Arduino – show both square and rectangular chips on them). Define wafer, microchip, and die and have students record them in their notebooks. Recommended to find images of each. To connect these, you can say microchips are often built from silicon – which is the substrate for the microchip. To go from silicon to chip, the silicon is made into a boule, which is cut into wafers, which are then cut into dies. The dies are in the shape of the final chip. The die may be wrapped in plastic or other material. Then there is a printed circuit board built on that foundation. These together make up a basic microchip. Watch the following video: https://youtu.be/g8Qav3vIv9s. Tell students that this will introduce some of the ideas that we will be exploring throughout the unit, but that they will learn more about boules, wafers, and microchips in future lessons. This video is not about the company they are working for. It is just an introduction to microchip fabrication.

6. **Reflect on engineers and engineering in their notebooks.** Have students individually answer the prompts: *What do engineers do? How do engineers solve problems?* Make sure to let them know that it is okay if they do not know very much about engineers or engineering – just have them answer these questions to the best of their ability.

7. **Form teams.** After students have finished the prompts, explain that for the rest of the unit they will start the day with a review of the engineering design process, and then look at a specific problem that will require the use of that process. Explain that students will be working in small teams to solve a problem being brought to them by the client. Divide students into teams of 3 or 4. (This can also be completed prior to the beginning of the unit if preferred.)

Activity

8. **Discuss engineers and engineering.** Allow students to share their answers from their notebook work. Define engineers and engineering and take some notes for students to type in their notebooks. As a class create a list of the different types of engineering and have students brainstorm careers that may fall within each type of engineering in their notebooks. Explain that the problem they will be solving falls under the category of materials engineering and draws on geometry and electronics to understand the context and generate a solution.

9. **Introduce the Engineering Design Process.** Display the Engineering Design Process poster and pass out individual EDP Sliders and a paper clip to each student. **Say:** *Engineers use an engineering design process, along with mathematics, science, and creativity, to understand a problem and come up with a solution. Since we are working as engineers during this unit, we will be using this engineering design process as a guide while we come up with a solution for our engineering problem.* Go through the EDP Slider and ask the students what they think each stage involves. Be sure to clarify any misconceptions and elaborate where needed. There is a detailed description of the EDP Slider in the front matter of the unit. **Ask:** *Based on what we have discussed so far, where do you think we are in the engineering design process?* **(Define).**

10. **Return to the problem.** Remind the students that the client has asked them to answer a question: *Why doesn't the area of circle of wafer/area of rectangle of chip (die size) final calculation actually estimate the number of chip die size we can get from a wafer?*

11. **Discuss the concept of area**. Tell the students we will move a bit in to the Learn stage to give feedback to the client. Ask the students to define area both physically and mathematically.

12. **Explore the question from the client using calculations.** Have the students calculate the number of die that the client thinks should be gotten from the wafer. *Area of the circle/area of the die*. Have the students work with a 200 mm diameter wafer and 1 cm square die. (Answer: 100π die, or approximately 314 die).

13. **Explore the question from the client using manipulatives.** Hand out one circle sheet *(1.C 200mm Wafer Model)* to each team that has a 200 mm wafer model on it (Alternatively,

have the students use a compass to make a circle of 200 mm diameter on a sheet of paper). Provide each team with at least 350 of the cm tiles. Have students explore how many of the cm "die" they can get from the circle.

14. **Reflect on the differences between the results of the calculation versus the manipulatives.** Tell the students we will move a bit in to the **Solution Generation** stages to give feedback to the client. Have the students share out their findings. Develop a list of reasons together of why they believe the number the client provided is or is not realistic. (Help the students think beyond just their model to the practicalities of actually cutting die from a wafer). Discussion should include: why you cannot count a partial square, why it is not like just finding the area of the circle, other possible things to consider (without leading the students to this): space to clamp the wafer in place for cutting, space for loss of material between each die.

15. **Write a reply to the client.** Using the conversation from the results, quickly craft a response to the client and "send" it. (*Optional*: draft a written response with the class using the process in *1.D Reply to Client Template*.)

Closure

16. **Reflect on the client's problem.** Have students reflect in their notebooks. Focus on these two prompts: *What did the client need from us today? and What is one thing you think could be improved on the printing methods of die on wafer based on what we did today?*

17. **Assign homework, if desired.** You may want to give to the students an assignment that reviews basic area.

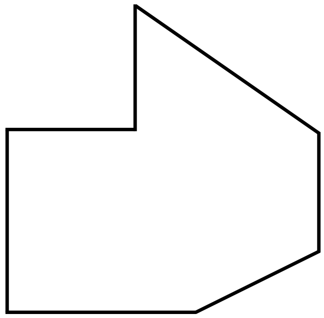
18. **Discuss the engineering process.** Tell the students that we will wait for a reply from the client as to what is next needed. Discuss the questions: *What do you think the client's bigger problem is? Is it different than what was asked of us?* The purpose: Students need to understand the root of the problem from the perspective of the client and other stakeholders before attempting a solution, but our client is not really giving us that information yet, so we need to see if we can understand the bigger issue.

Name____ Date_______________ Period __________

1.A Content Pre-Assessment

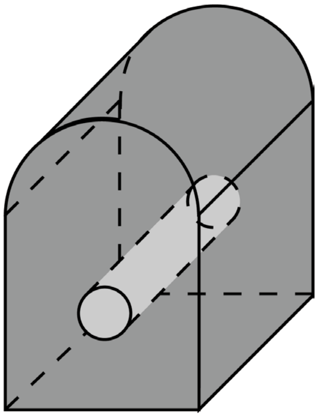
1. What is area in geometry?

2. Given this 2-dimensional shape and assuming you had all measurements that you needed, how would you go about finding the area?



3. What is volume in geometry?

4. Given this 3-dimensional shape and assuming you had all measurements that you needed, how would you go about finding the volume of the darker grey area?



5. What are the formulas for the area and circumference of a circle?

6. Why might it be important is it to consider waste in microchip production?

Name____ Date_______________ Period __________

1.A Content Pre-Assessment

7. What does the term, “microelectronics” mean?

8. How are microelectronics used in your everyday life?

9. What jobs would you be interested in that use microelectronics?

10. Provide one example of how microelectronics is used in that job.

1.B Client Letter

Dear Engineers,

The demand for our new gaming controller is skyrocketing! Our peak buying season is approaching and the company that manufactures our microchip tells me that if we do not optimize our wafer design, we will not be able to keep up with the forecasted increase in demand.

You may recall that we are still working off of our prototype design. The manufacturer has told me that we are getting 200 die per wafer, but there is a lot of waste. I did a rough calculation by taking the area of the circle of the wafer and dividing it by the area of the die. Based on this, if I assume that a wafer is 200 mm in diameter and the die size I want is 1 cm by 1 cm, I estimate that we can optimize our design and cut over 300 dies from one wafer. However, the manufacturer has told me that getting over 300 dies is impossible.

Could you help me understand why this is not possible? Please investigate this and reply to me with your ideas about my model and why you think it can or cannot provide over 300 dies. I need to recommend a new configuration to the supplier.

Thank you for your help on this urgent matter!

Sincerely,

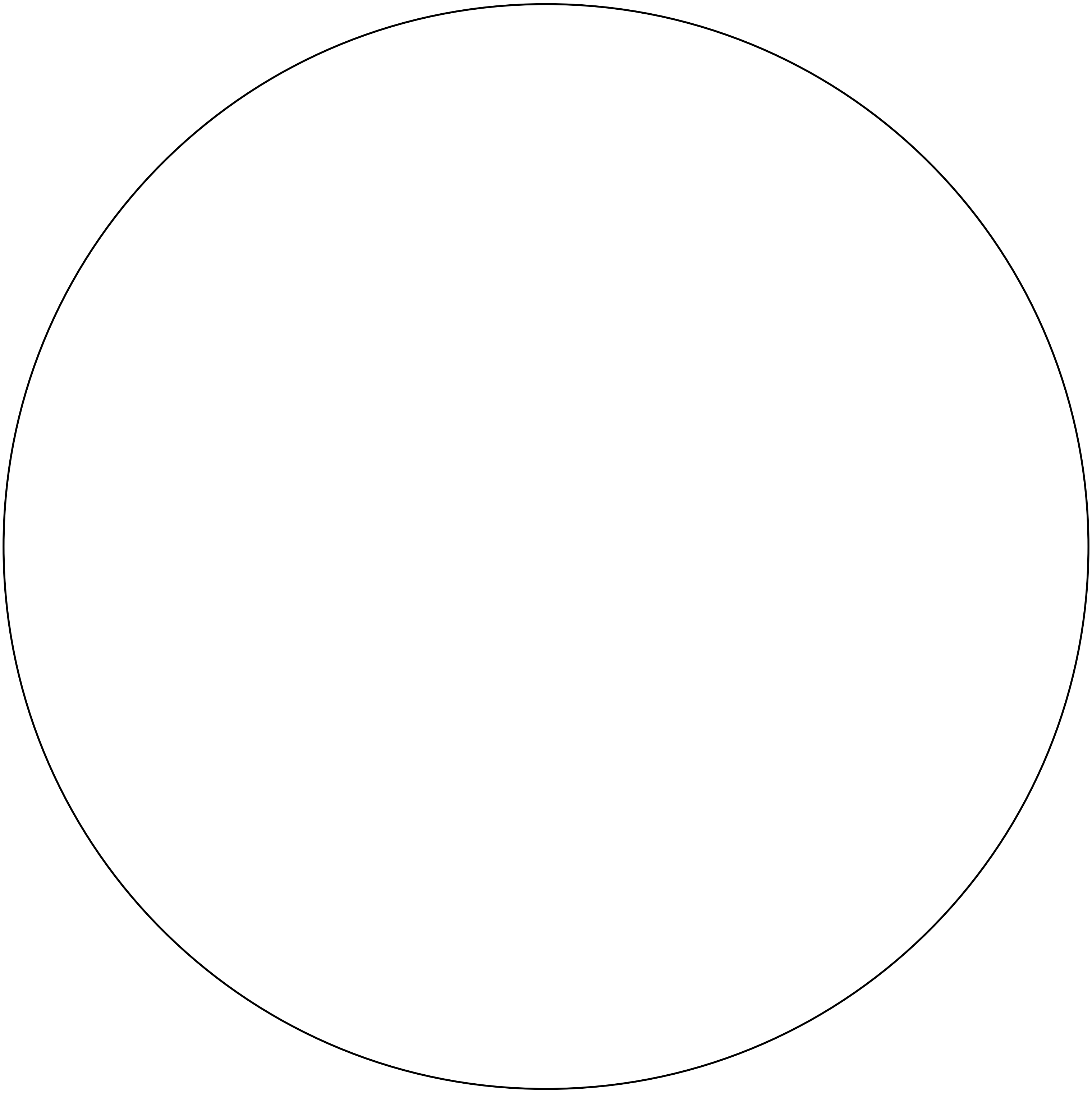
Skylar Geti

CEO, Geti Games

GETI GAMES

Name____ Date_______________ Period ___________

1.C 200 mm Wafer Model



1.D Reply to Client Template

Optional Template

This unit has multiple lessons where the class “responds” to their client after discussing what they have learned in the lesson, any outcomes that may answer questions posed by the client, or to ask the client any questions that they have. You can do these summaries orally with the class. But if you wish to model a more formal written process, you can use the template below.

A formal reply to the client should be professional and appropriate for a workplace. You want a greeting (or salutation) line, an optional concise subject line, a body with the content of your reply, and a closing. Use a writing tool of your choosing (Google Doc, Mircosoft Word, etc.) that you can share with the class as you work together to draft the reply. You could also model this as an email instead of a document.

> **Dear** <*Client name*>
>
> **Subject**: <*Concise statement describing the letter’s contents*>
>
> <*Body of letter*>
>
> **Sincerely**,
>
> <*Class name*>

Example Reply for Lesson 1

Dear CEO Geti,

Thank you for asking for our help! We worked with the 200mm wafer size and 1 cm x 1 cm squares for die size. You asked why you cannot get 300 die from the wafer. You are right that using math, you can calculate that over 300 dies should fit on the wafer. But that calculation includes full squares and partial squares, all summed together. Dies can only be full squares, not partial shapes where one side is an arc on the edge of the wafer. We could get around 270 complete dies from the wafer using your die size. The issue is because the wafer is a circle but the die shape is a square. You cannot fill a circle with perfect squares. Since the dies have to be full squares, we cannot count the partial squares along the edge of the wafer.

Please let us know if you need more help with your controller project.

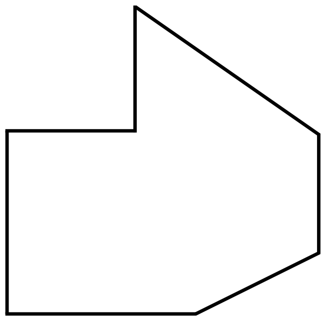
Sincerely,

Class 204

1.E Content Pre-Assessment KEY

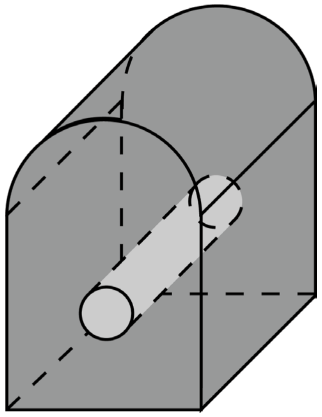
1. What is area in geometry?
   Answers will vary. Some examples: Area is the space inside the perimeter of a closed shape. Area is the size of the surface of an object, Area is measured in square unite like in^2, ft^2, cm^2

2. Given this 2-dimensional shape and assuming you had all measurements that you needed, how would you go about finding the area?
   a. Divide the 2-dimensional shape into basic shapes: i.e. square, triangle, rectangle
   b. Find the area of each basic shape separately
   c. Add all of the areas of the basic shapes together and share the answer in square units



3. What is volume in geometry?
   Answers will vary. Some examples: Volume is the amount of space occupied by any three dimensional solid. Volume is measured in cubed units like in^3, ft^3, cm^3

4. Given this 3-dimensional shape and assuming you had all measurements that you needed, how would you go about finding the volume of the darker grey area?
   a. Identify the different parts that the three dimensional solid is made of
   b. Work out the volume of each part independently
   c. Add all of the volumes of each basic part and share the answer in cubic units
   d. In this example, we would calculate the volume of a cylinder: $V=\pi r^2 h$



5. What are the formulas for the area and circumference of a circle?
   $A=\pi r^2$
   $C=2\pi r$

6. Why might it be important is it to consider waste in microchip production?
   Answers will vary. Some examples:
   - **Materials used in microchip production, especially hazardous waste, requires specific disposal strategies and can be costly to dispose of.**
   - **The cost of material waste, or scrap material that is left over and not used in the final product, can add up to a significant number.**

1.E Content Pre-Assessment KEY

7. What does the term “microelectronics” mean?
   Answers will vary. Some examples:
   - **Microelectronics is the design, manufacture, and use of microchips and microcirciuts.**
   - **Microelectronics is the design, development, and manufacture of very small electronic designs and parts**

8. How are microelectronics used in your everyday life?

   Answers will vary. Some examples:
   - **Computers**
   - **Cell phones**
   - **Calculators**
   - **Digital watches**
   - **All “smart” devices is also a pretty good answer examples since appliances, cars, homes, and classrooms all have microelectronic components in them. But have the students provide specific examples.**

9. What jobs would you be interested in that use microelectronics?
   Answers will vary. Pre-assessment may be lacking in good answers. That is okay. Some examples:
   - **Hardware engineer**
   - **Semiconductor engineer**
   - **Packaging engineer**
   - **Digital systems engineer**
   - **Clean room technician**

10. Provide one example of how microelectronics is used in that job.
    Answers will vary. Some examples:
    - **Hardware engineer – computer hardware requires microelectronics to work**
    - **Semiconductor engineer – Semiconductors are made from micro electronics**
    - **Packaging engineer – Microelectronic packaging involves printed wire board design that integrates microelectronics**
    - **Digital systems engineer – designing and testing systems that utilize microelectronics**
    - **Clean Room Technician – maintains the sterile environment required for precision manufacturing of microelectronics**

LESSON TWO:

Lesson Objectives
Students will be able to:
- Identify the problem from a client.
- Calculate waste based on area and volume.
- Develop a generalized model for wasted material on a wafer.

Time Required
One 50-minute lesson

Standards Addressed
HS ETS1-1, G.QP.4, G.CI.1, G.CI.3, G.TS.4, G.TS.5
8.NS.4, 8.GM.2, 8.GM.3
7.NS.7, 7.AF.1, 7.AF.2, 7.GM.2, 7.GM.3
6.NS.4, 6.AF.1, 6.GM.3, 6.GM.4
PS.1: Make sense of problems and persevere in solving them
PS.3: Construct viable arguments and critique the reasoning of others
PS.4: Model with mathematics
PS 5: Use appropriate tools strategically
PS.6: Attend to Precision

Key Terms
Client, engineering design process, criteria, constraints, microelectronics, wafer, microchip

Lesson Summary

In this lesson, students will work with the client's response which contains a new model, which has also been identified as problematic in that it has too much waste. Students will calculate waste using area of circles, rectangles, and simple volume ideas first on a specific example, then as a class to develop a model for the calculation of waste.

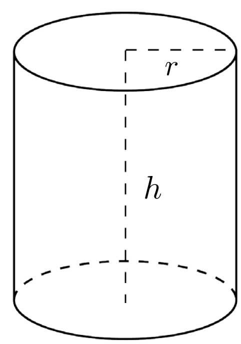
Background

Volume and formulas

Volume is the amount of space inside a 3-D shape. It can be represented as the number of 1-unit cubes that fit inside the shape. It can sometimes be calculated as the area of the base times the shape's height. Use definitions and formulas that are grade-level appropriate; consider your students' knowledge of pi.

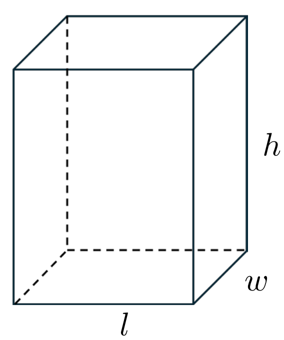
Cylinder

$$V = \pi r^2 h$$



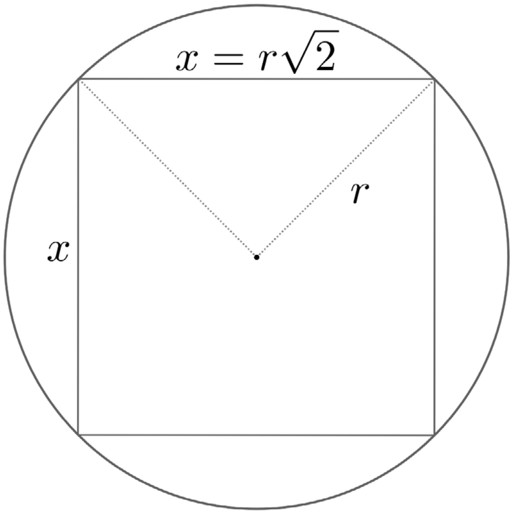
Rectangular prism

$$V = lwh$$



Inscribed square

You can define the side length of a square that is inscribed inside a circle using the circle's radius and the Pythagorean Theorem.



Vocabulary

waste	the amount of silicon that cannot be manufactured into chips

Before the Activity

Printouts

This lesson uses these duplication masters in the following quantities. Note for *2.B Die on Wafe*r: There are 3 versions of this sheet. Each team gets only 1 of the versions. Divide teams into three groups for assigning which teams get which version.

- ☐ 2.A Client Response — 1 per student
- ☐ 2.B.1 Die on Wafer — 1 per team in group 1
- ☐ 2.B.2 Die on Wafer — 1 per team in group 2
- ☐ 2.B.3 Die on Wafer — 1 per team in group 3

Classroom Instruction

Introduction

1. **Tie in the engineering problem. Ask:** *What did our client ask of us in the last class?*
2. **Read client response.** Hand out a copy of the letter *2.A Client Response* to each student. Encourage them to write or type in their notebooks as they read to keep track of important

Lesson Materials

Per classroom

- EDP Poster
- Chart paper

Per team

- transparent rulers marked in inches and cm (with marks for mm)

Per student

- EDP slider and paperclip
- Laptop/Chromebook/ Tablet
- Engineering notebook
- Pencils and erasers

Duplication Masters

2.A Client Response

2.B Die on Wafer

Assessment

Pre-Activity Assessment

Use classroom discussion on what they did previously and what they state the client needs from them after reading the 2.A Client Response to gauge students' current understanding of the problem.

Activity Embedded Assessment

Walk around and gauge student understanding as they work on the calculations of waste. Use the final responses that are shared to the class as a way to recognize student understandings and misconceptions.

Post-Activity Assessment
Provide related homework or practice as appropriate

information. Give students time to discuss in teams what information they read in the letter.

3. **Identify the new problem from the client.** Have the students reread the letter, if necessary, to identify the problem and type it in their notebooks.

Activity

4. **Discuss the concept of volume**. Ask the students to define volume both physically and mathematically. Discuss any issues they anticipate with the very small thickness values for the wafer.

5. **Have teams investigate the waste calculation problem.** Hand out *2.B Die on Wafer* such that each team gets one of the 3 configurations. Then assign one wafer thickness to each team (0.2 mm, 0.3 mm, and 0.4 mm) such that no two teams has the exact same configuration. The students will need measuring tools and potentially scissors (have these ready if they ask for them, but don't hand out scissors). Have students find the amount of waste on their configuration on their own.

6. **Present out findings.** Have students present their models to find the volume of the waste. Discuss the differences seen in each model (meaning the differences of approach). For example, one team may take the number of small rectangles multiplied by the area of the small rectangle and subtract that from the area of the circle and that quantity multiplied by thickness. Another team may take the area of the larger square subtracted from the area of the circle and then all of that multiplied by the thickness.

7. **Develop a general model for the configuration.** Lead a discussion to get the students working towards the volume of the waste based on radius of the circle, r. *Possible solution:* Find the waste area by taking the area of circle ($A_c = \pi r^2$) then subtract out the area of the square ($A_s = 2r^2$). The final model is the area of the waste multiplied by the thickness of the wafer.

8. **Write a reply to the client.** Using the conversation from the results, quickly craft a response to the client and "send" it. (*Optional*: draft a written response with the class using the process in *1.D Reply to Client Template*.)

Closure

9. **Reflect on the client's problem.** Have students reflect in their notebooks. Focus on these two prompts: *What did the client need from us today? and Why does this also not produce exactly the size of die for the chip as specified?*

10. **Discuss the engineering process.** Tell the students that we will wait for a reply from the client as to what is next needed. Discuss the questions: *What do you think the client's bigger problem is? Is it different than what was asked of us?* The purpose: Students need to understand the root of the problem from the perspective of the client and other stakeholders before attempting a solution, but our client is not really giving us that information yet, so we need to see if we can understand the bigger issue.

11. **Identify what they did with the engineering design process. Say:** *So far, we have worked through two small problems for our client.* Point out that the students worked the Engineering Design Process (EDP) using the poster and the EDP sliders now twice. Explain that you are going to continue to have a dialog with the client to help them solve their bigger problem.

2.A Client Response

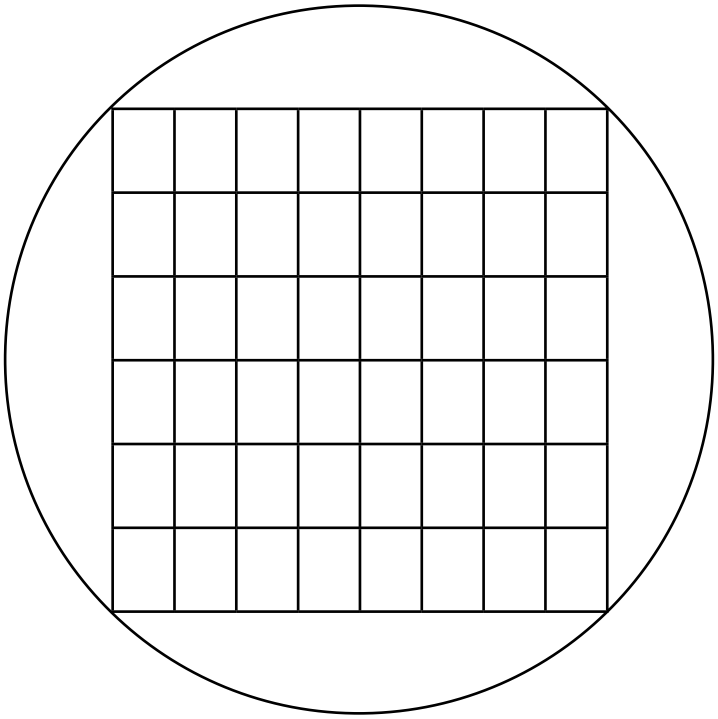
Dear Engineers,

Thank you for your help. With your insights I was able to recommend a new configuration of wafer layout to our supplier. Unfortunately, after further review my new recommendation was rejected. The basic configuration I recommended, which I have provided below, would not support the die size we need, nor the production quantity required. Therefore, I think we need to consider the waste that each wafer produces. I have provided several different layouts that I created and the thickness of the wafer can be 0.2 mm, 0.3 mm, or 0.4 mm. I would love for you to help me understand how much of the material is wasted in each design and if you could create a model that allows me to calculate the waste for any other similar configuration.

Sincerely,

Skylar Geti
CEO, Geti Games

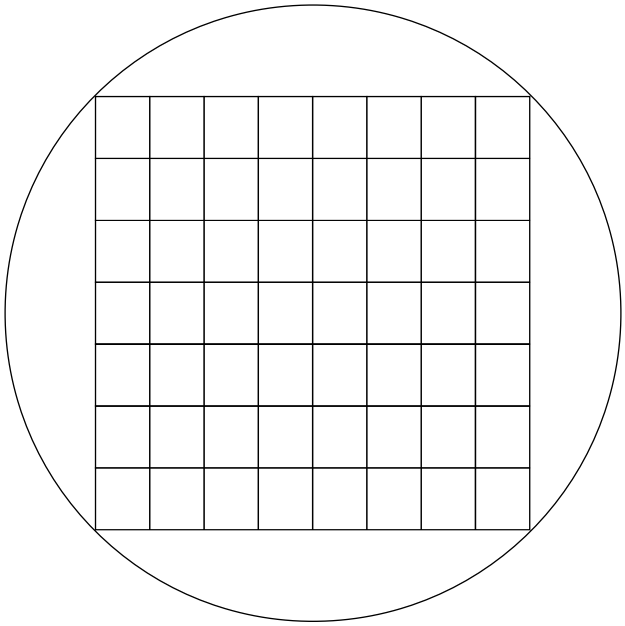
GETI GAMES



Name____ Date_______________ Period __________

2.B.1 Die on Wafer

Thickness of wafer ___________



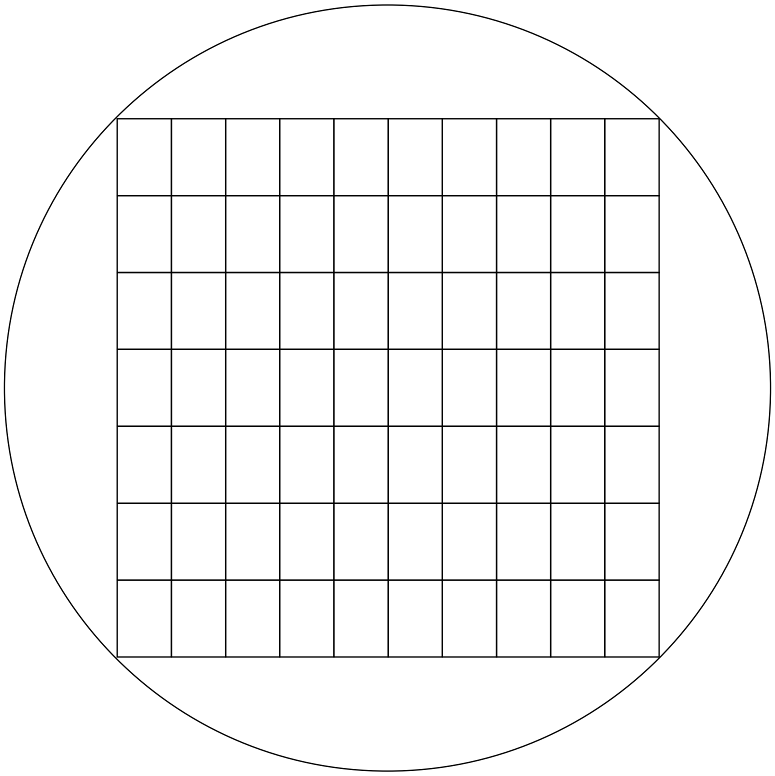
Calculations:

Total amount of waste in this configuration: ________________

Name____ Date_______________ Period __________

2.B.2 Die on Wafer

Thickness of wafer ___________



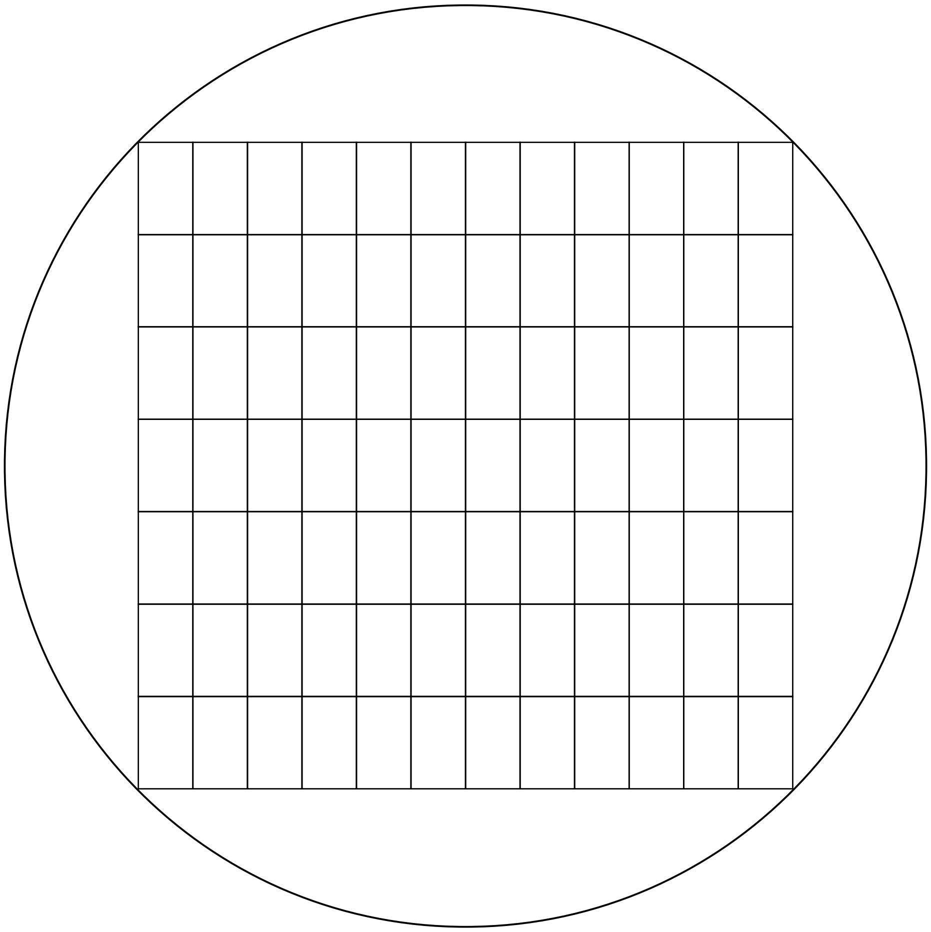
Calculations:

Total amount of waste in this configuration: ________________

Name____ Date_______________ Period __________

2.B.3 Die on Wafer

Thickness of wafer ___________



Calculations:

Total amount of waste in this configuration: ________________

LESSON THREE:

Lesson Objectives
Students will be able to:
- Discover which elements make wafers.
- Understand the difference between finite/infinite resources.

Time Required
One 50-minute lesson

Standards Addressed
HS ETS1-1
8.NS.1, 8.NS.4
7.NS.7, 7.RP.2, 7.AF.1, 7.AF.2
6.NS.4, 6.RP.4, 6.AF.1
PS.1: Make sense of problems and persevere in solving them
PS.3: Construct viable arguments and critique the reasoning of others
PS.4: Model with mathematics
PS 5: Use appropriate tools strategically
PS.6: Attend to Precision

Key Terms
Resource abundance, finite, infinite

Lesson Summary

Students will learn about resource abundance and how readily available silicon is to be used to manufacture wafers. Students will research the abundance and geographic location of the sand used to make silicon. They will compare finite and infinite resources and discuss why this is important for the engineering design challenge.

Background

Vocabulary

abundance	how readily available a material is, or having extra material available
finite resource	resources we only have so much of; we will eventually run out of a finite resource
infinite resource	resources we will never run out of; we will never run out of a infinite resource
percent	percent = part/whole x 100

Before the Activity

Printouts

This lesson uses these duplication masters in the following quantities.

- ☐ 3.A Client Memo — 1 per student
- ☐ 3.B Resource Abundance — 1 per team
- ☐ 3.C Resource Abundance Calculations — 1 per team

Classroom Instruction

Introduction

1. **Tie in the engineering problem. Ask:** *What is our engineering design problem?*
2. **Read 3.A Client Memo.** Read aloud or hand out a copy of the memo *3.A Client Memo*. Encourage students to write or type in their notebooks as they read to keep track of important information.

3. **Identify where they are in the engineering design process (Learn). Say:** *So far, we have defined the problem with help from our client. But we need more background information before we can solve the problem.* Point out the "Problem" block on the Engineering Design Process (EDP) poster and have students look at their EDP sliders. **Ask:** *What step of the engineering design process are we in?* The students should identify that they are in the "Learn" stage.

Activity

Activity #1: Element Discovery

4. **Introduce the topic of wafer materials.** Hand out gloves to students and then pass around the element samples and allow students a moment to make observations. **Say:** *In earlier lessons, we learned that wafers serve as the base layer for a microchip to be built upon.* **Ask:** *What material or materials do you think the wafer is made from? What elements would make a good wafer? Why?* Have students think through why a certain material may make a good wafer and ask them to give their logic behind their answer. **Say:** *Wafers are primarily made from silicon or germanium due to their crystalline structure.*

5. **Introduce the topic of sourcing raw materials. Say:** *Materials like silicon or germanium have to be mined from one location and then transported to the location where they'll be used to make a microchip.* **Ask:** *Where do you think these materials might be mined? Or what types of materials are mined to find silicon and germanium?* Students may not know the answer to these questions, but it will get them thinking about the concepts of material sourcing and transportation.

6. **Assign students the task of researching material location and availability.** Hand out *3.B Resource Abundance*. **Say:** *Let's find out where we can find silicon, how abundant it is, and how far it has to travel to get to a manufacturing plant in the United States. In your teams, work together to fill out the worksheet.*

7. **Share out results with the class. Say:** *Now that you have learned about silicon, let's discuss your results as a class.* **Ask:** *What did you discover about silicon?* Facilitate a classroom discussion about their results.

8. **Assign students the task of completing calculations related to silicon.** Hand out *3.C Resource Abundance Calculations*. For this activity, you may want physical maps of the world and the

Lesson Materials

Per classroom

- EDP Poster
- Element sample box
- Silicon sample

Per student

- EDP slider and paper clip
- Laptop/Chromebook/Tablet
- Engineering notebook
- Pencils and erasers
- Calculator
- Gloves to handle materials

Duplication Masters

3.A Client Memo

3.B Resource Abundance

3.C Resource Abundance Calculations

Educator Resources

3.D Resource Abundance KEY

US that students can draw on. This can be on paper or online. **Say:** *Now that we know how abundant the resource is and where it is located, let's perform some calculations to see what those numbers really mean. Fill out Sheet 3.C with your team and we will report out to the class in a few minutes.*

9. **Share out results with the class. Say:** *What values did you find for the fraction and decimal of resource abundance? How far does the resource have to travel to get to West Lafayette, Indiana?*

Activity #2: Finite and Infinite Resources

10. **Introduce the concept of finite vs. infinite numbers. Ask:** *What is the difference between a finite number and an infinite number?* If students do not know this concept yet, you can skip this question and instead ask if anyone knows what the term, "infinity" means. **Say:** *If infinity means never ending, then an infinite number is a number that never ends. For example, pi is an infinite number because the numbers after the decimal place never end. A finite number does have an end do it.* **Ask:** *Can someone give an example of a finite number?*

11. **Introduce the idea of finite vs. infinite resources. Ask:** *What is a finite or an infinite resource?* Lead a class discussion about finite and infinite resources. You may provide the example of wind being an infinite resource while oil is a finite resource.

12. **Connect infinite/finite resources to wafers. Ask:** *What resource did we identify as the source for making a wafer? Is it a finite or infinite resource? Would it be better for us to use a finite or an infinite resource?*

Closure

13. **Connect the activity to the engineering design challenge. Ask:** *What did we learn today that will help us provide a recommendation to the client? Why is it important to know how a resource is finite or infinite? Why is resource abundance important? How does the geographic location of a resource impact the manufacturing process?* Work with the class to summarize the findings. You can take notes and tell the class that you will "send" it later. (*Optional*: draft a written response with the class using the process in *1.D Reply to Client Template*.)

Assessment

Pre-Activity Assessment

Listen to students' responses about what elements would make the best material for wafers based on their observations of the element samples.

Activity Embedded Assessment

Review students' duplication masters to see if they correctly calculated resource abundance and distance traveled.

Post-Activity Assessment

Listen to student answers for the conclusion questions; were students able to identify how the lesson connects to the engineering design challenge?

3.A Client Memo

Dear Engineers,

Thank you for your helping me understand how much waste we will have! This is going to be very helpful as we consider the cost of manufacturing. However, I'm wondering why it costs so much to manufacture boules in the first place. Could you please investigate silicon and where it comes from? I'm curious how far it has to travel to get to the manufacturing plant, perhaps that is the reason why the cost is so high. Let me know if you can find any information about silicon resource abundance!

Sincerely,

Skylar Geti
CEO, Geti Games

GETI GAMES

Name____ Date_______________ Period __________

3.B Resource Abundance

With your teammates, answer the following questions. You can use your laptop or tablet to research answers. Write down a general source where you found the information, like “USDA Website” or “Purdue News Article”.

1. **Where is silicon found in nature?**

2. **Is silicon found pure in nature? If not, what process must be completed to extract silicon from other minerals?**

3. **Geographically, where is silicon found?**

4. **What is the resource abundance for silicon (as a percentage)?**

Name____ Date_______________ Period __________

3.C Resource Abundance Calculations

Answer the following questions individually and then share your answers with your team.

5. **Convert the resource abundance percentage you found to a decimal.**

6. **Convert the resource abundance percentage to a fraction WITHOUT decimals. All numbers should be whole numbers.**

7. **If silicon has to travel from its original location to Lafayette, Indiana to be made into a wafer, how far does it have to travel? Keep in mind that it cannot be a direct distance, but it will travel in segments.**

3.D Resource Abundance KEY

1. **Where is silicon found in nature?**

   Silicon is found as silica or silicates in sand, rocks, clays, and soils. [https://periodic.lanl.gov/14.shtml]

2. **Is silicon found pure in nature? If not, what process must be completed to extract silicon from other minerals?**

   No, silicon is not found pure in nature but is found as silica or silicates. It is extracted by blending the source with carbon and then superheating it. The carbon and oxygen react to form CO_2 gas, leaving almost pure silicon. [https://youtu.be/5eVsQSn_EWc] (*Note: there are other extraction methods but we will reference this one in Lesson 4*)

3. **Geographically, where is silicon found?**

   Silicon is found and mined in many places, but the largest produces are China, Russia, Norway, and Brazil. Other locations include the US, France, and Malaysia. [https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-silicon.pdf has information regarding world production and US production/use]

4. **What is the resource abundance for silicon (as a percentage)?**

   Answers may vary but should be in near 25% of Earth's crust by mass.
   [Royal Chemical Society: 27.7% [https://www.rsc.org/periodic-table/element/14/silicon]
   [Los Alamos National Lab: 25.7% (see link in Problem 1)]

5. **Convert the resource abundance percentage you found to a decimal.**

   (27.7)/100=0.277

6. **Convert the resource abundance percentage to a fraction WITHOUT decimals. All numbers should be whole numbers.**

   (27.7)/100= 277/1000

7. **Choose one location where silicon is found geographically. If silicon has to travel from there to Lafayette, Indiana to be made into a wafer, how far does it have to travel? Keep in mind that it cannot be a direct distance, but it will travel in segments due to where planes can land, ships can dock, or where trucks can drive.**

   Answers can vary. The Measure tool in Google Maps was used to track the distance to travel from China to Lafayette, Indiana. This tool shows a total distance of 10,480 miles traveled. You could use a combination of flight paths/sea routes/ground transportation.

LESSON FOUR:

Lesson Objectives
Students will be able to:
- Calculate yield through purification process.

Time Required
One 50-minute lesson

Standards Addressed
HS ETS1-1
8.NS.1, 8.NS.4, 8.AF.8
7.NS.7, 7.RP.2, 7.AF.2
6.NS.4, 6.RP.2, 6.RP.4, 6.AF.1
PS.1: Make sense of problems and persevere in solving them
PS.3: Construct viable arguments and critique the reasoning of others
PS.4: Model with mathematics
PS 5: Use appropriate tools strategically
PS.6: Attend to Precision

Key Terms
Purification, yield, abundance

Lesson Summary

In this lesson, students will learn about the purification process that takes place to extract silicon from sand. They will complete calculations to learn about the percent yield of silicon from sand. Students will then play a game to experience being part of the microelectronics industry while trading money and resources.

Background

Resources Game Materials

You can play the lesson game using the provided paper tokens in Duplication Master 4.C or you can use classroom manipulatives (colored counters).

If using ***paper tokens***: Print off one copy of 4.A Microelectronics Resources Game Pieces per team. Cut out the pieces.

If using ***manipulatives***: Gather colored counters. You need these quantities:

Manipulative	*Quantity*
Yellow counters	40 per team
Red counters	40 per team
Blue counters	40 per team
Green counters [or $1 paper money tokens]	56 per team

Vocabulary

purification	the process of removing undesired material from your raw materials
yield	the amount of desired material you get from a process; *theoretical yield* is the highest possible yield and assumes a perfect process, and *actual yield* is the real-life yield that is lower than the theoretical due to losses during the process
percent yield	a comparison of the actual yield of a process to the theoretical yield in a perfectly executed process

mole	the base unit for the amount of substance in atoms or molecules.1 mol = 6.022 x 10^{23} units of the substance; for example, 1 mol of silicon contains 6.022 x 10^{23} silicon atoms, which has a mass of 28.09 grams. The abbreviation is "mol"
Si	the chemical symbol for silicon on the periodic table; pronounce each letter ("S-I")
SiO_2	the chemical symbol for silicon dioxide; this is the molecule that makes up the sand that becomes silicon for wafers; pronounce each letter and number ("S-I-O-2")
Cu	chemical symbol of copper, a metal used in microelectronics
Co	chemical symbol of cobalt, a metal used in microelectronics

Before the Activity

Printouts

This lesson uses these duplication masters in the following quantities.

- ☐ 4.A Client Memo 1 per student
- ☐ 4.B Silicon Yield 1 per student

For the game instructions *Microelectronics Resource Game Instructions*, print off 4.D if you are using paper tokens from 4.C or print off 4.E if you are using manipulatives.

- ☐ 4.D or 4.E Microelectronics Resources Game Instructions 1 per team

Classroom Instruction

Introduction

1. **Tie in the engineering problem. Ask:** *What is our engineering design problem?*
2. **Read 4.A Client Memo.** Read aloud or hand out a copy of the memo *4.A Client Memo*. Encourage students to write or type in their notebooks as they read to keep track of important information.

Lesson Materials

Per classroom

- EDP Poster

Per Team

If using paper cutouts

- 40 yellow Si tokens
- 40 blue Co tokens
- 40 red Cu tokens
- 56 green $1 tokens

If using classroom manipulatives

- 40 yellow counters
- 40 blue counters
- 40 red counters
- 56 green counters (or $1 tokens)

Per Student

- EDP slider and paper clip
- Laptop/Chromebook/ Tablet
- Engineering notebook
- Pencils and erasers
- Calculator

Duplication Masters

4.A Client Memo

4.B Silicon Yield

4.C Microelectronics Resources Game Pieces

4.D Microelectronics Resources Game Instructions

4.E Microelectronics Resources Game Instructions

Educator Resources

4.F Silicon Yield KEY

Assessment

Pre-Activity Assessment
Check students' responses as they recall the client's problem and brainstorm possible topics they need to learn to understand the problem. Do students understand the problem itself?

Activity Embedded Assessment
Review 4.B Silicon Yield and evaluate students' answers to determine if they can properly perform the necessary calculations.

Post-Activity Assessment
Listen to students' responses to the closing questions. Do they understand how this lesson relates to the client's challenge? Can students explain some of the challenges in the microelectronics industry?

3. **Identify where they are in the engineering design process (Learn). Say:** *So far, we have defined the problem with help from our client and learned about silicon. But we need more background information before we can solve the problem.* Point out the "Problem" block on the Engineering Design Process (EDP) poster and have students look at their EDP sliders. **Ask:** *What step of the engineering design process are we in?* The students should identify that they are in the "Learn" stage.

Activity

Activity #1: Purification Process and Yield

4. **Introduce the concept of yield. Ask:** *What is the process for extracting silicon from sand or other materials?* Students should recall from the previous lesson that silicon is mixed with a carbon source and then ultra-heated, at which point carbon dioxide gas is formed, leaving silicon. **Say:** *Let's determine how much silicon we can extract from sand so that we know how much sand we need for one wafer.*

5. **Complete the percent yield calculations.** Hand out *4.B Silicon Yield*. The worksheet has some definitions to help students who are not familiar with chemistry.

   - **Note for middle school or some high school classes:** Your students may still need help with the vocabulary. The unit conversions in Problem 1 may be too difficult. You may want to work through those as a class. Once you have the answer to 1c, you can ask students to do Problems 2 and 3.

6. **Say:** *Use the formulas on the page to calculate the percent yield of silicon from sand.* Allow students a few minutes to complete the calculations and then check their answers with their teammates. Alternatively, the teacher can walk through these calculations with the class if they have not taken chemistry or cannot perform dimensional analysis.

Activity #2: Resource Game

7. **Pass out materials for the resources game. Say:** *Let's play a game that lets us experience what it is like to try and trade resources and money.* Hand out the game pieces (paper tokens from Duplication Master 4.C Microelectronics Resources Game Pieces if using those, or counters if using those).

8. **Provide background and instructions for the game. Ask:** *Who can remind us of what a boule is?* Help students define a boule as a single crystal that is cast into a shape for further

processing. **Say:** *In this game, each member of your team will have a different goal to achieve. One play may start with a lot of money, but their goal is to make as many boules as possible. Another player may start with a lot of resources, and their goal is to sell them all to make money. You want to achieve your personal goal, but it will also be beneficial to help your team members achieve their goals*.

9. **Allow students time to play the game.** Hand out instructions for the game (Duplication Master 4.D or 4.E, depending on the token type). Read through the rules with students and answer any questions. Provide students with a few minutes to play the game. If time allows, you may have students to rotate their roles and complete another round.

10. **Discuss how the game went. Ask:** *How many of you achieved your goal? What was the hardest part of the game?* **Say:** *Imagine that each player represents a different country. For example, the player who starts with a lot of Silicon might be China, since we learned in our last lesson that much of our Silicon comes from China. Perhaps the person with the most money was the USA. By playing this game, you were able to experience what it is like to be in the microelectronics industry! You have to be careful about how much money you spend or how many resources you give away*

Closure

11. **Connect the activity to the engineering design challenge. Ask:** *What did we learn today that will help us provide a recommendation to the client? How much sand does it take to create one wafer? What are some of the challenges that countries face within the microelectronics industry?* Work with the class to summarize the findings. You can take notes and tell the class that you will "send" it later. (*Optional*: draft a written response with the class using the process in *1.D Reply to Client Template*.)

4.A Client Memo

Dear Engineers,

Thank you for helping provide some background on where silicon comes from! I'm now curious how we even get silicon. If it starts at sand, how does it become silicon? And how much waste is left over from that process? It would be great if you could let me know about the purification process.

Sincerely,

Skylar Geti
CEO, Geti Games

GETI GAMES

Name____ Date_______________ Period __________

4.B Silicon Yield

Before you can get silicon wafers, you must get pure silicon. The first step is to mix sand, called silicon dioxide, with carbon and heat it to very high temperatures. That breaks apart the silicon dioxide and make two new chemicals: silicon (what we want) and carbon dioxide (which is a waste product).

To understand this process, let's work with sand that is easy to buy. Playground sand is for sale at any hardware store. How much silicon could we get out of a bag of playground sand? One bag of sand has a mass of 50 pounds. That is the same as 22.7 kilograms. Use that mass to answer the questions below.

Helpful Information

mole	A unit to measure the amount of a substance - it relates the number of atoms or molecules in the amount of the substance to its mass. 1 mole of a substance equals 6.022×10^{23} atoms or molecules of the substance.
Si	The chemical symbol for silicon on the periodic table. 1 mole of silicon has a mass of 28.09 grams.
SiO_2	The chemical symbol for silicon dioxide, which is the sand that becomes silicon. 1 mole of silicon dioxide has a mass of 60.08 grams.
C	The chemical symbol for carbon on the periodic table.
CO_2	The chemical symbol for carbon dioxide.

1. **Calculate the theoretical yield of Si from SiO_2.**
    a. **Start by converting 22.7 kilograms of SiO_2 to number of moles of SiO_2. You know the molecular weight of SiO_2 from the table above. Hint: This is just a unit conversion.**

    b. **Next, let's find the number of moles of Si we can get when we heat the sand with carbon. We can do that if we know the chemical equation for the purification process:**

Name____ Date_______________ Period __________

4.B Silicon Yield

$$SiO_2 + C \rightarrow Si + CO_2$$

This equation means that 1 mole of SiO_2 plus 1 mole of C will *yield* 1 mole of Si and 1 mole of CO_2. So, the number of moles you calculated for SiO_2 equals the number of moles of Si.

____________________ moles SiO_2 = ____________________ moles Si

c. Now, let's convert moles of Si to kilograms of Si. This is the theoretical yield of silicon (Si) that you could get from a bag kg of sand (SiO_2).

2. After putting our bag of sand through the purification process, we got 8.56 kg of silicon. This is the actual yield of the purification process.

a. What percent of the original bag of SiO_2 sand became Si, using the theoretical yield?

b. What percent of the original bag of SiO_2 sand became Si, using the actual yield?

Name____ Date_______________ Period __________

4.B Silicon Yield

3. **Find the percent yield of the purification process used on our playground sand.**

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} * 100$$

4. **Why is there a difference between the theoretical yield and the actual yield? Why is percent yield important?**

4.C Microelectronics Resources Game Pieces

$1	$1	$1	$1	$1	$1	$1	$1
$1	$1	$1	$1	$1	$1	$1	$1
$1	$1	$1	$1	$1	$1	$1	$1
$1	$1	$1	$1	$1	$1	$1	$1
$1	$1	$1	$1	$1	$1	$1	$1
$1	$1	$1	$1	$1	$1	$1	$1
$1	$1	$1	$1	$1	$1	$1	$1

4.C Microelectronics Resources Game Pieces

Si	Si	Si	Si	Si	Si
Si	Si	Si	Si	Si	Si
Si	Si	Si	Si	Si	Si
Si	Si	Si	Si	Si	Si
Si	Si	Si	Si	Si	Si
Si	Si	Si	Si	Si	Si
Si	Si	Si	Si		

4.C Microelectronics Resources Game Pieces

Co	Co	Co	Co	Co	Co
Co	Co	Co	Co	Co	Co
Co	Co	Co	Co	Co	Co
Co	Co	Co	Co	Co	Co
Co	Co	Co	Co	Co	Co
Co	Co	Co	Co	Co	Co
Co	Co	Co	Co		

4.C Microelectronics Resources Game Pieces

Cu	Cu	Cu	Cu	Cu	Cu
Cu	Cu	Cu	Cu	Cu	Cu
Cu	Cu	Cu	Cu	Cu	Cu
Cu	Cu	Cu	Cu	Cu	Cu
Cu	Cu	Cu	Cu	Cu	Cu
Cu	Cu	Cu	Cu	Cu	Cu
Cu	Cu	Cu	Cu		

4.D Microelectronics Resources Game Instructions

Let's play the microelectronics resources game! Here are the rules:

Yellow	Blue	Red	Green
Silicon (Si)	Cobalt (Co)	Copper (Cu)	$1

1. Each person will be assigned a Player Role. Your job is to achieve the goal for that Role.

Player	Start with this much money:	Start with this many resources:	GOAL:
A	$30	0 Si 0 Co 0 Cu	Make as many boules as possible.
B	$5	15 Si 15 Co 15 Cu	Make at least $10 and 5 boules.
C	$0	0 Si 20 Co 0 Cu	Make as much money as possible without running out of resources.
D	$15	5 Si 5 Co 5 Cu	Make boules while maintaining at least 1/3 of your resources.

2. To create a boule, you must have one of each resource:
   1 Si + 1 Co + 1 Cu = 1 boule

3. Players can trade resources and money, but both players must agree on the trade before it is completed.

4. At the end of the game, add up your total points to see who won.

   $1 = 3 points

   1 Si = 1 point

   1 Co = 1 point

   1 Cu = 1 point

   1 boule = 6 points

4.E Microelectronics Resources Game Instructions

Let's play the microelectronics resources game! Here are the rules:

Yellow	Blue	Red	Green
Silicon (Si)	Cobalt (Co)	Copper (Cu)	$1

1. Each person will be assigned a Player Role. Your job is to achieve the goal for that Role.

Player	Start with this much money:	Start with this many resources:	GOAL:
A	$30	0 Si 0 Co 0 Cu	Make as many boules as possible.
B	$5	15 Si 15 Co 15 Cu	Make at least $10 and 5 boules.
C	$0	0 Si 20 Co 0 Cu	Make as much money as possible without running out of resources.
D	$15	5 Si 5 Co 5 Cu	Make boules while maintaining at least 1/3 of your resources.

2. To create a boule, you must have one of each resource:
   1 Si + 1 Co + 1 Cu = 1 boule (1 yellow + 1 blue + 1 red = 1 boule)

3. Players can trade resources and money, but both players must agree on the trade before it is completed.

4. At the end of the game, add up your total points to see who won.

   $1 = 3 points

   1 yellow Si = 1 point

   1 blue Co = 1 point

   1 red Cu = 1 point

   1 boule = 6 points

Name____ Date_______________ Period ___________

4.F Silicon Yield KEY

Before you can get silicon wafers, you must get pure silicon. The first step is to mix sand, called silicon dioxide, with carbon and heat it to very high temperatures. That breaks apart the silicon dioxide and make two new chemicals: silicon (what we want) and carbon dioxide (which is a waste product).

To understand this process, let's work with sand that is easy to buy. Playground sand is for sale at any hardware store. How much silicon could we get out of a bag of playground sand? One bag of sand has a mass of 50 pounds. That is the same as 22.7 kilograms. Use that mass to answer the questions below.

Helpful Information

mole	A unit to measure the amount of a substance - it relates the number of atoms or molecules in the amount of the substance to its mass. 1 mole of a substance equals 6.022×10^{23} atoms or molecules of the substance.
Si	The chemical symbol for silicon on the periodic table. 1 mole of silicon has a mass of 28.09 grams.
SiO_2	The chemical symbol for silicon dioxide, which is the sand that becomes silicon. 1 mole of silicon dioxide has a mass of 60.08 grams.
C	The chemical symbol for carbon on the periodic table.
CO_2	The chemical symbol for carbon dioxide.

1. **Calculate the theoretical yield of Si from SiO_2.**

   a. **Start by converting 22.7 kilograms (kg) of SiO_2 to number of moles of SiO_2. You know the molecular weight of SiO_2 from the table above. Hint: This is just a unit conversion.**

$$22.7 \text{ kg } SiO_2 * \frac{1000 \text{ g}}{1 \text{ kg}} * \frac{1 \text{ mol } SiO_2}{60.08 \text{ g}} = 377.83 \text{ mol } SiO_2$$

Middle school: We are using dimensional analysis to do this unit conversion. Each fraction is equivalent to 1 because each numerator and denominator are equal to each other, just in different units. You can cancel out units that exist in both a numerator and a denominator. Done correctly, you will be left with only the units you want for you final answer.

$$22.7 \ \cancel{\text{kg } SiO_2} * \frac{1000 \ \cancel{\text{g}}}{1 \ \cancel{\text{kg}}} * \frac{1 \quad \text{mol } SiO_2}{60.08 \quad \cancel{\text{g}}} = 377.83 \text{ mol } SiO_2$$

The first multiplication converts kilograms to grams. The second multiplication converts the number of grams to moles of silicon dioxide (sand).

   b. **Next, let's find the number of moles of Si we can get when we heat the sand with carbon. We can do that if we know the chemical equation for the purification process:**

Name____ Date_______________ Period ___________

4.F Silicon Yield KEY

$SiO_2 + C \rightarrow Si + CO_2$

This equation means that 1 mole of SiO_2 plus 1 mole of C will *yield* 1 mole of Si and 1 mole of CO_2. So, the number of moles you calculated for SiO_2 equals the number of moles of Si.

___377.83___ moles SiO_2 = ___377.83___ moles Si

c. **Now, let's convert moles of Si to kilograms of Si. This is the theoretical yield of silicon (Si) that you could get from a 22.7 kg bag of sand (SiO_2).**

$$377.83 \text{ mol Si} * \frac{28.09 \text{ g}}{1 \text{ mol Si}} * \frac{1 \text{ kg}}{1000 \text{ g}} = 10.61 \text{ kg Si}$$

Middle school: We are using the same dimensional analysis approach as in 1.a. The first multiplication converts moles to grams. The second multiplication converts grams to kilograms.

$$377.83 \cancel{\text{mol Si}} * \frac{28.09 \cancel{\text{g}}}{1 \cancel{\text{mol Si}}} * \frac{1 \text{ kg}}{1000 \cancel{\text{g}}} = 10.61 \text{ kg Si}$$

2. **After putting our bag of sand through the purification process, we got 8.56 kg of silicon. This is the actual yield of the purification process.**

   a. **What percent of the original bag of SiO_2 sand became Si, using the theoretical yield?**

$$\text{Percent} = \frac{\text{part}}{\text{whole}} * 100 = \frac{10.61}{22.7} * 100 = 46.74\ \%$$

   b. **What percent of the original bag of SiO_2 sand became Si, using the actual yield?**

$$\text{Percent} = \frac{\text{part}}{\text{whole}} * 100 = \frac{8.56}{22.7} * 100 = 37.71\ \%$$

Name____ Date_______________ Period __________

4.F Silicon Yield KEY

3. **Find the percent yield of the purification process used on our playground sand.**

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} * 100$$

$$\text{Percent Yield} = \frac{8.56}{10.61} * 100 = 80.68\ \%$$

4. **Why is there a difference between the theoretical yield and the actual yield? Why is percent yield important?**

Answers will vary.

Why is there a difference? There are always losses in a chemical process like purification. Reasons could be

- Impurities in the sand and carbon mixture
- Fluctuation in temperature leading to some sand not fully melting
- The amounts of sand and carbon are not perfectly balanced (i.e., equal moles of each)

Why is percent yield important? Because it tells us how well our process is working. Reasons include:

- Helps us plan how much raw material we need to use.
- Helps us know what our costs of production will be.
- Helps us figure out when there are inefficiencies in our process.

LESSON FIVE:

Lesson Objectives
Students will be able to:

- Understand that silicon boules are grown to specifications in order to be sliced to create wafers with the least amount of waste.
- Decompose 3-D models of boules to calculate volume and determine wafer yield.

Time Required
One 50-minute lesson

Standards Addressed
HS ETS1-1 G.CI.1, G.TS.4, G.CI.3
8.GM.2
7.GM.2, 7.GM.3
6.GM.3, 6.GM.4
PS.1: Make sense of problems and persevere in solving them
PS.3: Construct viable arguments and critique the reasoning of others
PS.4: Model with mathematics
PS 5: Use appropriate tools strategically
PS.6: Attend to Precision

Key Terms
area, circumference, volume, composite solid, cone, hemisphere, cylinder, die, chip, boule, kerf loss

Lesson Summary

Silicon is made into boules to create wafers that are then cut into die. In this lesson, students will focus on understanding how to model the volume of a boule, which is a composite 3-D shape. They will also consider where the waste from the manufacturing process of boule to wafer comes from. As a class, the students will develop a simple model to determine wafer yield from a boule.

Background

Boule and wafer review

You may want to review the process to make silicon boules and wafers. Here is the link to the video in Lesson 1 for reference (https://youtu.be/g8Qav3vIv9s)

An overview of the wafer manufacturing process can be found here. (https://www.universitywafer.com/how-to-make-silicon-wafers-into-computer-chips.html)

Boule and wafer manipulatives

Consider printing a variety of 3D wafers and 3D boules from the files provided.

Wafers	Boules
place file links here for: Wafer.gcode	place file links here for: Boule Parts.gcode
place file links here for: Wafer.3mf	place file links here for: Boule.3mf
place file links here for: Wafer.gcode	place file links here for: Boule.gcode
	place file links here for: Boule Parts.3mf

Note the boules are different designs: One model with a hemisphere on either end, one with cones on either end, and one that is a cone on one end and a hemisphere on the other.

If you do not have access to a 3D printer, there are other options for printing the parts. When inquiring, ask if they accept .3mf or ,gcode data files.

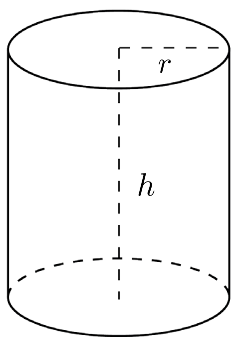
- **Your Local Library.** Check your local library to see if they have a media lab or a 3D printing machine.
- **Community college**. Check your local community college to see if they have media lab or a 3D printing machine.
- **The UPS Store.** Some UPS stores are able to print objects from 3D printing files. https://www.theupsstore.com/print/3d-printing
- **Web based printers.** There are websites that aggregate 3D printing companies, but you would want to make sure you vet the provider. One example of such a website is Treatstock.com; please exercise due diligence when using this or other websites.

Volume and formulas

Volume is the amount of space inside a 3-D shape. Use definitions and formulas that are grade-level appropriate; consider your students' knowledge of pi.

Cylinder

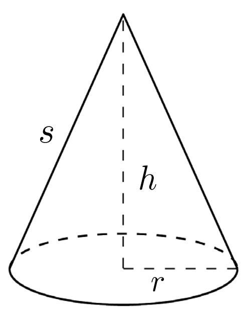
$$V = \pi r^2 h$$



Cone

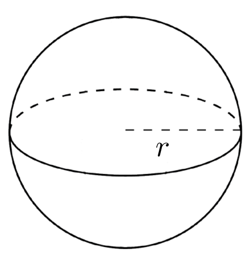
$$V = \frac{\pi r^2 h}{3}$$

$$V = \frac{\pi r^2 \sqrt{s^2 - r^2}}{3}$$



Sphere

$$V = \frac{4\pi r^3}{3}$$



Lesson Materials

Per Classroom
- EDP poster
- Playdough
- Strings of varying widths
- Ruler

Per Team
- Variety of 3D models representative of boules
- Variety of thin, circular disks representative of wafers

Per Student
- EDP slider and paper clip
- Laptop/Chromebook/Tablet
- Engineering notebook
- Pencils and erasers
- Transparent ruler
- Calculator
- PowerPoint slides

Duplication Masters

5.A Client Response

Educator Resources

5.B Boule Shapes

5.C Kerf Loss Demonstration

LESSON FIVE:

Assessment

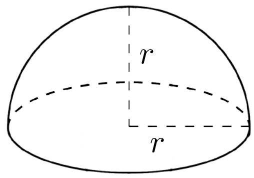
Pre-Activity Assessment
Check students' responses as they recall the client's problem and brainstorm possible topics they need to learn to understand the problem. Do students understand the problem itself?

Activity Embedded Assessment
Observe students' discussions on the 3D shapes used for a boule. Do they understand the concept of minimizing boule waste? What is their logic for using certain shapes?

Post-Activity Assessment
Listen to students' responses to the closing questions. Do they understand how this lesson relates to the client's challenge? Can students explain the difference between wafer waste and boule waste?

Hemisphere

$$V = \frac{2\pi r^3}{3}$$



Vocabulary

boule	single crystal ingot (a bar or rod of material) that is produced for further processing; boules for microchip production are generally made of silicon
kerf loss	amount of material lost during a cutting process. Instinctively, the kerf loss would seem to follow a pattern of greater material lost as the abrasive size and width of the cutting blade increases

Before the Activity

Printouts

This lesson uses these duplication masters in the following quantities.

☐ 5.A Client Memo — 1 per student

Other preparation

☐ Either prepare 5.B Boule Shapes to project the images to the class or print out copies for each team.

Classroom Instruction

Introduction

1. **Tie in the engineering problem. Ask:** *What did our client ask of us in the last class?*
2. **Read client response.** Hand out a copy of the letter 5.A Client Response to each student. Encourage them to write or type in their notebooks as they read to keep track of important

information. Give students time to discuss in small teams what information they read in the letter.

3. **Identify the new problem from the client.** Have the students reread the letter, if necessary, to identify the problem and type it in their notebooks. **Ask:** *Why do you think it important to consider waste in the wafer production?*

Activity

4. **Hand out models of boules and have students identify the boule shape components.** Give each team a model of a boule. Have students label their notebooks with "Boule shapes" and make a quick sketch of their boule. Ask them to identify 3-D shapes (that they already know) that together make up the boule model that they have. Have teams trade their boule shapes and repeat for at least one more boule shape. Discuss that these are just models and that real manufactured boules are not this perfect in shape. Tell students that engineers often model real-world things using equations or shapes that are easy to use mathematically. That is what we are doing here.

5. **Discuss the shapes found and ask how they could be used to find the volume of the whole. The purpose here is to get the students to recognize that if** they take the volume of each of the separate shapes and add them together, then they will have the total volume.

6. **Identify the volume formulas of the shapes that make up the different boule configurations.** Discuss what shapes each team found. **Ask:** *Do you know how to find the volume of these shapes?* Either provide the formulas and explain or have the students look up the formulas and then discuss. Add any mathematical conversation that you deem necessary to make sure the volume formulas are understood.

7. **Modeling real boules.** Show students the boules on 5.B Boule Images. You can print and handout or project them in some manner. Discuss how they might model these boules.

8. **Have teams find the volume of their current boule through measurement and calculation.** Pass out transparent rulers and calculators. Tell students your preference of estimating pi (and to what decimal place) or leaving pi in their answer – that is up to you. Tell students that they will measure their boule and then calculate the volume. It is recommended to allow them to use whichever units they prefer. It will also give you the opportunity to make comparisons with units when they share out.

9. **Have the students consider how the boule will be cut into wafers. Ask:** *How do you think the boule will be sliced into wafers?* Compare answers and see if anyone breaks it down to cutting off the cones or hemispheres, wants to not waste the hemispheres or cones, what they think they could do with the waste, etc. Typically, the ends are cut off as waste.

10. **Demonstrate kerf loss**. This can be done as a teacher demonstration or as a class activity. See 5.C Kerf Loss Demonstration.

11. **Show how wafers are cut from the boule.** Show the website: https://www.universitywafer.com/silicon-boules.html Show the image in the section "How Are Boules Sliced Into Semiconductor Wafers?" Have students compare and contrast their ideas from your discussion with how this depicts them cut. Lead a discussion of how we might model how many wafers we could get from a boule (Simple answer: the height of the cylinder remaining after ends are cut divided by the thickness of the wafer – but also students should consider any waste created from the cutting (kerf loss)).

12. **Write a reply to the client.** Lead a discussion to pull all ideas from the day together to answer the questions from the client regarding how many wafers can be manufactured from a boule (wafer yield) and how much waste from each boule will be left when the wafers are cut. Also discuss with the class the question from the memo: *Where does the waste of the silicon come from during the boule to wafer process?*

13. Using the conversation, quickly craft a response to the client and "send" it. (*Optional*: draft a written response with the class using the process in *1.D Reply to Client Template*.)

Closure

14. **Reflect on the client's problem.** Have students reflect in their notebooks. **Say:** *Today we focused on boule waste. We have previously focused on wafer waste. How are these things related?* Have students record ideas in their notebook then lead a short discussion on this to help the students make the connection that today the boule waste was mainly from the ends, but the wafer waste also plays a role in overall boule waste.

15. **Discuss the engineering process.** Reflect on what we have accomplished so far. Have them reflect on how what we have done is related to the EDP. (Note: we are doing mostly

complete modeling tasks each class right now, so we are going completely through mini-EDPs each class. Take ideas from the students about where they anticipate the client might take the class next as they reflect on what they believe the overall problem.

5.A Client Response

Dear Engineers,

Thank you for all of your work so far in helping me rethink some of my die cutting models and considering materials for the chip manufacturing. I really appreciate all of the hard work you are putting into this project for me. It will mean that we will potentially be able to meet the demand of our new controller.

Demand for our new gaming controller keeps growing. Now we want to manufacture our own silicon wafers as a step toward making our own chips. So we will now be cutting the wafers from silicon boules too. This means that we will need to minimize even more silicon waste.

Can you please help me understand how many wafers I can get from a boule (wafer yield) and how much waste from each boule will be left in the process of cutting out the wafers? It would also be helpful for me to understand where the waste comes from during the boule-to-wafer process.

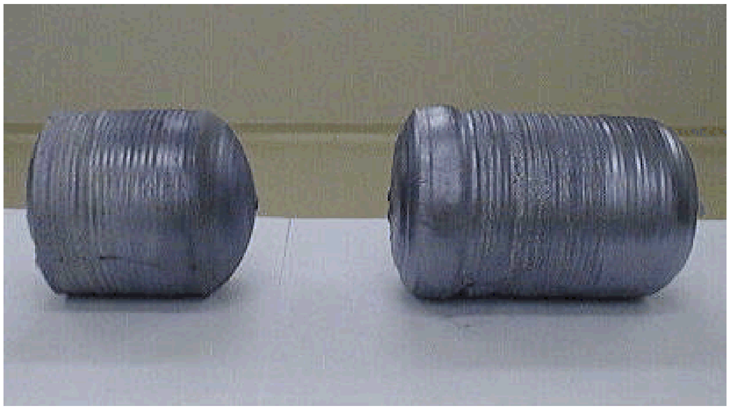
I look forward to hearing what you learned.

Sincerely,

Skylar Geti
CEO, Geti Games

GETI GAMES

5.B Boule Images



Images from:
https://www.microwaves101.com/encyclopedias/growing-semiconductor-boules
https://www.chipsetc.com/silicon-wafers.html
https://supersfmk.life/
https://www.morediamondwheel.com/products/cylindrical_wheel_for_silicon_ingot.html

5.C Kerf Loss Demonstration

Introduction

Using simple materials, you can demonstrate the concept of kerf loss. You can do this as a teacher demonstration or as a class activity.

Concept video

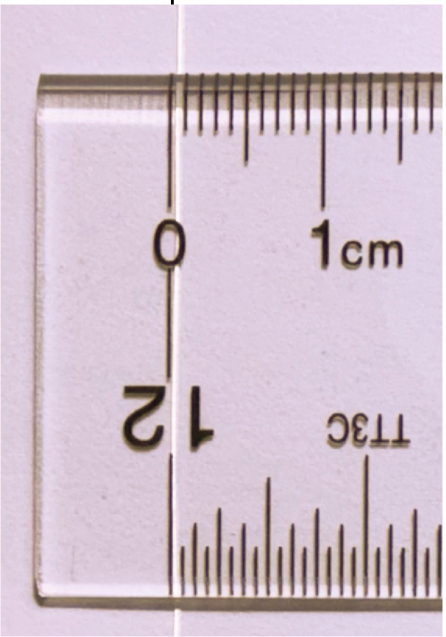
The video context is woodworking/construction but the concept is exactly the same across disciplines: (https://youtu.be/3Jes-j6EuYw)

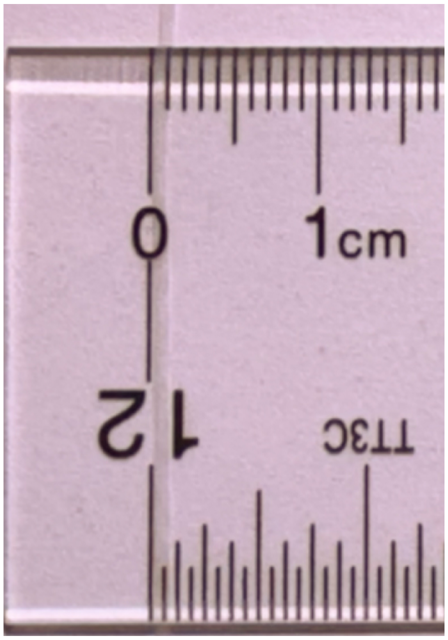
Materials

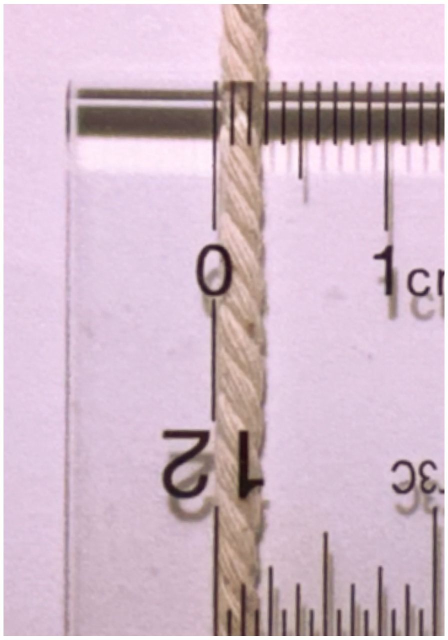
- ☐ Playdough
- ☐ Strings or cutting tools of different widths (This demonstration uses 0.4 mm fishing line, 1mm dental floss, and 3 mm cotton cording but any string will work.)
- ☐ Ruler
- ☐ Overhead projection

Steps

1. Measure your string widths to show that they are variable. You may find it easier to anchor the strings with some tape.

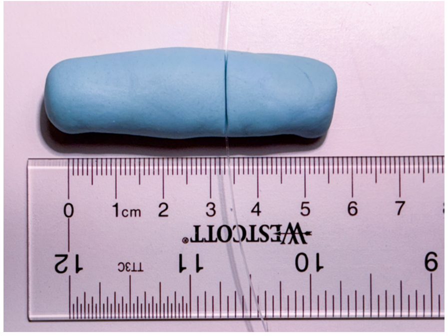
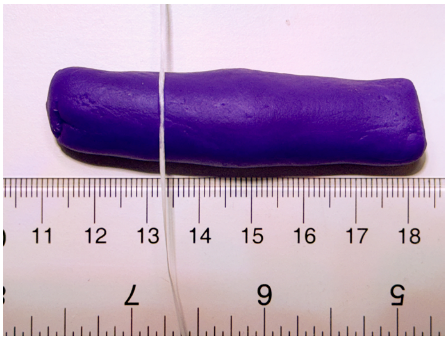
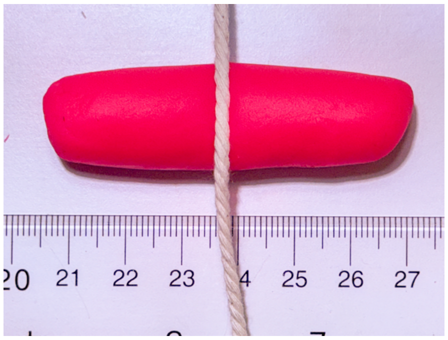
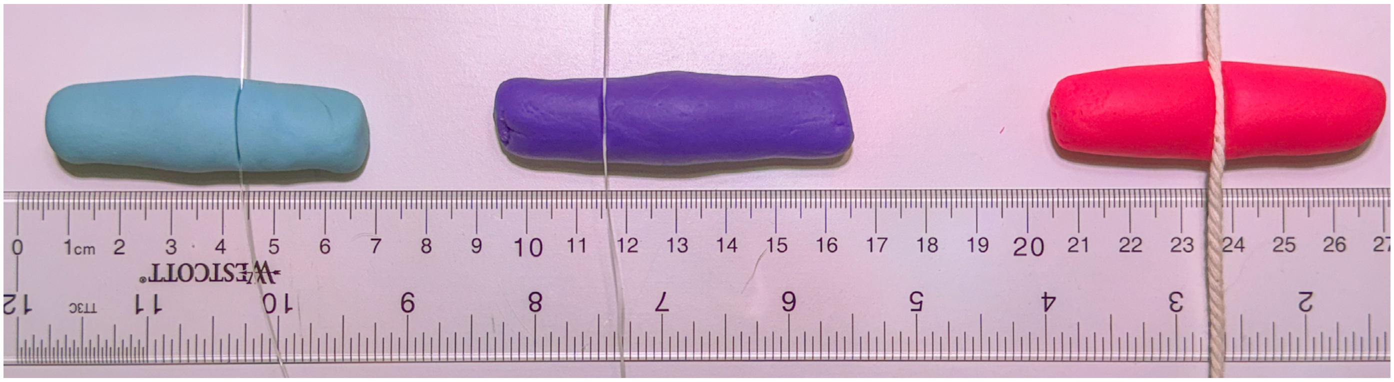




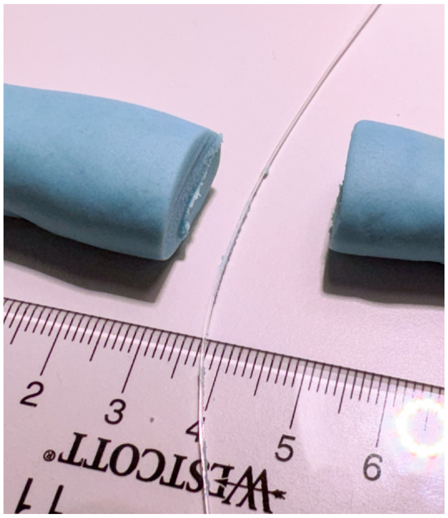
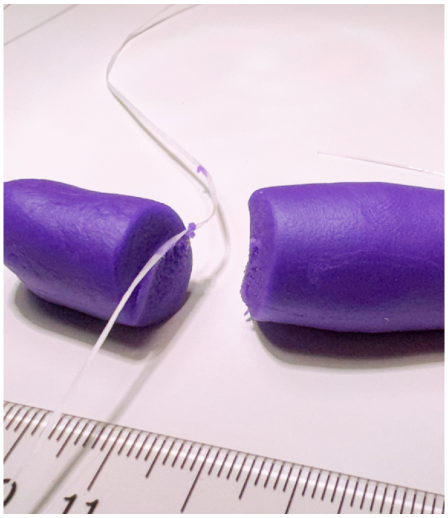


2. Roll out a cylinder of playdough for each string. Don't make it too skinny - you want some thickness to the cylinders. Measure the length of each cylinder of playdough.

3. Show how the different widths of string make different sized cuts.

4. Wrap the string around the playdough and cut through it. Notice the size of the cuts made by the different strings. Because playdough is malleable, the kerf can be somewhat difficult to capture, but look for debris on the string and deformation of the cylinder.


5. Measure the pieces. Are they equal to the original cylinder?

LESSON SIX:

Lesson Objectives
Students will be able to:
- Define the problem including client and end user needs
- Identify and explain criteria and constraints
- Identify background knowledge needed to develop a solution
- Design a process to layout a silicon wafer that supports rectangular die of many different sizes and any of the standard size silicon wafer diameters (i.e., 50 mm, 100 mm, 150 mm, 200 mm), when given constraints of spacing (vertical and horizontal) and handling space.
- Use evidence-based reasoning to defend design decisions

Time Required
Three 50-minute class periods

Lesson Summary

The client shares the root of the problem that needs to be solved to help the end user increase productivity in the microchip manufacturing process. Here students will learn about the wafer dicing process used to cut a silicon wafer into dies. Students will learn how to scope the problem, identify criteria, constraints, and knowledge gaps needed to successfully solve the client's challenge. Students will generate individual process design ideas and then collaborate as a team, arriving at a final design by consensus. Students will use evidence-based reasoning to defend their design decisions.

Background

In this lesson students will finally understand the client's problem. It is important to understand that as we ask the client questions and continue to learn, we sometimes find ourselves back at the beginning of the engineering design process because the problem itself changes or our understanding of the problem changes. If helpful revisit the **Problem Scoping** and **Solution Generation** background in Unit Background.

Wafer dicing

This is the process of cutting dies out of the wafer. Wafers can be given a specific type of edge cutting prior to dicing, to help with safe handling of the wafer (https://waferpro.com/what-do-silicon-wafers-have-flats-or-notch/). Two types of edges are a flat, where a straight edge is cut off the round wafer disk, and a notch, where a notch is cut into the edge of the wafer disk.

Evidence-based Reasoning

Evidence-based reasoning (EBR) refers to the engineering practice of providing rationale for design ideas and decisions. It is somewhat similar to scientific argumentation in the sense that it involves using evidence and explanations to support a statement, but it is ultimately different. In EBR, the statement being supported is an engineering design idea or decision, whereas in scientific argumentation it is a claim or conclusion about a natural phenomenon. EBR is used in the context of generating solutions for engineering problems; scientific argumentation is used to answer scientific questions about nature. Science and mathematical principles are important justifications for scientific argumentation and EBR. However, EBR often also includes justifications related to the context, criteria, and constraints of the engineering problem (e.g., cost, user needs, technical feasibility). In this lesson, students will use EBR to think deeply about their proposed design ideas and to justify them with information about the engineering problem and their science and mathematics knowledge.

Evidence-based Reasoning poster

You will find a template for this poster in 6.I Evidence-Based Reasoning Poster. This poster will contain explanations of the terms and what kind of information goes in each section. You may want to display the poster throughout the lesson, but it is most heavily used in Activity #3. Options include drawing it on one poster-size sheet of sticky note paper, putting it on a whiteboard, or digitally projecting it. You can decide if you want to create the poster in advance of the lesson or if you want to fill it out as the lesson goes along. Either way, leave space on the poster for additional information if students make additional suggestions.

Students will use this poster as a guide to help them fill out their own versions of the template during the lesson. Students will likely refer to the EBR poster beyond this lesson, so it may be useful to have it visible for the remainder of the unit.

Client response to student questions

In Activity #1, your students will generate questions to ask the client. Some of these questions may be answered in 6.C Client Letter – Process Design Requirements but some may need to answered by you, acting as the client, in a separate document 6.B Client Response. You can use the Microsoft Word letter template [insert link and filename here] to match the style of the unit client letters. See resource 6.G Problem Scoping Questions and Answers for more information.

Worksheets versus engineering notebooks

Activities 1 and 2 have students using their engineering notebooks. Activity 3 has worksheets [duplication masters 6.D, 6.E, and 6.F]. You can have the students do the worksheet activities directly in their notebooks, if you prefer.

Standards Addressed

HS ETS1-1, G.QP.4, G.CI.1, G.CI.3, G.TS.4, G.TS.5
8.NS.4, 8.GM.2, 8.GM.3
7.NS.7, 7.AF.1, 7.AF.2, 7.GM.2, 7.GM.3
6.NS.4, 6.AF.1, 6.GM.3, 6.GM.4
PS.1: Make sense of problems and persevere in solving them
PS.3: Construct viable arguments and critique the reasoning of others
PS.4: Model with mathematics
PS 5: Use appropriate tools strategically
PS.6: Attend to Precision

Key Terms

Problem scoping, criteria, constraints, brainstorm, sketch, refine, evidence-based reasoning

Lesson Materials

Per classroom

- 1 Engineering Design Process (EDP) poster, chart paper

Per Student

- EDP slider and paper clip
- Laptop/Chromebook/ Tablet
- Engineering notebook
- Pencils and erasers
- transparent rulers marked in inches and cm (with marks for mm)
- Calculator

LESSON SIX:

Duplication Masters

6.A Client Letter – Scoping the Problem

6.B Client Response [*Word document template*]

6.C Client Letter – Process Design Requirements

6.D Brainstorming Worksheet

6.E Evidence-Based Reasoning Worksheet

6.F Design Sketching

Educator Resources

6.G Problem Scoping Questions and Answers

6.H Problem Scoping Prompts

6.I Evidence-Based Reasoning Poster

Assessment

Pre-Activity Assessment

Check students' ability to explain the engineering problem, including their understanding of criteria and constraints as learned in prior lessons.

Activity Embedded Assessment

Check students' progressive understanding through their verbal and written responses when deciding upon a design idea and filling out 6.E Evidence-Based Reasoning Worksheet (either on the worksheet or in their notebook). This is especially important because the

Vocabulary

problem scoping	defining the problem and learning about the problem
criteria	features of the solution that the client wants
constraints	a specific type of criteria; the criteria that limit design possibilities or ways that the problem can be solved
evidence-based reasoning	supporting a solution or recommendation with scientific analysis and/or data

Before the Activity

Printouts

This lesson uses these duplication masters in the following quantities.

☐ 6.A Client Memo
1 per student

☐ 6.B Client Response [*from Word document; will be prepared between Activity 1 and 2, if needed*]
1 per student

☐ 6.C Client Letter – Process Design Requirements
1 per student

☐ 6.D Brainstorming Worksheet
1 per student

☐ 6.E Evidence-Based Reasoning Worksheet
1 per student

☐ 6.F Design Sketching
1 per student

Classroom Instruction

Introduction

1. **Tie in the engineering context.** Review Lessons 1-5. Remind students what questions they have already answered for the client and what they have learned along the way. You can highlight how area and volume concepts are used in wafer layout, boule and wafer waste, and kerf loss. NOTE: you may want to plan an area/volume practice worksheet to reinforce the topics.

2. **Read the client letter**. Hand out a copy of 6.A Client Letter – Scoping the Problem to each student. Encourage them to write or type in their notebooks as they read to keep track of important information. Give students time to discuss the letter in their teams.
3. **Identify the new problem from the client.** Have the students reread the letter, if necessary, to identify the problem and enter it into their notebooks.

Activity #1 - Question Generation

4. **Start problem scoping (generating questions)**. Student may know what the client wants them to do but should feel like they more information to before they can actually work on a solution. **Ask**: *Do you think the client has given us all the information we need to solve their problem?* The problem statement given in 6.A Client Letter – Scoping the Problem is purposefully does not provide all of the information necessary to solve the problem. Students will need to decide what information they need and will then write questions that they can ask the client to get more information. **Say:** *We will not be able to speak with the end users directly, but we now have the opportunity to ask the client questions about the problem so we can understand it better.*
5. **Develop questions in their notebooks**. Have students think of possible questions individually and then record them in their notebooks. Students should generate questions that 1) they need answered to solve the problem and 2) will help them understand the problem better. Encourage students to research wafer dicing processes as they develop their questions. Have students respond to the following prompt in their notebooks: *What questions do you want to ask the client?*

   Students will probably have many relevant questions, but if they struggle you can give them an example. See 6.G Problem Scoping Questions and Answers for sample questions and strategies.
6. **Collect questions as a class**. Ask students to share their questions. Record the questions so that they are visible for all students to see. Keep a copy of the questions for yourself to prepare for Activity #2. Once students have exhausted their questions, tell them that you will share the questions with the client and get back to them with more information.
7. The client should provide answers to these questions as much as possible. Only answer a question in class if necessary to keep the activity moving forward.

students will need to use information from the previous lessons.

Post-Activity Assessment
Check the student teams' design ideas and justifications to see if they make sense with the context of the problem.

8. **Identify where they are in the engineering design process (Defining the problem). Ask:** *Where are we in the engineering design process?* Allow time for responses. (Defining the problem) **Ask:** *Does it seem like we have been at this stage before? Allow time for responses. How do you think we ended up back at the beginning of the engineering design process?* Allow time for responses. **Say:** *As we ask questions and continue to learn, we sometimes find ourselves back at the beginning of the engineering design process because the problem itself changes or our understanding of the problem changes.*

Activity #2 - Problem Scoping

9. **Prior to this activity, prepare 6.B Client Response letter**. Use the questions from Activity #1 and follow the guidance in 6.G Problem Scoping Questions and Answers resource.

10. **Read the new client information**. Hand out a copy of 6.C Client Letter - Process Design Requirements and 6.B Client Response (if using).

11. **Work on problem scoping individually**. Have students answer the questions in 6.H Problem Scoping Prompts in their notebooks. Give students enough time to review the original client letter (6.A) along with the new ones (6.B and 6.C) as they work through the prompts.

    Note for middle school and some high school: You may want to discuss definitions for “end user”, “criteria” and “constraint” more explicitly as a class before starting.

12. **Discuss problem scoping answers as a team**. Once all of the students have completed the prompts individually, have students discuss their answers with their team. Using a different colored pen or pencil, students should add to or change their answers based on the consensus within the team (or write in the team answers section). Make sure that students indicate which color represents individual and team work.

13. **Discuss as a class**. Call students back together for a whole group discussion. **Ask**: *What is the client’s problem?* (The client has to do the silicon wafer cutting process in their own factory and needs to define a manufacturing process) **Ask**: *What is your role in solving the problem?* (Design a process for cutting dies from silicon wafers that maximize the number of dies cut from the wafer and minimize the waste generated). **Ask**: *What questions do you still have about the situation or your role in*

addressing it? (Answers will vary – you can either write these questions immediately or record them and include the answers in a later client letter) Say: *These questions are helping us understand the bigger issue.*

14. **Identify where they are in the engineering design process**. **Ask**: *Which phase of the engineering design process are we in right now?* (Still defining the problem and learning background information)

Activity #3 - Solution Generation

15. **Have students reread 6.C Client Letter - Process Design Requirements**. The client has a very clear set of parameters for the process that needs to be designed. The letter moves students into the “Plan” stage of the engineering design process and provides a comprehensive description of the criteria and constraints for the process to be designed.

16. **Identify where students are in the engineering design process (Plan) Say**: *So far, we have defined the problem with help from our client.* Point out the “Problem” block on the EDP poster and have the students look at their EDP sliders. **Say**: *Before we can start designing solutions. We need more information.* **Ask**: *What step of the engineering design process are we in?* The students should identify that they are in the “Plan” stage.

17. **Identify what students need to learn about**. **Say**: *In the previous activity you learned about the process for cutting dies from a silicon wafer and began scoping the problem.* **Ask**: *What other information will you need to know in order to solve the problem.*

18. **Discuss tools to generate ideas for a solution**. **Say**: *There are different ways that engineers generate ideas to solve a problem. Brainstorming and sketching are tools that we can use to work toward solving the challenge. Brainstorming is the generation of ideas to work toward a goal. Sketching your ideas will help visualize the process for laying out the wafer so that your team mates can ask questions about how it works.*

19. **Introduce Brainstorming worksheet and Individual Brainstorming Time. Say**: *We are going to brainstorm individually, and then work in teams to continue brainstorming solutions to the client’s problem.* Hand out 6.D Brainstorming Worksheet and allow a few minutes for the students to brainstorm individually. **Say**: *Using the questions on the*

brainstorming worksheet, generate possible ideas for your process. Remember, the client has encouraged you to explore multiple possibilities of how to geometrically layout the wafer in order to increase the number of dies that are cut from one wafer. So don't get locked into your first idea.

20. **Collaborate within teams to continue brainstorming. Say**: *Now that you have come up with some ideas on your own, work in your teams to review your ideas and continue coming up with new solutions. Engineers often collaborate on ideas to gather feedback on opportunities for improvement. Questioning, refining and iterating on ideas as a group helps engineers think through different possibilities.* Allow the students a few minutes to discuss.

NOTE: Option to end class period here. Next steps bring the concept of evidence-based reasoning and reaching consensus on an idea.

21. **Define the goal for the team's solution. Say:** *Engineers use evidence to support their choices. You have a list of wafer layout ideas that you brainstormed as individuals and then with your teams. Next, as a team, you will decide on a single design and you will state your evidence to support why that design solves the client's problem*.

22. **Introduce evidence-based reasoning**. Introduce the EBR poster (see Teacher Background for setup guidance). Hand out 6.E Evidence-Based Reasoning Worksheet to each student or have them draw a similar version of the EBR template in their notebooks. **Say**: *To help you continue planning your design, we are going to be using evidence-based reasoning. This means that you will need to support your design choice with evidence and explanations. We will discuss each of the parts together*. Clarify with students that the Evidence-Based Reasoning poster will have general explanations and reminders of what kind of information should go in each section. This is different from what the students will write in the templates. They will fill out the boxes with information specific to their solution.

23. **Review the problem**. Direct students' attention to the "Problem with Criteria and Constraints" section of the 6.E worksheet and poster. On the poster, write down a general definition of "problem" (i.e., the problem the client asked you to solve). Instruct students to discuss in their teams and write a summary of the engineering problem in this section of their worksheet or notebook, leaving room for criteria and constraints.

24. **Review the criteria and constraints of the problem**. **Ask**: *Can anyone remind me what the words "criteria" and "constraints" mean?* Criteria are the requirements, or goals, of the designed solutions. Constraints are things that limit design possibilities. Write these definitions on the EBR poster. Refer students back to their lists of criteria and constraints from their notes when they answered the questions in 6.H Problem Scoping Prompts. **Ask**: *What are some of the criteria and constraints of our engineering problem?* Discuss the criteria and constraints of the problem, and have students write them in the worksheet or their engineering notebooks.

25. **Introduce the concept of simplifying assumptions. Say**: *Engineers usually don't deal with every single aspect of a problem at once, otherwise it becomes too difficult to solve. Instead, they make a complex problem simpler, sometimes by ignoring some of the details of the problem and sometimes by pretending certain things are true about the problem when they actually aren't.* Write "ways to make a complex problem simpler" in the "Simplifying Assumptions (if any)" section of the Evidence-Based Reasoning poster. **Ask**: *What are some parts of our engineering problem that we can make simpler?* This may be a difficult concept for students, so provide an example or two if students struggle.

    - Simplifying assumptions (things to ignore): size of the machine to be used, shipping costs of the boule
    - Simplifying assumptions (assume certain things are true when they aren't): values used in our model are exactly the values used for production

26. **Explain what information goes in each of the remaining sections**. Have students guess at what kind of information they think should go in the "Design Idea," "Data/Evidence," and "Justification" sections of the 6.E Evidence-Based Reasoning worksheet. Write down relevant student suggestions in the appropriate section of the Evidence-Based Reasoning poster. This could include:

    - **Design Idea**: Description of the design idea; drawings of the design idea possibly with different dimensions/ sizes; label elements of the design idea to show interesting features of the design idea;
    - **Data/Evidence**: Observations and data that show why you think your design will work. Examples: data calculations, waste calculations

- **Justification**: Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

27. **Select a design solution**. **Have students work in their teams**. **Say**: *As you share and talk about all of your teammates' design ideas, think about the pros and cons of each of the solution ideas. As you think about developing one design solution, remember that you can choose one design idea or use the best parts from multiple design ideas.* Have students get into teams and discuss their design ideas. If needed help teams engage each other by asking probing questions like: what information about the process has the client requested? Did you consider different geometric layouts? Were you able to increase the dies cut from a single wafer with different geometric layouts?

28. **Justify the design solution**. When student teams have figured out what their design solution is, have them fill out the rest of their 6.E Evidence-Based Reasoning worksheet or template in their notebook with their team's design. Circulate during these discussions, listening and touching base with the teams. Ask why they would choose certain elements of the process design. Remind teams to think about the information they wrote in the "Problem including Criteria and Constraints" and "Simplifying Assumptions" sections when they justify their chosen design solution.

    NOTE: Each student does not need to complete the evidence-based reasoning template; only one completed template is required per team. However, if you would like, each student can fill out 6.G to include in their notebooks.

29. **Sketch top design choice**. Hand out 6.F Design Sketching Say: *Every member of your team should sketch out the final design so that you can see if your visualizations are similar or different. Be sure your sketch includes your wafer design with the die cuts.* Allow students time to sketch their primary idea on the worksheet or in their notebooks.

Closure

30. **Connect the activity to the engineering design challenge.** **Ask**: *What did we learn today that will help us provide a recommendation to the client? Why is brainstorming individually important? Why is brainstorming in a team important? Why do we use different tools when we brainstorm? How does*

collaboration with team mates help refine an idea? How did evidence-based reasoning help support the wafer layout process that you are recommending? How did sketching help explain your idea? **Say**: *We will continue in the Try stage during our next class.*

6.A Client Letter – Scoping the Problem

Dear Engineers,

It has been hard to identify why we are not able to produce enough microchips to keep up with the demand. In solving problems, it is sometimes hard to identify the root problem right away, so we keep asking questions and learning from the solutions to those questions.

So far you have helped me understand why the area of a circle of wafer divided by the area of a rectangle of chip does not actually estimate the number of dies we can cut from a wafer. You have helped me understand the waste that is generated once a wafer is cut. Additionally, you have helped me understand how silicon is made from sand and the waste generated when a boule of silicon is made into wafers.

Since we will be producing our own chips from the silicon wafers, our manufacturing team needs to understand the process of laying out a silicon wafer so that we can maximize the number of dies cut from the wafer and minimize the amount of waste generated from the process. When it comes to actually cutting the dies from the wafer, I am struggling to understand how the wafer is held in place and how the machine knows where to make the cuts into the wafer. I would like to enlist your help in finding the answers to these questions and identifying other critical questions related to the process of cutting dies from a silicon wafer so that we can maximize the number of dies cut from the wafer and minimize the waste generated. Feel free to send me questions about things I might not have shared as of yet.

Thank you for all of your help!
Sincerely,

Skylar Geti
CEO, Geti Games

GETI GAMES

6.C Client Letter – Process Design Requirements

Dear Engineers,

During our production meeting this week, our manufacturing team discussed increasing flexibility in our process by allowing them to use any standard size die and any standard size wafer to produce the number of dies that we need. They assure me that this flexibility will provide the steadiest supply of materials and support the 24/7 production runs required to meet the increased demand for our game controllers.

I am asking for your help in designing a process to layout a silicon wafer so that we can produce the number of dies that we need to keep up with demand. Your process needs to be flexible enough to support rectangular die of many different sizes (die areas of: 1 mm^2, 100 mm^2, 200 mm^2) and any of the standard size silicon wafer diameters (i.e., 50 mm, 100 mm, 150 mm, 200 mm). The process needs to incorporate the constraints of spacing (vertical and horizontal), edge clearance. For the layout of the silicon wafer, assume a flat/ v-notch height of 1 mm. For the boule, your process should take into account a geometrical shape that includes a cylinder which is flat on one end and topped by a cone on the other end. Your process should be able to support boules with many different cylinder lengths (i.e., 1 m, 2 m), many different diameters (i.e., 50 mm, 100 mm, 150 mm, 200 mm), and variable cone heights (i.e., 75 mm, 150 mm)

Along with the process design, you will need to calculate some critical data points:

- **Number of dies cut from a silicon wafe**r: Use what you have already learned as a foundation to calculate the number of dies that can be cut from a silicon wafer using your design process.
- **Cost per die cut from the silicon wafer**: For this calculation we can assume that every horizontal cut and every vertical cut made on the silicon wafer costs $1.00 each. While it is unrealistic to think that the cost is actually $1.00 per cut, using this assumption simplifies the calculation for purposes of this part of the engineering design process.
- **Total waste per silicon wafer**: For this calculation revisit what you have already learned.
- **Total waste per boule of silicon**: Use what you have already learned as a foundation for this calculation. You can assume that the silicon wafers you cut from the boule are 1 mm thick.

I realize that there is a lot to learn in this challenge. As you design your process, don't be locked into your first ways of thinking. Be willing to explore multiple possibilities of how to geometrically lay out the wafer design in order to increase the number of dies that are cut from one wafer.

Also, remember to use all of your resources and work together to navigate your recommendations. We are looking for the best process, so we would like different teams of engineers to develop alternate proposals. With your team, you will need to explain your process and why it is our best option for wafer layout. You will need to justify your reasoning to show why your process is the best.

Sincerely,

Skylar Geti
CEO, Geti Games

Name____ Date_______________ Period __________

6.D Brainstorming Worksheet

For each idea, ask yourself the following questions:

- What important elements of the process to layout wafers will your design highlight? (i.e, minimize waste, maximize number of dies cut, high yield of undamaged dies, precision and accuracy of cut (minimal variation in dimensions and alignment)
- How will your process minimize wafer waste?
- How will your process increase the number of dies cut from the wafer?
- Why will your process be the best option for wafer layout?

When brainstorming, you get to ask the questions! Try to figure how the idea will help our client with their challenge.

Idea #1

Idea #2

Idea #3

Idea #4

Idea #5

Idea #6

Name______________________________________ Date______________ Period __________

6.E Evidence-Based Reasoning Worksheet (1/2)

Think about your process design. What went well? What did not go well? Use the prompts from this sheet to document in your notebook the reasons why you believe the design you have chosen is the best design.

Problem with Criteria & Constraints • Explain the client's problem that needs a solution and why it is important to solve. • List criteria and constraints you will use to decide if your solution is working.	
Problem: **Criteria:** **Constraints:**	
Simplifying Assumptions • List things that might be important but you have decided not to worry about.	
Design Idea #___ • Plan including drawing, labels of materials used, and labels of what each part does.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.

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6.E Evidence-Based Reasoning Worksheet (2/2)

Justification - Why do you think this design idea will work? • Explain how your data and evidence support your design idea in order to meet criteria/constraints.

Name______________________________________ Date______________ Period __________

6.F Design Sketching

Now that you have chosen which idea will be proposed as your solution to the engineering design challenge, it is time to draw it! Make a sketch of your design in the box below. Add labels to make sure you show die spacing and layout.

6.G Problem Scoping Questions and Answers

Guidance for problem scoping questions

Students will come up with a variety of questions, but good problem scoping questions help clarify the problem, identify what needs to be done, and identify the acceptable ways it can be done. Here are some sample questions/responses. Note that many of the questions will be answered with later client letters, so a promise to find the information and send it later might suffice for some questions.

Relevant Questions:

- **How does the manufacturing machine know where to make the cuts for each die in the wafer?**
  POSSIBLE ANSWER: When laying out the design of the die cuts on the wafer, it is necessary to include horizontal spacing and vertical spacing that will specify the width of the horizontal and vertical cuts between each if the dies.
- **How does the manufacturing machine know that it cannot cut all the way to the edge of the wafer?**
  POSSIBLE ANSWER: That is a good question. The layout of the wafer should include an edge clearance value. The edge clearance is the outermost distance from the wafer's edge where it is hard to achieve good die cuts. The smaller the edge clearance needed, the greater number of dies that can be cut.
- **How is the wafer held in place during the manufacturing process without damaging or contaminating the wafer?**
  POSSIBLE ANSWER: When designing the layout of the wafer, we include a location on the wafer where the machine can align and grip the wafer without damaging or contaminating the surface. This is called the flat or v-notch.

Less relevant Questions:

- **How big is the machine that will be used to cut the dies from the wafer? How much will the machine cost? Who will run the machine?**
  POSSIBLE ANSWER: These are really important questions, and we have another team who is working on defining all of this. We are also working on the budget needed to purchase the equipment and to hire the teams of people needed to run the machines.
- **How long will it take the machine to cut the dies from the wafer?**
  POSSIBLE ANSWER: I like the way you think. It is important to understand how long it will take to cut the dies from the wafer. The manufacturing team will have more information on this after the process is defined and the machines are tested.

Creating 6.B Client Response letter

After Activity #1, you will have a list of student questions for the client. Before Activity #2, read 6.C Client Letter - Process Design Requirements and compare it with your list of student questions. Any relevant questions not answered in 6.C will need to be answered in 6.B Client Response. You can create 6.B using the provided Microsoft Word template [insert name and link here].

6.H Problem Scoping Prompts

Directions: Please answer these questions in your engineering notebook. First, complete each prompt on your own. Then write your revised answer (if different) to the prompt, based on the discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. The client is:

2. The client's problem is:

3. The problem is important to solve because:

4. The end-users are:

5. An effective solution for the client will meet the following criteria:

6. The constraints (or the limits) of the solution are:

7. Think about the problem of reducing the amount of waste in manufacturing microchips. In terms of number of dies that can be cut, the amount of waste from both the wafer and boule, and cost to cut out one die from a wafer. What have you learned that will useful in this process? What might you still need to learn? Make sure to consider all important aspects of the problem. Be specific.

6.I Evidence-Based Reasoning Poster

Poster template with explanations.

<table>
<tr><td colspan="2">Problem with Criteria & Constraints
• Explain the client's problem that needs a solution and why it is important to solve.
• List criteria and constraints you will use to decide if your solution is working.</td></tr>
<tr><td colspan="2">Problem: the engineering problem the client asked you to solve

Criteria: the requirements, or goals, of the designed solutions

Constraints: things that limit design possibilities</td></tr>
<tr><td colspan="2">Simplifying Assumptions (if any)
• List things that might be important but you have decided not to worry about.</td></tr>
<tr><td colspan="2">Ways to make a complex problem simpler</td></tr>
<tr><td>Design Idea #___
• Plan including drawing, labels of materials used, and labels of what each part does.</td><td>Data/Evidence
• List science/mathematics learned and/or results of tests that support your design idea.</td></tr>
<tr><td>• Description of the design
• Drawings of the design, different views
• Dimensions (sizes)
• Label materials in design (show where they are used)
• Interesting features</td><td>Observations and data that show why you think your design will work</td></tr>
<tr><td colspan="2">Justification - Why do you think this design idea will work?
• Explain how your data and evidence support your design idea in order to meet criteria/constraints.</td></tr>
<tr><td colspan="2">Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.</td></tr>
</table>

LESSON SEVEN:

Lesson Objectives

Students will be able to:

- Implement a design while working together within a design team
- Analyze the performance of their design
- Communicate science, technology, engineering and mathematics ideas through presentation and written communication
- Compare their design's performance with the performance of their peer's designs

Time Required

One 50-minute lesson

Standards Addressed

HS ETS1-1, G.QP.4, G.CI.1, G.CI.3, G.TS.4, G.TS.5
8.NS.4, 8.GM.2, 8.GM.3
7.NS.7, 7.AF.1, 7.AF.2, 7.GM.2, 7.GM.3
6.NS.4, 6.AF.1, 6.GM.3, 6.GM.4
PS.1: Make sense of problems and persevere in solving them
PS.3: Construct viable arguments and critique the reasoning of others
PS.4: Model with mathematics
PS 5: Use appropriate tools strategically
PS.6: Attend to Precision

Key Terms

Decision matrix, communication

Lesson Summary

In this lesson, students will test and evaluate their process designs with a specific set or parameters from the client. Students will record and review the results of their designs using the decision matrix prior to providing a final recommendation to the client. (Optional) Students will prepare presentations as a team to share their design and results with the class. Students will review one another using the decision matrix prior to providing a final recommendation to the client.

Background

Engineers often need to validate their solutions in some way, either through prototyping, or other ways of demonstrating the solution as a proof of concept. (Optional) In this lesson, students will be making presentations to convince the client that their process is the best option.

Vocabulary

design matrix	a tool used to compare, assess, and prioritize a set of options based on weighted criteria

Printouts

This lesson uses these duplication masters in the following quantities.

- ☐ 7.A Decision Matrix Rubric 1 per team
- ☐ 7.B Decision Matrix Activity 1 per team
- ☐ 7.D Content Post-Assessment 1 per team
- ☐ *Optional* (if doing presentations): 7.C Class Report to the Client (1 per team)

Classroom Instruction

Introduction

1. **Tie in the engineering problem. Ask:** *What is our engineering design problem?*
2. **Identify where they are in the engineering design process**

(Try). Say: *So far, we have defined the problem with help from our client.* Point out the "Problem" block on the Engineering Design Process (EDP) poster and have students look at their EDP sliders. Before we can start designing solutions, we need more information. **Ask:** *What step of the engineering design process are we in?* The students should identify that they are in the "Try" stage.

3. **Identify what students need to learn about. Say:** *In the previous lesson you brainstormed as a team to come up with your final design idea, which you sketched.* **Ask:** *What other information will you need to know in order to solve the problem?*

Activity

4. **Provide an overview of how students should spend their time. Say:** *Today you will be testing your process designs as a team. As you are testing, you will need to calculate how much your design will cost, how many dies will be cut from the wafer, and the total waste that your design would produce from the silicon wafer and from boule of silicon that is used.*

5. **Try/Test/Decide. Say:** *Each team will test their recommended process using a* ***300mm diameter silicon wafer and a rectangular die size of 10mm by 10 mm****. The boule will be a cylinder which is flat on one end and topped by a cone on the other end. The cylinder of the boule will be 2m in length, 300mm in diameter, and have a cone height of 75mm. The remaining criteria and constraints and calculations needed are the same as provided in 6.D Client Letter #3.* (i.e., "The process needs to incorporate the constraints of spacing (vertical and horizontal), edge clearance. For the layout of the silicon wafer, assume a flat/ v-notch height of 1 mm.") *Use the remaining time for today to gather into your teams and try your recommended process. Once you have tested your process design, revisit your Evidence Based reasoning worksheet from our last lesson, and update it with any insights you have learned. Remember to calculate the data required by our client: number of dies cut from a silicon wafer, cost per die cut from the silicon wafer, total waste per silicon wafer, total waste per boule of silicon.* Allow students to gather into their design teams and work through their process designs.

6. **Explain the evaluation process: Say:** *A decision matrix is a tool that evaluates and prioritizes your options to help you make the best decisions.* Hand out 7.A Decision Matrix Rubric. **Say:**

Lesson Materials

Per classroom

- EDP Poster

Per student

- EDP slider and paper clip
- Laptop/Chromebook/ Tablet
- Engineering notebook
- Pencils and erasers
- transparent rulers marked in inches and cm (with marks for mm)
- Calculator

Duplication Masters

7.A Decision Matrix Rubric

7.B Decision Matrix Activity

7.C (Optional) Class Report to the Client

7.D Content Post-Assessment

Educator Resources

7.E Content Post-Assessment KEY

Assessment

Pre-Activity Assessment

Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment

Check students' progressive understanding through their discussions. Check for evenly distributed team participation.

Activity Embedded Assessment

During the (optional) class presentation or closure activity, ask students to justify the recommended process designs. The purpose is to get students to refer back to the decision matrix rubric and activity.

Review the students' post-assessment to see if their understand has improved over the course of this unit.

We have been considering cost per cut, number of dies cut per wafer, waste per boule in designing our processes. We will use this decision matrix rubric to help evaluate the process you developed. Allow students a few minutes to review the decision matrix rubric and ask any questions.

7. **Use the decision matrix to assess design recommendations. Say:** *Based on the results you collected from using your recommended process in this activity, you are welcome to present your data.* Hand out 7.B Decision Matrix Activity. **Say:** *Please add your team's data to this table or in your notebook.* ***(Optional)*** *You will also be able to use this worksheet or your notebook to score the processes presented by other teams.*
8. **(Optional) Prepare a class report to the client. Say:** *Once a recommendation is decided upon, engineers need to communicate their findings to the client with scientific justification – or evidence-based reasoning - behind the choice.* Handout 7.C Optional: Client Report to the Client - Communication Requirements. Invite students who have finished their activity to present their findings to the class and explain the process features they think will make their recommendation successful. While each team is presenting, the students should be using Handout 7.B Decision Matrix Activity to score each process design presented.
9. **Why is it important to communicate results?** Facilitate a discussion about why communication of results is vital to engineering design.

Closure

10. **Connect the activity to the engineering design challenge. Ask:** *What did we learn today that will help us provide a recommendation to the client? What was your cost per cut? How did the number of dies cut from the wafer impact your process design? How did the amount of waste generated impact your process design? What did you learn from the evaluation process? How can a decision matrix be helpful in evaluating options?*
11. **Complete Duplication Master 7.D Content Post Assessment.** Note that this is an important step in the process and students should be given time to complete this individually.

7.A Decision Matrix Rubric

A decision matrix is a tool that evaluates and prioritizes your options to help you make the best decision. You will be evaluating the process you designed to layout a silicon wafer based on the three calculations required by the client: The rubric helps you assign points to establish how well your process client requirements. Using a design matrix can help highlight strengths and weaknesses of a design, accelerating the path to improvement.

The three row headings represent important data to consider when making your recommendation to the client. For this decision matrix, each factor will be rated on a scale from 1 to 5. A rating of 1 indicates that the design does not meet expectations for the category, while a rating of 5 indicates that the design exceeds expectations for the category. An explanation of each category is given below.

Data Category	Explanation	A rating of 1 indicates...	A rating of 3 indicates...	A rating of 5 indicates...
Number of dies cut per wafer	Using the process you designed to layout a silicon wafer, calculate the maximum number of dies produced.	Less than 250 dies cut per wafer	Between 251 and 500 dies cut per wafer	More than 500 dies cut per wafer
Cost per die cut from wafer	Using the process you designed to layout a silicon wafer, calculate the cost per die cut from the wafer	More than \$0.50 per die cut from the wafer	Between \$0.20 and \$0.50 per die cut from the wafer	Less than \$0.20 per die cut from the wafer
Waste per silicon wafer (volume, cubic millimeters)	Using the process you designed to layout a silicon wafer, calculate the waste per silicon wafer generated by your design	No waste calculated	Waste calculated but not 29,317 mm^3	29,317 mm^3
Waste per Boule (volume, cubic millimeters)	Using the process you designed to layout a silicon wafer, calculate the waste per silicon boule	No waste calculated	Waste calculated but not 562,500π mm^3	562,500π mm^3

Name____ Date________________ Period ___________

7.B Decision Matrix Activity

Record your design team's data on the Decision Matrix

If group presentations are made, take notes while each group gives their presentation on their water filtration system, paying specific attention to the presenters' comments on each of the three categories. Once the presentation is finished, rate the process for laying out a silicon wafer for each of the three categories on their given scale. Find the total score for each row. The row with the highest value is what you consider to be the best process for laying out a silicon wafer to recommend to the client based on these criteria.

My team's results

Number of dies cut per wafer	Cost per die cut	Waste per wafer	Waste per boule	Total Score

Whole Class results

Design Team	Number of dies cut per wafer	Cost per die cut	Waste per wafer	Waste per boule	Total Score

7.C. (Optional) Class Report to the Client

Client Communication Requirements

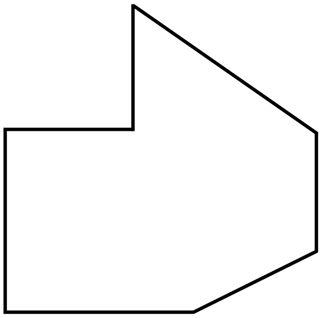
- Students introduce themselves.
- Students summarize the client's problem including criteria and constraints.
- Students explain why it is important to design a silicon wafer layout process
- Students describe their solution to the problem:
    - Describe the wafer layout process
    - Explain the test results they found.
    - Explain their redesign process.
    - Provide a recommendation to the client about their final design.
- Students show data and evidence gathered and used in their design.
- Students justify their decision using data and evidence.
- All team members have a role in the presentation.
- Students demonstrate in-depth knowledge of their wafer layout process.
- Students describe how their wafer layout process is the best design

Name_______________________________________ Date_______________ Period ___________

7.D. Content Post-Assessment

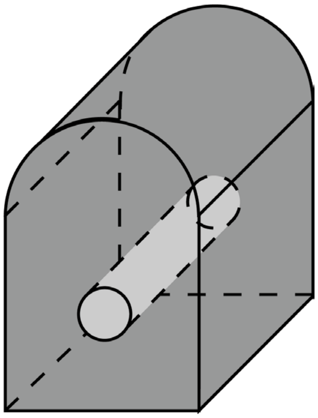
1. What is area in geometry?

2. Given this 2-dimensional shape and assuming you had all measurements that you needed, how would you go about finding the area?



3. What is volume in geometry?

4. Given this 3-dimensional shape and assuming you had all measurements that you needed, how would you go about finding the volume of the darker grey area?



5. What are the formulas for the area and circumference of a circle?

6. Why might it be important is it to consider waste in microchip production?

Name____ Date________________ Period ___________

7.D. Content Post-Assessment

7. What does the term, “microelectronics” mean?

8. How are microelectronics used in your everyday life?

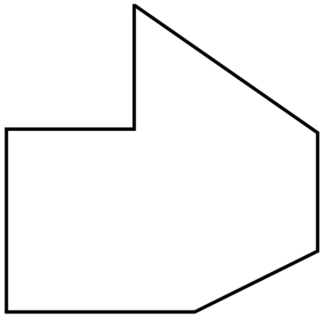
9. What jobs would you be interested in that use microelectronics?

10. Provide one example of how microelectronics is used in that job.

7.E. Content Post-Assessment KEY

1. What is area in geometry?
   Answers will vary. Some examples: Area is the space inside the perimeter of a closed shape. Area is the size of the surface of an object, Area is measured in square unite like in^2, ft^2, cm^2

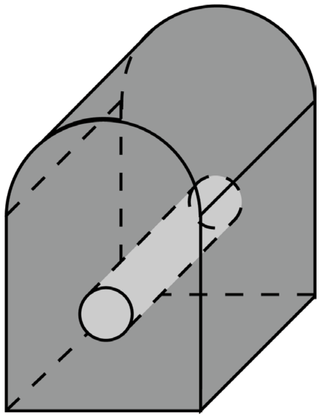
2. Given this 2-dimensional shape and assuming you had all measurements that you needed, how would you go about finding the area?



   a. **Divide the 2-dimensional shape into basic shapes: i.e. square, triangle, rectangle**
   b. **Find the area of each basic shape separately**
   c. **Add all of the areas of the basic shapes together and share the answer in square units**

3. What is volume in geometry?
   Answers will vary. Some examples: Volume is the amount of space occupied by any three dimensional solid. Volume is measured in cubed units like in^3, ft^3, cm^3

4. Given this 3-dimensional shape and assuming you had all measurements that you needed, how would you go about finding the volume of the darker grey area?



   a. **Identify the different parts that the three dimensional solid is made of**
   b. **Work out the volume of each part independently**
   c. **Add all of the volumes of each basic part and share the answer in cubic units**
   d. **In this example, we would calculate the volume of a cylinder: $V=\pi r^2 h$**

5. What are the formulas for the area and circumference of a circle?
   $A=\pi r^2$
   $C=2\pi r$

6. Why might it be important is it to consider waste in microchip production?
   Answers will vary. Some examples:
   - **Materials used in microchip production, especially hazardous waste, requires specific disposal strategies and can be costly to dispose of.**
   - **The cost of material waste, or scrap material that is left over and not used in the final product, can add up to a significant number.**

7.E. Content Post-Assessment KEY

7. What does the term “microelectronics” mean?

   Answers will vary. Some examples:
   - **Microelectronics is the design, manufacture, and use of microchips and microcirciuts.**
   - **Microelectronics is the design, development, and manufacture of very small electronic designs and parts**

8. How are microelectronics used in your everyday life?

   Answers will vary. Some examples:
   - **Computers**
   - **Cell phones**
   - **Calculators**
   - **Digital watches**
   - **All “smart” devices is also a pretty good answer examples since appliances, cars, homes, and classrooms all have microelectronic components in them. But have the students provide specific examples.**

9. What jobs would you be interested in that use microelectronics?

   Answers will vary. Pre-assessment may be lacking in good answers. That is okay. Some examples:
   - **Hardware engineer**
   - **Semiconductor engineer**
   - **Packaging engineer**
   - **Digital systems engineer**
   - **Clean room technician**

10. Provide one example of how microelectronics is used in that job.

    Answers will vary. Some examples:
    - **Hardware engineer – computer hardware requires microelectronics to work**
    - **Semiconductor engineer – Semiconductors are made from micro electronics**
    - **Packaging engineer – Microelectronic packaging involves printed wire board design that integrates microelectronics**
    - **Digital systems engineer – designing and testing systems that utilize microelectronics**
    - **Clean Room Technician – maintains the sterile environment required for precision manufacturing of microelectronics**