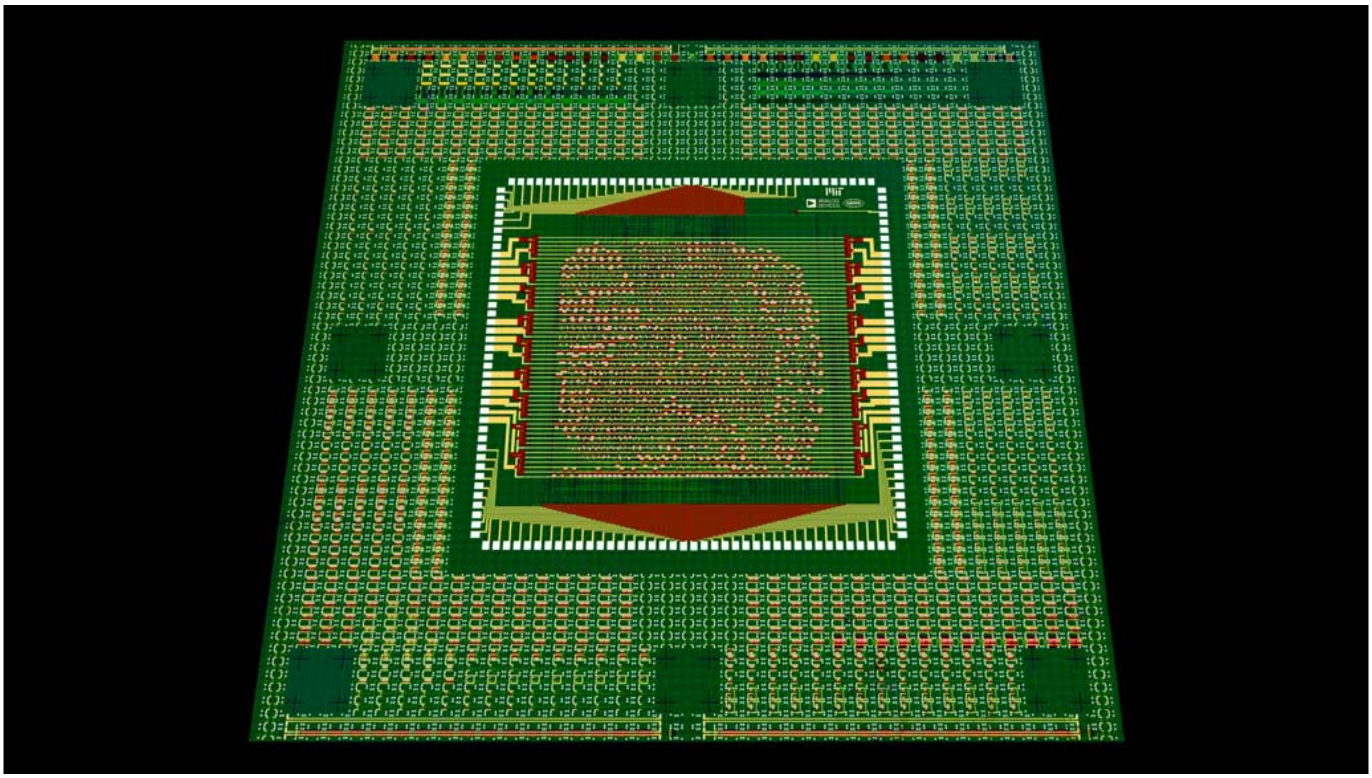
Science News
EDUCATOR GUIDE



G. HILLS ET AL/NATURE *2019*

September 28, 2019
Computer Chip Milestone Reached

SOCIETY FOR SCIENCE & THE PUBLIC

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About this Guide

This guide, based on the *Science News* article "Computer chip milestone reached," asks students to explore transistors and Moore's Law. The activity leads students as they design a simple circuit out of logic gates.

This Guide includes:

Article-Based Comprehension Q&A — These questions, based on the *Science News* article "Computer chip milestone reached," Readability: 11.9, ask students to compare silicon transistors to ones made of carbon nanotubes. Another version of the article, "Computer chips from carbon nanotubes, not silicon, mark a milestone," Readability: 8.5, is available from *Science News for Students.* Related standards include NGSS-DCI: HS-PS2, HS-PS3, HS-PS4, HS-ETS1.

> **Student Comprehension Worksheet —** These questions are formatted so it's easy to print them out as a worksheet.

Cross-curricular Discussion Q&A — After watching a video about transistors, your class can use these discussion prompts to analyze transistor technology and predict future trends in computer processing. Related standards include NGSS-DCI: HS-PS1, HS-PS2, HS-PS3, HS-PS4, HS-ETS1.

> **Student Discussion Worksheet —** These questions are formatted so it's easy to print them out as a worksheet.

Activity: Digital circuit design

> **Summary:** Students will practice designing an integrated circuit that can accomplish a simple task. The activity will help students understand that digital circuits are composed of logic gates made up of transistors. Related standards include NGSS-DCI: HS-PS2, HS-ETS1.
>
> **Approximate class time:** 1 class period to complete the activity questions and circuit design.

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Article-Based Comprehension, Q&A

Directions for teachers: After your students read "Computer chip milestone reached," ask them to answer the following questions.

1. A milestone is a significant point in the progress or development of something. What milestone does the headline refer to and why is that milestone important?

Scientists built the first computer chip that uses thousands of carbon nanotube transistors to run programs. Carbon nanotube computer chips could lead to faster, more energy-efficient electronics.

2. What is a transistor and what does it do inside a computer?

A transistor is a tiny electronic switch. Transistors' "on" and "off" states are determined by whether electric current is flowing or not. Those states encode the 1s and 0s of computer data. Groups of transistors together perform computations.

3. Computer chips have traditionally been made with silicon transistors. Why are scientists now looking for alternatives to silicon?

Silicon transistors can't get much smaller and more efficient than they already are, which means the performance of computers that rely on these transistors can't improve much more either.

4. What does a carbon nanotube look like? What advantages could carbon nanotube transistor technology have over silicon in the future?

The nanotubes are cylindrical tubes made of atomically thin sheets of carbon, which means researchers can pack a lot of the nanotubes onto a single chip. The nanotubes also conduct electricity better than silicon. Taken together, that means carbon nanotube–based computer chips could run faster while consuming less energy than traditional computer chips. Carbon nanotubes could help overcome the barrier to performance gains.

5. Identify and explain two problems that the scientists ran into when designing a computer chip with carbon nanotube transistors.

The researchers found that carbon nanotubes tended to clump together when the tubes were put on a computer chip wafer, which prevented the transistors from working. The researchers also found that some of the nanotubes were metallic. Metallic nanotubes cannot properly switch between being conductive and insulating, which can affect how transistors process information.

6. How did the scientists solve the problems?

To address the clumping, the researchers gently vibrated the wafer after spreading the nanotubes onto the chip. The researchers also designed the computer chip's circuits to avoid transistor layouts that were most affected by metallic nanotubes.

7. Identify and explain an analogy that *Science News* reporter Maria Temming uses in the article. How does the analogy help you understand the scientific concept being discussed? Write your own analogy that incorporates information from the article.

Temming likened metallic nanotubes to missing letters in a word. Some words are readable when letters are missing while others are completely garbled. In the same way, some transistor layouts are less affected than others by the metallic nanotubes. Student reasons and analogies will vary.

8. How does the performance of carbon nanotube transistors in this chip prototype compare with silicon transistors used in modern electronics? How do the transistors' sizes compare? What is the order of magnitude difference in each case?

The carbon nanotube transistors can switch on and off about a million times each second, compared with silicon nanotubes, which can switch billions of times per second. That's three orders of magnitude. The carbon nanotube transistors are about a micrometer in diameter each. Current silicon transistors are two orders of magnitude smaller, measuring just tens of nanometers across.

9. What can researchers do to improve carbon nanotube transistors?

Making the nanotube transistors smaller could help them switch on and off more quickly. And placing the transistors parallel within a circuit could boost processing speed.

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Student Comprehension Worksheet

Directions: After reading "Computer chip milestone reached," answer the following questions.

1. A milestone is a significant point in the progress or development of something. What milestone does the headline refer to and why is that milestone important?

2. What is a transistor and what does it do inside a computer?

3. Computer chips have traditionally been made with silicon transistors. Why are scientists now looking for alternatives to silicon?

4. What does a carbon nanotube look like? What advantages could carbon nanotube transistor technology have over silicon in the future?

5. Identify and explain two problems that the scientists ran into when designing a computer chip with carbon nanotube transistors.

6. How did the scientists solve the problems?

7. Identify and explain an analogy that *Science News* reporter Maria Temming uses in the article. How does the analogy help you understand the scientific concept being discussed? Write your own analogy that incorporates information from the article.

8. How does the performance of carbon nanotube transistors in this chip prototype compare with silicon transistors used in modern electronics? How do the transistors' sizes compare? What is the order of magnitude difference in each case?

9. What can researchers do to improve carbon nanotube transistors?

Computer Chip Milestone Reached

Cross-curricular Discussion, Q&A

Directions for teachers: As a class, watch the video "How transistors work" by TED-Ed and discuss the general history, structure and function of a transistor. Then divide students into small groups and have them analyze the graph "Transistor count on largest microprocessors 1975–2010" and the mathematical expression of Moore's Law in the Computer History Museum article "Moore's Law@50: 'The most important graph in human history.'" Students should skim the article to learn the basics of Moore's Law but focus mostly on the graph. Next, ask groups to read the *Science News* article "Computer chip milestone reached" and answer the questions in that section. Finally, come together as a class to discuss students' predictions for what the future trend of computer processing might look like. (Note: If you would like to dig deeper into how computers work, check out this series of videos from Khan Academy.)

Transistors in focus

After watching the TED-Ed video "How transistors work," discuss these questions as a class. Consult other resources if necessary.

Before transistors existed, what technology was used in early computing devices? How did this early technology work?

Before transistors, diode or triode vacuum tubes were used as "switches" to control the flow of electric current in a computing device. Heating up a triode's negatively charged cathode by applying a voltage freed electrons. The electrons flowed across an electrode called a grid to the positively charged anode. Adjusting the voltage applied to the grid controlled the flow of electrons between the cathode and the anode, making fast current switching possible.

What is the function of a transistor in a computer? How does a transistor work?

Transistors act as switches to control the flow of electric current through microprocessors, or computer chips. Transistors have two states, "on" and "off." Varying the input voltage can switch the transistor's states. When a high electric voltage is applied to a transistor, it is "on." When the voltage is low or zero, the transistor is "off." In a computer program, these states are represented by the numbers 1 and 0.

What are common transistors made of? List a few properties of this substance and explain how it reacts with neighboring atoms.

Commonly used transistors are made out of silicon. Silicon is a semiconductor with four valence electrons that covalently bonds with four other silicon atoms in its crystalline solid structure. Silicon atoms can bond with atoms of other elements, which can enhance the ability to conduct electricity.

How are triodes and transistors different, and how are they similar?

Instead of the electrodes used by triodes, transistors use semiconductors — typically silicon. Combining silicon with other elements creates N type and P type components. N type components emit electrons, akin to the negatively charged cathode in a triode. P type components absorb electrons, akin to the triode's positively charged anode. Some transistors are layered in an NPN configuration. The point where the N and P layers meet, called a P-N junction, acts sort of like a triode's grid. It conducts electricity (turning the transistor "on") only when a certain voltage is met or exceeded.

Why are transistors considered revolutionary?

Transistors are much smaller, more durable and don't require as much energy as triodes. Because of this, transistors have made computing devices smaller while boosting the devices' efficiency and computing power.

Level up

In small groups, use the Computer History Museum article "Moore's Law@50: 'The most important graph in human history'" and other online resources to answer the following questions.

Who is Gordon E. Moore, and what does his "law" state? Is Moore's Law considered a scientific law?

Based on his observations of technology trends, engineer Gordon E. Moore predicted that computing would increase in power, and decrease in relative cost, at an exponential rate. Moore's Law says that the number of transistors on a computer chip should double every two years. Moore's Law is not a scientific law, rather it's an observation of technological computing advances. The law has served as a guiding principle for computer technology for more than 50 years.

According to Moore's Law, if 1 million transistors were on an integrated circuit one year, how many would be on it two years later? What about after four, eight and 10 years?

There would be twice as many, or 2 million transistors on the integrated circuit after two years, 4 million after four years, 16 million after eight years and 32 million after 10 years.

Does Moore's Law describe linear or exponential growth? Write an expression that explains the growth, based on the dataset that you just created. Hint: Write the expression in terms of n, where n equals the number of years that have passed divided by 2.

Moore's Law is a function that shows exponential growth, as it states the number of transistors will double *every two years. A general expression for Moore's Law could be written as* $T_{final} = T_{initial} * 2^n$.

Look at the graph "Transistor count on largest microprocessors 1975–2010," in the article. Do your answers in the previous question align with the trend line shown? Explain why the trend line in the graph is straight.

Yes, my answers generally align with the trend line given. In 1990, approximately 1 million transistors were on an integrated circuit. Ten years later, in 2000, it appears that computer chips contained roughly 30 million transistors. The trend line is straight because the y-axis values are given on an exponential scale. If the y-axis were on a linear scale, the result would be a curved graph, increasing exponentially.

Elemental search

In your same groups, refer to the *Science News* article "Computer chip milestone reached" and other resources to answer the following questions.

According to the *Science News* article, scientists are engineering transistors made of carbon nanotubes that might one day replace silicon transistors. On an atomic level, how does carbon compare with silicon?

Carbon atoms and silicon atoms are different elements with their own unique number of protons. However, because carbon and silicon atoms have the same number of valence electrons, the atoms will react similarly with neighboring atoms of other elements within a crystalline structure.

Why are scientists engineering new types of transistors? What problem are scientists trying to solve?

Performance gains of silicon transistors are beginning to level off, because the transistors are nearly as fast and efficient as they can get. To continue to uphold Moore's Law, new materials and technologies may be needed.

Pushing limits

Discuss the following questions as a class.

Is it important to explore alternative transistor materials, and find new ways to continue the current rate of performance improvement? Why or why not?

Student answers will vary. They may express that it is important to continue developing computing technology at an exponential rate, but might not know how it could be possible. Or, students may think that carbon nanotube technology is a viable solution that should receive more resources.

In addition to transistor materials, what factors might affect the rate of computing technology progress?

Student answers will vary, but may include the amount of scientific funding this research receives, consumer demand based on social and cultural trends, discovery of new materials, mining technologies and geopolitical relations since materials come from around the world.

Why has Moore's Law been important over the last 50 years? Will Moore's Law hold true in the future? If so, for how long? You may want to think back to the graph "Transistor count on largest microprocessors 1975–2010," in the article "Moore's Law@50: 'The most important graph in human history.'"

Student answers will vary. They may discuss how engineers and scientists in the tech industry try to keep up with Moore's Law. Students should think about how factors including the maximum speed at which information can travel and the physical limitations of silicon and potential replacement materials might affect the exponential rate of computing power improvement dictated by Moore's Law. Students may make an educated guess at when the graph will become asymptotic because of the limitations of silicon transistor technology, because of the absence of replacements to silicon transistors that are as efficient, or a combination of factors.

Why is increasing computing power important?

Student answers will vary. They might mention that increasing computing power is important for running climate simulations or other complex computing tasks. Ask students to reflect on how increasing computing power may be important for their everyday lives.

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Student Discussion Worksheet

Directions: As a class, watch the video "How transistors work" by TED-Ed and discuss the history, structure and function of a transistor. Then divide up into small groups and answer questions based on the Computer History Museum article "Moore's Law@50: 'The most important graph in human history'" and the *Science News* article "Computer chip milestone reached." Finally, as a class, discuss what the future trend of computer processing might look like.

Transistors in focus

After watching the TED-Ed video "How transistors work," discuss these questions as a class. Consult other resources if necessary.

Before transistors existed, what technology was used in early computing devices? How did this early technology work?

What is the function of a transistor in a computer? How does a transistor work?

What are common transistors made of? List a few properties of this substance and explain how it reacts with neighboring atoms.

How are triodes and transistors different, and how are they similar?

Why are transistors considered revolutionary?

Level up

In small groups, use the Computer History Museum article "Moore's Law@50: 'The most important graph in human history'" and other online resources to answer the following questions.

Who is Gordon E. Moore, and what does his “law” state? Is Moore’s Law considered a scientific law?

According to Moore’s Law, if 1 million transistors were on an integrated circuit one year, how many would be on it two years later? What about after four, eight and 10 years?

Does Moore’s Law describe linear or exponential growth? Write an expression that explains the growth, based on the dataset that you just created. Hint: Write the expression in terms of n, where n equals the number of years that have passed divided by 2.

Look at the graph “Transistor count on largest microprocessors 1975–2010,” in the article. Do your answers in the previous question align with the trend line shown? Explain why the trend line in the graph is straight.

Elemental search

In your same groups, refer to the *Science News* article “Computer chip milestone reached” and other resources to answer the following questions.

According to the *Science News* article, scientists are engineering transistors made of carbon nanotubes that might one day replace silicon transistors. On an atomic level, how does carbon compare with silicon?

Why are scientists engineering new types of transistors? What problem are scientists trying to solve?

Pushing limits

Discuss the following questions as a class.

Is it important to explore alternative transistor materials, and find new ways to continue the current rate of performance improvement? Why or why not?

In addition to transistor materials, what factors might affect the rate of computing technology progress?

Why has Moore's Law been important over the last 50 years? Will Moore's Law hold true in the future? If so, for how long? You may want to think back to the graph "Transistor count on largest microprocessors 1975–2010," in the article "Moore's Law@50: 'The most important graph in human history.'"

Why is increasing computing power important?

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Activity Guide for Teachers: Digital Circuit Design

Purpose: Students will practice designing an integrated circuit that can accomplish a simple task. The activity will help students understand that digital circuits are composed of logic gates made up of transistors. Those logic gates provide output signals based on the input signals.

Procedural overview: Students will design an integrated circuit for a car that triggers a quiet alarm if the car's lights are left on or a door is left open when the key is left in the ignition.

Approximate class time: 1 class period to complete the activity questions and circuit design.

Supplies:
Digital Circuit Design student activity guide
A projector for introducing the activity (optional)

Directions for teachers:

For a general introduction to computer chips and their design, students should read the *Science News* article "Computer chip milestone reached." Review answers to any relevant comprehension questions before beginning the activity.

If a projector is available, open Image 1, "Symbols and truth tables for logic gates" so students can view it on the screen; if a projector is not available, students can find the image in their activity guide.

Explain to students that a computer chip contains many transistors. Review the information in the article that transistors have "on" and "off" states. In the on state, current is flowing through the transistor. In the off state, current is not flowing through the transistor. The on state is coded with the value "1," while the off state is coded with the value "0." This binary code (0s and 1s) makes up all computer data.
Explain that transistors are used as building blocks to build small circuits that perform logical operations. These circuits, called Boolean gates or logic gates, test yes/no type questions (such as "Is one of the lights on?" or "Are both lights on?") to determine an outcome. Each gate sends along current (if the answer is yes) or doesn't (if the answer is no) depending on the results of the test it is performing. These gates, which contain one or more transistors, are then used to build larger circuits that perform highly complex operations.

There are seven basic types of logic gates that change one or two binary value inputs (1s and 0s) into a single binary value output (also 1s and 0s). For example, an AND gate checks that both inputs are 1s (on) and if so, outputs a 1 (on). An OR gate checks that either input is a 1 (on) and if so, outputs a 1 (on). A NOT gate changes the input binary value to the opposite binary value as an output (either from a 0 to a 1, or from a 1 to a 0).

The names, symbols and tables of input and output values of the gates are shown in Image 1. Input values, labeled *A* and *B*, are on the left of the symbol, and the single output value is on the right of the symbol. There is another gate used in circuits, the buffer gate, which does not perform a logic operation. This gate does not change the input value, but is instead used to boost signal strength when needed.

Briefly review the seven kinds of logic gates and the buffer gate with your students, being sure to review the NOT, AND and OR gates in detail. For each, review the truth tables so that students understand that a gate requiring one type of input has two possible input values (0 and 1). A gate with two types of inputs, however, has four possible combinations of input values (0,0; 0,1; 1,0; and 1,1). These combinations are represented vertically in the truth tables, with the output value that results from each combination in the final row. Explain that even though there are different ways of achieving the outputs, there are only two possible output values (0 and 1). Then, to give students an example of how logic gates are used in a task, describe the example given in Image 2: “Street lights turn on computer chip.”

In this example, the OR gate’s input types are “day or night” and “raining or not.” If it is night (1) <u>or</u> it is raining (1), the output will be street light on (1); since an OR gate is used, it does not need to be both night and raining. The NOT gate’s input is “light outside.” If it is not light outside (0), the output value will be 1. Finally, the two previous output values are combined in an AND gate. If it is not light outside (1) <u>and</u> it is either night or raining (1), then the output value will be 1 and the street light will turn on. Since this final gate is an AND gate, it must be both dark out and nighttime or raining for the street light to turn on.

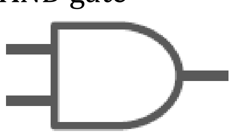
In the activity, students will use logic gates to design a simple computer program. The computer program should turn on a quiet alarm if a vehicle’s lights are on or a door is open when the key is left in the ignition. Introduce the activity and the goal for the circuit design to students.

Directions for students:

Image 1 shows basic logic gates used in computer chips and Image 2 shows how these logic gates can be connected to form a simple program. After reviewing the general information about the symbols and tables below with your teacher, answer the questions that follow. The questions will help you understand the general aspects of the gates below. When needed, use an additional resource to find background information.

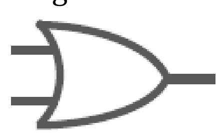
Image 1: Symbols and truth tables for logic gates

AND gate



Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	0	0	0	1

OR gate



Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	0	1	1	1

XOR gate

Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	0	1	1	0

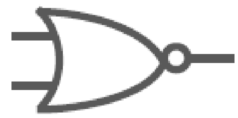
NOT gate

Input	0	1
Output	1	0

NAND gate

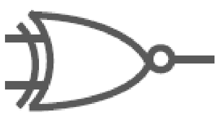
Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	1	1	1	0

NOR gate



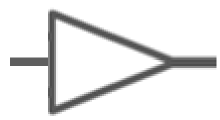
Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	1	0	0	0

XNOR gate



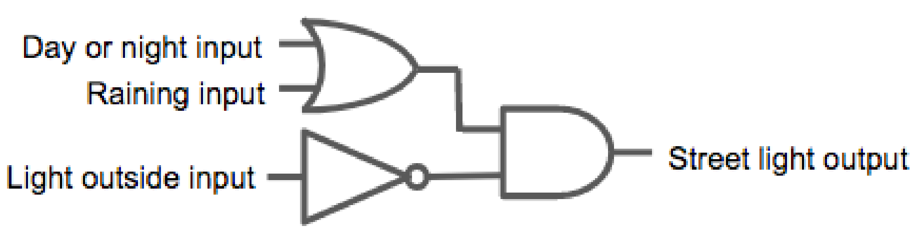
Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	1	0	0	1

Buffer gate



Input	0	1
Output	0	1

Image 2: Street lights turn on computer chip



Background questions

1. The symbols for both the AND and the NOT gates start with two lines on the left but end with one line on the right. What does this tell you about the inputs and outputs?

The two lines on the left represent the two inputs, and the one line on the right represents the one output.

2. The symbol for the NOT gate has only one line on the left and one line on the right. What does this tell you about the gate?

The NOT gate has one input and one output.

3. What kind of data are used in the gates?

The data are digital, represented as 1s and 0s.

4. How can the data used in gates be transmitted by transistors in circuits?

A 1 means current is flowing and 0 means no current is flowing.

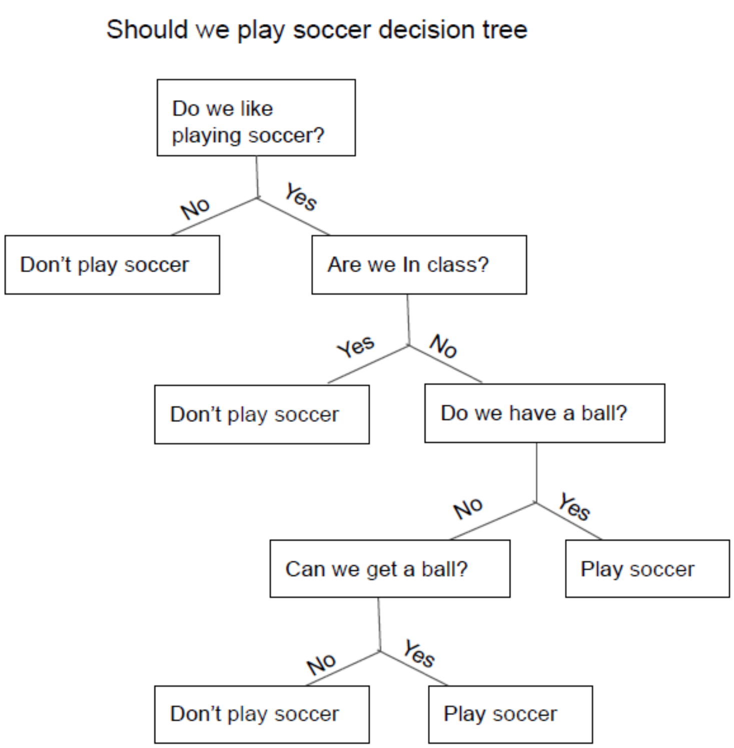
5. The table accompanying each gate in Image 1 is called a "truth table." What does a truth table tell you?

The output value based on all possible combinations of input values.

6. Which gates are a combination of two other gates? How did you determine this?

The NAND gate is a combination of the AND and NOT gates. The NOR gate is a combination of OR and NOT gates. The XNOR gate is a combination of XOR and NOT gates. The names, truth tables and symbols all provide clues. For example, NAND looks like a combination of NOT and AND. In the image, the D shape indicates AND and the small circle indicates NOT, so together they are NOT and AND. In the truth table the output value is 0 (NOT) if both input values A <u>and</u> B (AND) are 1.

7. Decision trees are a model of possible decisions and their outcomes. An example of a decision tree is below. How are circuits that use logic gates similar to decision trees? How are they different?



Both circuits that use logic gates and decision trees show a series of steps (either actions or questions with answers) to determine an outcome. Logic gates start with any possible combination of input values on the left and reduce to a single output value on the right, while decision trees start with one question at the top and expand to show all possible outcomes underneath.

Circuit design

In this activity, you will use logic gates to design a simple computer program. The computer program should start a quiet alarm if a vehicle's lights are on or a door is open when the key is left in the ignition. Table 1 shows the binary values for the different types of inputs and outputs. To begin designing the program, first think about how you would separate the program into separate steps and then think about the circuits for those steps. Note that for the alarm to be turned on, the binary output of the final gate must be 1.

Table 1: Binary values for car actions

Inputs and outputs		Binary value
Key	Left in ignition	1
	Removed from ignition	0
Running lights	On	1
	Off	0
Interior lights	On	1
	Off	0
Door	Closed	1
	Open (not closed)	0
Quiet alarm	On	1
	Off	0

8. Which data will be the inputs for the car circuit you will design?

The input of the circuit is all the actions and their values in Table 1 except for "quiet alarm on" and "quiet alarm off."

9. Which data will be the outputs of the circuit you will design?

The outputs of the circuit are the actions "quiet alarm on" and "quiet alarm off" and their binary values.

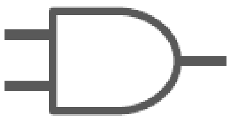
10. For a circuit that determines if the running lights were on when the key was left in the ignition, what would the inputs be? What would their binary values have to be to turn the alarm on?

The inputs would be the key and the running lights. They would both have to be 1 for the alarm to go on.

11. Complete the truth table that shows these input and output values, and draw its logic gate.

Input$_A$	Key	0	0	1	1
Input$_B$	Running lights	0	1	0	1
Output	Quiet alarm	0	0	0	1

I would use an AND gate:



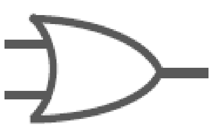
12. For a circuit that determines if either the running lights or the interior lights were on, what would the inputs be? What would their binary values be to make the alarm go on?

The inputs would be the running lights and the interior lights. Either one would have to be 1 for the alarm to go on.

13. Complete the truth table that shows these input and output values, and draw its logic gate.

Input$_A$	Interior lights	0	0	1	1
Input$_B$	Running lights	0	1	0	1
Output	Quiet alarm	0	1	1	1

I would use an OR gate:



14. For a circuit that determines if the door was open when a key was left in the ignition, what would the inputs be? What would their binary values be to make the alarm go on?

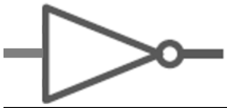
The inputs would be the key and the door. The key would have a value of 1, but the open door has a value of 0.

15. If you wanted to use an AND gate to combine these inputs to turn the alarm on (1), what other gate would you have to use first? Why?

For an AND gate to produce the output of 1, both inputs must be 1 as well. However, the open door has a value of 0. I would need to use a NOT gate to transform the open door's value of 0 into a 1. Then I would have two 1s for the inputs and I could use the AND gate.

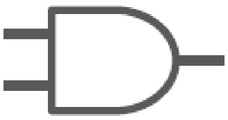
16. Create the truth tables for your two gates that show the input and output values, and draw their logic gates.

NOT gate:



Door	0	1
Output	1	0

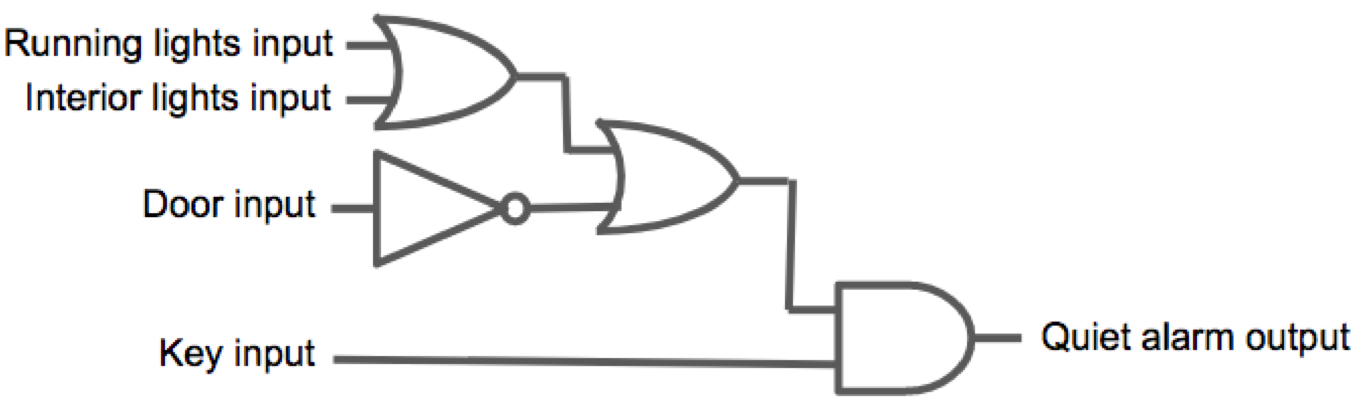
AND gate:



Key	0	0	1	1
NOT door	0	1	0	1
Quiet alarm	0	0	0	1

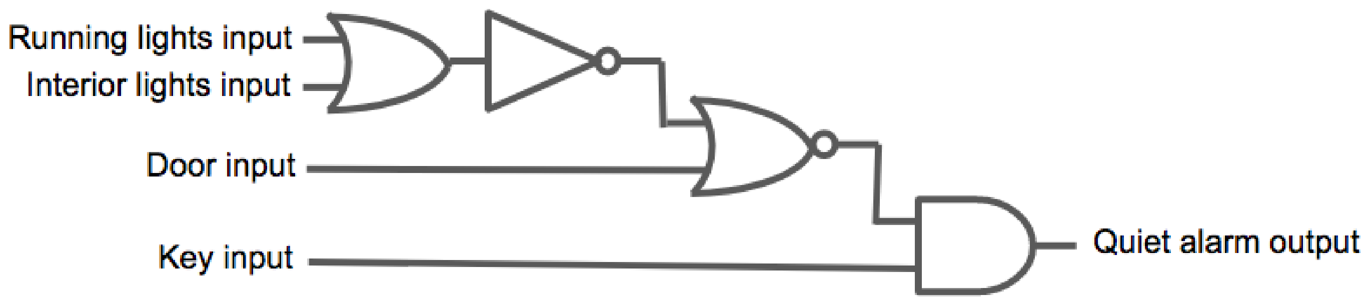
17. Now think about how to combine these functions into a single program that could be built on one computer chip. Combine the three types of circuits you just drew to create a single computer chip that will turn on the quiet alarm if the key is in the ignition while the door is open or any of the lights are on.

Student answers will vary; a sample answer is given below, but other designs are possible since there are multiple possible positions for the OR gate. Students should combine their three types of circuits.



18. Brainstorm with a partner another way to design a circuit to create the same alarm under the same circumstances. (Hint: Doing this could require rearranging the gates, using more or fewer gates or using different gates.) Draw the logic gates you would use in your new design and how they connect to each other.

Student answers will vary; a sample answer is given below, but other designs are possible. If students struggle with this task, state the problem in words to help students identify the gates they can use. Lead the students to understand that since the final output depends on having running lights, interior lights or the *door open* <u>*and*</u> *having the key in the ignition, any successful circuit they draw will require at least one OR gate and at least one AND gate to turn on the alarm.*



SN EDUCATOR GUIDE

September 28, 2019

Computer Chip Milestone Reached

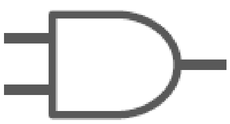
Activity Guide for Students: Digital Circuit Design

Directions:

Image 1 shows basic logic gates used in computer chips and Image 2 shows how these logic gates can be connected to form a simple program. After reviewing the general information about the symbols and tables below with your teacher, answer the questions that follow. The questions will help you understand the general aspects of the gates below. When needed, use an additional resource to find background information.

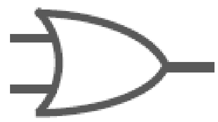
Image 1: Symbols and truth tables for logic gates

AND gate



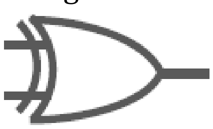
Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	0	0	0	1

OR gate



Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	0	1	1	1

XOR gate

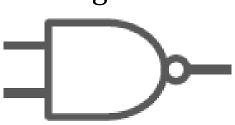


Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	0	1	1	0

NOT gate

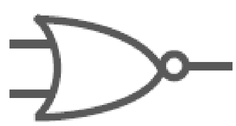
Input	0	1
Output	1	0

NAND gate



Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	1	1	1	0

NOR gate

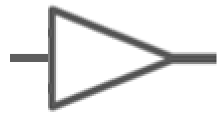


Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	1	0	0	0

XNOR gate

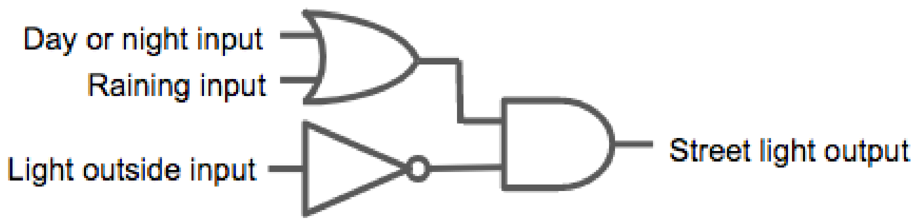
Input$_A$	0	0	1	1
Input$_B$	0	1	0	1
Output	1	0	0	1

Buffer gate



Input	0	1
Output	0	1

Image 2: Street lights turn on computer chip



Background questions

1. The symbols for both the AND and the NOT gates start with two lines on the left but end with one line on the right. What does this tell you about the inputs and outputs?

2. The symbol for the NOT gate has only one line on the left and one line on the right. What does this tell you about the gate?

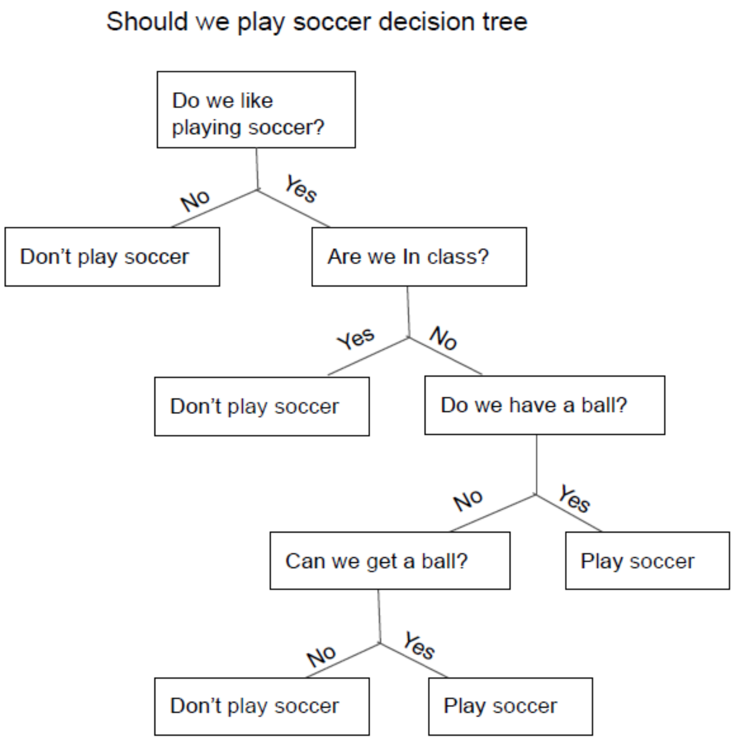
3. What kind of data are used in the gates?

4. How can the data used in gates be transmitted by transistors in circuits?

5. The table accompanying each gate in Image 1 is called a “truth table.” What does a truth table tell you?

6. Which gates are a combination of two other gates? How did you determine this?

7. Decision trees are a model of possible decisions and their outcomes. An example of a decision tree is below. How are circuits that use logic gates similar to decision trees? How are they different?



Circuit design

In this activity, you will use logic gates to design a simple computer program. The computer program should start a quiet alarm if a vehicle's lights are on or a door is open when the key is left in the ignition. Table 1 shows the binary values for the different types of inputs and outputs. To begin designing the program, first think about how you would separate the program into separate steps and then think about the circuits for those steps. Note that for the alarm to be turned on, the binary output of the final gate must be 1.

Table 1: Binary values for car actions

Inputs and outputs		Binary value
Key	Left in ignition	1
	Removed from ignition	0
Running lights	On	1
	Off	0
Interior lights	On	1
	Off	0
Door	Closed	1
	Open (not closed)	0
Quiet alarm	On	1
	Off	0

8. Which data will be the inputs for the car circuit you will design?

9. Which data will be the outputs of the circuit you will design?

10. For a circuit that determines if the running lights were on when the key was left in the ignition, what would the inputs be? What would their binary values have to be to turn the alarm on?

11. Complete the truth table that shows these input and output values, and draw its logic gate.

$Input_A$	Key	0			
$Input_B$	Running lights	0			
Output	Quiet alarm	0			

12. For a circuit that determines if either the running lights or the interior lights were on, what would the inputs be? What would their binary values be to make the alarm go on?

13. Complete the truth table that shows these input and output values, and draw its logic gate.

$Input_A$	Interior lights	0			
$Input_B$	Running lights	0			
Output	Quiet alarm	0			

14. For a circuit that determines if the door was open when a key was left in the ignition, what would the inputs be? What would their binary values be to make the alarm go on?

15. If you wanted to use an AND gate to combine these inputs to turn the alarm on (1), what other gate would you have to use first? Why?

16. Create the truth tables for your two gates that show the input and output values, and draw their logic gates.

17. Now think about how to combine these functions into a single program that could be built on one computer chip. Combine the three types of circuits you just drew to create a single computer chip that will turn on the quiet alarm if the key is in the ignition while the door is open or any of the lights are on.

18. Brainstorm with a partner another way to design a circuit to create the same alarm under the same circumstances. (Hint: Doing this could require rearranging the gates, using more or fewer gates or using different gates.) Draw the logic gates you would use in your new design and how they connect to each other.

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