STEM

Binary

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September 03, 2024

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Objectives

These activities will enable students to:

- Identify Binary Code.
- Understand the difference between Decimal and Binary number systems.
- Explain how the computer processes language and symbols.
- Practice using binary code to encode and decode written language.
- Practice using binary code to encode and decode decimal numbers.
- Explain how binary is related to memory chips.
- Optional: Practice using hexadecimal code to encode and decode written language.

Standards

This lesson aligns with the following Standards:

Next Generation Science Standards (NGSS):

- 4-PS4-3. Generate and compare multiple solutions that use patterns to transfer information.
- MS-PS4-3. Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.
- HS-PS4-2. Evaluate questions about the advantages of using digital transmission and storage of information.

Common Core State Standards (CCSS): While not explicitly mentioning binary, these standards emphasize mathematical practices and computational thinking, which are foundational for understanding binary code.

Throughout this document, black text indicates optional talking points, green text indicates actions/tasks for the instructor that support the talking points for the instructor.

Introduction

This activity guide provides information about Binary Code, Circuits and how information is stored in semiconductor memory chips. The activities should be delivered in the sequence stated, starting with binary and ending with memory chips. The Binary and Circuits activities could be delivered at separate times, with the memory chips activity following either.

History of Binary – skip this for younger learners and return to it after the activities

The current binary numbers system was created by a 17th-century philosopher and mathematician, Gottfried Wilhelm Leibniz. Born on July 1, 1646, Leibniz made great strides in the fields of philosophy and math. He developed a form of calculus around the same time as Sir Isaac Newton. He was also an inventor, coming up with variations of the mechanical calculator. He then invented a binary number system in 1689 and he used only zeros and ones.

When the first computers were developed in the early 20th century, early computer scientists used binary to represent on and off or ones and zeroes. As computers became more sophisticated, binary code became the most used language. Leibniz's development of the code set the foundation to bring forth the Digital Age almost 300 years before.

Joke – this may not make sense until AFTER the binary counting section

There are only 10_2 types of people in the world.

01_2 - Those that understand binary

10_2 - Those that don't understand binary

Binary Numbers

Humans count in Base 10, with 10 digits, 0, 1, 2, 3… 9. Computers only know 2 digits and work in Base 2.

Show the slide with the bicycle

Q: What is in this picture?

A: Bike / Bicycle – emphasize the 'BI' when saying the word

Q: Can you think of something with a name that indicates it has 3 of something?
A: Tricycle / Tripod / Trident / etc.

Optional: Continue with a discussion of other prefixes that indicate a number, such as quad or hex or other.

The prefix 'BI' means two. The Base 2 number system has only 2 digits and is called Binary.

Q: What are the two digits for the Base 2 number system?
A: 0 and 1 – Zero and One

In Binary code, Zero and One are Binary Digits. Computer scientists refer to each of them as a 'BIT'. This is an abbreviation of 'Binary Digit'.

Q: What is a BYTE?
A: 8 BITs is one BYTE.

Q: What is the name for 4 BITs?
A: 4 BITs is a NIBBLE.

We will talk more about a memory chip later. For now, consider the Binary Code of "1" or a "0" applied to each state that a switch on a memory chip happens to be in.

Q: Do you think a "1" means "on" or "off"?
A: ON

If the switch is "ON," it is represented as a "1." If the switch is "OFF," it is represented as a "0."

Consider the symbol on the on/off switch on a remote control, a phone, or other electronic device. Point out that the symbol, shown here, is a "1" superimposed on a "0", the universal symbol for "on/off". Optional: Pass around a remote control so students can see the "on/off" button symbol.

Counting

When you learned how to count the number system that you used is called the decimal system. The word decimal relates to a number system based on powers of ten. The decimal number system has ten symbols. The ten symbols are 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Each of these symbols is a digit in the Base 10 number system.

Write on the board the numbers 0-9.

Q: What happens next, after we reach 9?
A: Start over with 0 and add a 1 in front of each.

Write on the board the numbers 10-19.

Q: What happens after we reach 19?
A: Start over with 0 and add a 2 in front.

Write on the board the numbers 20-29. Continue and eventually jump ahead to 99.

Q: What happens after we reach 99?
A: Start over with 00 and add a 1 in front.

Write on the board the numbers 101-109… 999.

With just these ten symbols you can count forever. Use combinations of three digits to get all the way up to 999. Use combinations of four digits to go from 1000 to 9999. And so on…

Q: How do we count beyond 0 and 1 if we only have two digits?
A: Call on a few students to get their ideas…

Write on the board a 0, then below it a 1. Point out that these numbers and values are the same for humans and computers. Ask what comes next. Often, students call out ‘2’, and we just need to remind them that there is no ‘2’ in Binary.

Before we count in Binary, Base 2, let’s explore counting in Base 10 a bit more. In the Base 10 number system, each place value increases by a power of 10.

Thousands	*Hundreds*	*Tens*	*Units*
10^3	10^2	10^1	10^0
10x10x10	10x10	10	1
1000	100	10	1

Look at the number 5732
- 5 is in the Thousands place value = 5000
- 7 is in the Hundreds place value = 700
- 3 is in the Tens place value = 30
- 2 is in the Units (ones) place value = 2
- 5000+700+30+2 = 5732

In Base 2 number system, each place value increases by a power of 2.

Eights	*Fours*	*Twos*	*Units*
2^3	2^2	2^1	2^0
2x2x2	2x2	2x1	1
8	4	2	1

Look at the number 1011_2
- 1 is in the Eights place = 1000_2
- 0 is in the Fours place = 000_2
- 1 is in the Twos place = 10_2
- 1 is in the Units place = 1_2
- $1000_2+10_2+1_2 = 1011_2$

Translate 1011_2 from Binary to Decimal
- 1 is in the Eights place = 8
- 0 is in the Fours place = 0
- 1 is in the Twos place = 2
- 1 is in the Units place = 1
- 8+0+2+1 = 11

Hand out the Binary Counting activity paper and have the students count in Binary and translate to Decimal. Work through the activity paper, which takes us to Decimal 15. Optional: If there is time and students are interested to go beyond the 4 bit activity sheet, continue beyond 1111_2 to 8 bits. 8 bits combined is one byte.

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
128	*64*	*32*	*16*	*8*	*4*	*2*	*1*

If you wrote down all the different possible combinations of ones and zeros that could make up a byte, you would have 256 different combinations a way to do this is to start with 00000000_2 and count in binary up to 11111111_2.

Q: What is the decimal value of binary 11111111_2?
A: 128+64+32+16+8+4+2+1=255

Binary Letters & ASCII

A computer uses only "0" and "1" to do all the things a computer can do. For the computer to do this, it changes what we give it—text, numbers, sounds, colors, and pictures—into binary code and then turns the code back into text, pictures or anything else that humans understand.

Ask students if they have ever worked with secret codes.

When you type an “A” on your keyboard, the computer assigns it binary code 01000001. A “B” is 01000010. A “J” is 01001010. Every letter in the whole alphabet has its own unique binary code.

In addition to the alphabet, numbers, punctuation, colors, pictures, everything that appears on your screen is merely a series of “0”s and “1”s. That’s the Binary Code. And it’s the secret language of computers!

The code used with computers that translates letters, numbers and symbols to binary is called “ASCII” (pronounced “ask-ee”). **A**merican **S**tandard **C**ode for **I**nformation **I**nterchange. Below is the ASCII table with the binary codes for upper and lower case letters. Each character on your keyboard has its own ASCII binary code. There is a full ASCII table in the appendix.

Letter	ASCII	Binary	Letter	ASCII	Binary	Letter	ASCII	Binary	Letter	ASCII	Binary
A	065	01000001	N	078	01001110	a	097	01100001	n	110	01101110
B	066	01000010	O	079	01001111	b	098	01100010	o	111	01101111
C	067	01000011	P	080	01010000	c	099	01100011	p	112	01110000
D	068	01000100	Q	081	01010001	d	100	01100100	q	113	01110001
E	069	01000101	R	082	01010010	e	101	01100101	r	114	01110010
F	070	01000110	S	083	01010011	f	102	01100110	s	115	01110011
G	071	01000111	T	084	01010100	g	103	01100111	t	116	01110100
H	072	01001000	U	085	01010101	h	104	01101000	u	117	01110101
I	073	01001001	V	086	01010110	i	105	01101001	v	118	01110110
J	074	01001010	W	087	01010111	j	106	01101010	w	119	01110111
K	075	01001011	X	088	01011000	k	107	01101011	x	120	01111000
L	076	01001100	Y	089	01011001	l	108	01101100	y	121	01111001
M	077	01001101	Z	090	01011010	m	109	01101101	z	122	01111010

Binary Conclusion

Now you know the language of computers. Teach your family and friends the secret code.

Q: What is the language of computers called?
A: Binary Code.

Q: What are the two digits used in binary code?
A: 0 and 1.

Q: What does the “0” mean?
A: The bit is OFF.

Q: What does the “1” mean?
A: The bit is ON.

Print the activity papers to have students practice Binary. All are provided in the Appendix & available to print individually on the website.

- Activity – Counting in Binary
- Activity – Binary Beads – Initials Bracelet
- *Handout – ASCII Table – required for the next two activities*
- Activity – Write your name in ASCII
- Activity – Translate a Message

Memory Chips

Show the slide of memory chips

Q: What are these devices?
A: Answers will vary. Correct answer – Memory chip, computer chip

Q: What are some everyday things memory chips are used in?
A: Answers will vary. Write their answers on the board.

Some possible answers, and there are many more:

Airplane	Digital clock	Refrigerator
Cell phone	Drone	Remote control toy
Car	Game Boy	Smart watch
Cloud storage	Microwave oven	Stove
Coffee maker	PlayStation	TV
Computer	Printer	Xbox

Memory chips store information in all the devices mentioned, and this information is known as "data." These chips use millions of microscopic storage spaces called capacitors to hold data. Each capacitor is paired with a switch called a transistor, which functions like a light switch, turning "on" or "off." When the transistor is "on" and the capacitor holds a charge, it represents a "one." When the transistor is "off" and the capacitor does not hold a charge, it represents a "zero." This simple on/off mechanism forms the basis for all the numbers, letters, colors, and images displayed on any digital screen.

Memory chips store data in binary! A memory chip with one gigabit of storage has over one billion individual spaces for storing data bits.

Q: What is a typical amount of storage in a cell phone or gaming system?
A: Answers will vary. Typical answers are 4 or 8 Gig or GB. This is a Giga BYTE, not Giga BIT.

Raise your hand if you are familiar with the following terms: kilobyte, megabyte, gigabyte, terabyte, and others.

Q: What is a kilobyte?
A: 1,024 bytes, which is typically rounded to 1,000 bytes

Q: What is a megabyte?
A: 1,024 kilobytes, and 1,048,576 bytes (typically rounded to one million bytes)

Q: What is a gigabyte?
A: 1,024 megabytes, and1,073,741,824 bytes (rounded to one billion bytes)

1 gigabyte (GB) of memory can store any of the following:

- **Photos**: 200-500 high-quality photos (if each photo is about 2-5 MB)

- **Music**: 200-250 songs (if each song is about 4-5 MB)
- **Books**: 1,000-2,000 eBooks (if each eBook is about 0.5-1 MB)
- **Videos**: 1-2 hours of standard-definition video (if each minute of video is about 12.5 MB)

Larger memory sizes are listed below

- 1 terabyte (TB) = 1,024 gigabytes (GB)
- 1 petabyte (PB) = 1,024 terabytes (TB)
- 1 exabyte (EB) = 1,024 petabytes (PB)
- 1 zettabyte (ZB) = 1,024 exabytes (EB)
- 1 yottabyte (YB) = 1,024 zettabytes (ZB)

If you are permitted to show videos and have access to YouTube, below are links to videos from the Micron Corporate YouTube Channel:

- Data Lives (youtube.com)
- Making Memory Chips – Semiconductor manufacturing process (youtube.com)
- Memory is at the Heart of Micron (youtube.com)
- A milestone of innovation: 50,000 patents | Micron Technology (youtube.com)
- Transforming How the World Uses Information (youtube.com)

OPTIONAL Extension – Hexadecimal

Let's do a quick review.

Q: What is 8 bits called?
A: One byte

Q: What is 4 bits called?
A: One nibble

Q: How many nibbles per byte?
A: Two

A nibble, which consists of 4 bits, is represented in the base 16 number system known as hexadecimal (or simply hex). The hexadecimal number system uses the digits 0-9 and the letters A-F. This system provides a more compact way to represent binary code.

Decimal	Binary	Hex
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

Let's look at an ASCII letter:

W = 01010111 binary

That is one byte of information. That is a lot of 1's & 0's to keep track of, 8 to be exact.

The bits can be packaged as nibbles:

W = 0101 0111 binary

And Hex can be used to represent the information in a more compact form:

W = 5 7 hex

Use the 'Write Your Name in HEX' activity paper to have students practice Hexadecimal.

ACTIVITY SHEETS

The following pages can be found in the directory to print out individually

- Activity – Counting in Binary
- Activity – Binary Beads – Initials Bracelet
- *Handout – ASCII Table – required for the next two activities*
- Activity – Write your name in ASCII
- Activity – Translate a Message
- Activity – Write your name in HEX

Counting in Binary

Complete the table to translate binary numbers to decimal

2^4	2^3	2^2	2^1	2^0		
2x2x2x2	2x2x2	2x2	2x1	1	Decimal	Decimal
16	8	4	2	1	Count	Value
0	0	0	0	0	0+0+0+0	0
0	0	0	0	1	0+0+0+1	1
0	0	0	1	0	0+0+2+0	2
0	0	0	1	1	0+0+2+1	3
0	0	1	0	0	0+4+0+0	
0	0	1	0	1	0+4+0+1	
0	0	1	1	0	0+4+2+0	
0	0	1	1	1		
0	1	0	0	0		
0	1	0	0	1		
0	1	0	1	0		
0	1	0	1	1		
0	1	1	0	0		
0	1	1	0	1		
0	1	1	1	0		
0	1	1	1	1		
1	0	0	0	0		

Make a binary initials bracelet

Decoding your initials

STEP 1 – Write your initials in the spaces provided.

STEP 2 – Write the ASCII binary representations in the boxes beside each initial.

Initials		ASCII binary representation	
First name initial: ______	=	☐☐☐☐	☐☐☐☐
Middle name initial: ______	=	☐☐☐☐	☐☐☐☐
Last name initial: ______	=	☐☐☐☐	☐☐☐☐

ASCII binary decoder key

A	0100 0001
B	0100 0010
C	0100 0011
D	0100 0100
E	0100 0101
F	0100 0110
G	0100 0111
H	0100 1000
I	0100 1001
J	0100 1010
K	0100 1011
L	0100 1100
M	0100 1101
N	0100 1110
O	0100 1111
P	0101 0000
Q	0101 0001
R	0101 0010
S	0101 0011
T	0101 0100
U	0101 0101
V	0101 0110
W	0101 0111
X	0101 1000
Y	0101 1001
Z	0101 1010

Building your binary initials bracelet

Bead color key

White bead = ‘0’	Black bead = separator
Blue bead = ‘1’	Yellow bead = starter

STEP 1 – Take a black bead and tie the cord to the bead with a good knot. Leave a 2- to 3-finger space as a tail.

STEP 2 – String on a yellow bead. This is your starting point.

STEP 3 – String white and blue beads representing your first name initial, according to your worksheet.

STEP 4 – String on a black separator bead.

STEP 5 – Repeat for the middle and last name initials, separating each with a black separator bead.

ASCII Binary Table

Use this table for writing your name and decoding messages in Binary ASCII.

Symbol	ASCII	Binary	Symbol	ASCII	Binary
blank	032	01000001	[	091	01011011
!	033	01000001	/	092	01011100
"	034	01000001	]	093	01011101
#	035	01000001	^	094	01011110
$	036	01000001	_	095	01011111
%	037	01000001	'	096	01100000
&	038	01000001	a	097	01100001
(	040	01000001	b	098	01100010
)	041	01000001	c	099	01100011
*	042	01000001	d	100	01100100
,	044	01000001	e	101	01100101
-	045	01000001	f	102	01100110
.	046	01000001	g	103	01100111
A	065	01000001	h	104	01101000
B	066	01000010	i	105	01101001
C	067	01000011	j	106	01101010
D	068	01000100	k	107	01101011
E	069	01000101	l	108	01101100
F	070	01000110	m	109	01101101
G	071	01000111	n	110	01101110
H	072	01001000	o	111	01101111
I	073	01001001	p	112	01110000
J	074	01001010	q	113	01110001
K	075	01001011	r	114	01110010
L	076	01001100	s	115	01110011
M	077	01001101	t	116	01110100
N	078	01001110	u	117	01110101
O	079	01001111	v	118	01110110
P	080	01010000	w	119	01110111
Q	081	01010001	x	120	01111000
R	082	01010010	y	121	01111001
S	083	01010011	z	122	01111010
T	084	01010100			
U	085	01010101			
V	086	01010110			
W	087	01010111			
X	088	01011000			
Y	089	01011001			
Z	090	01011010			

Write Your Full Name in ASCII Binary

Using your ASCII table, write your full name (first, middle initial and last) and translate to the ASCII and Binary. Use both upper and lower case letters as appropriate. Don't forget spaces. Use one letter per row, if you run out of room continue on the back side of the paper.

Letter	ASCII decimal	Binary Conversion							
N	078	0	1	0	0	1	1	1	0

Translate a Message

Translate the ASCII codes to letters in the English language. The coded message includes spaces between words and uses other punctuation marks.

00100010	01010100	01101000	01100001	01110100
01100000	01110011	00100000	01101111	01101110
01100101	00100000	01110011	01101101	01100001
01101100	01101100	00100000	01110011	01110100
01100101	01110000	00100000	01100110	01101111
01110010	00100000	01100001	00100000	01101101
01100001	01101110	00101100	00100000	01101111
01101110	01100101	00100000	01100111	01101001
01100001	01101110	01110100	00100000	01101100
01100101	01100001	01110000	00100000	01100110
01101111	01110010	00100000	01101101	01100001
01101110	01101011	01101001	01101110	01100100
00101110	00100010	00100000	00100000	00101101
01001110	01100101	01101001	01101100	00100000
01000001	01110010	01101101	01110011	01110100
01110010	01101111	01101110	01100111	00101100
00100000	01000001	01110000	01101111	01101100
01101100	01101111	00100000	01001101	01101001
01110011	01110011	01101001	01101111	01101110

Write Your Name in Hex!

Use the ASCII table (separate handout) and the Hex table (on this page) to decipher your name in Hex!

Example: W = 01010111 binary - one byte (from ASCII table)
W = 0101 0111 binary - two nibbles
W = 5 7 hex (from Hex table)

Letter	Binary (divide into nibbles)	Hex
	____ ____	_ _
	____ ____	_ _
	____ ____	_ _
	____ ____	_ _
	____ ____	_ _
	____ ____	_ _
	____ ____	_ _
	____ ____	_ _
	____ ____	_ _
	____ ____	_ _

Binary	Hex
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	A
1011	B
1100	C
1101	D
1110	E
1111	F

My name in Hex is:

Note: spaces given are for a name with up to 10 letters, each letter represented by a two digit Hex number

__ __ __ __ __ __ __ __ __ __

Counting in Binary - Answer key

Complete the table to translate binary numbers to decimal

2^4	2^3	2^2	2^1	2^0		
2x2x2x2	2x2x2	2x2	2x1	1	Decimal	Decimal
16	8	4	2	1	Count	Value
0	0	0	0	0	0+0+0+0	0
0	0	0	0	1	0+0+0+1	1
0	0	0	1	0	0+0+2+0	2
0	0	0	1	1	0+0+2+1	3
0	0	1	0	0	0+4+0+0	4
0	0	1	0	1	0+4+0+1	5
0	0	1	1	0	0+4+2+0	6
0	0	1	1	1	0+4+2+1	7
0	1	0	0	0	8+0+0+0	8
0	1	0	0	1	8+0+0+1	9
0	1	0	1	0	8+0+2+0	10
0	1	0	1	1	8+0+2+1	11
0	1	1	0	0	8+4+0+0	12
0	1	1	0	1	8+4+0+1	13
0	1	1	1	0	8+4+2+0	14
0	1	1	1	1	8+4+2+1	15
1	0	0	0	0	16+0+0+0+0	16

Translate a Message – Answer Key

"That's one small step for man, one giant leap for mankind."
- Neil Armstrong, Apollo Mission