3 SWITCHES
DIGITAL ACTIVITY MATERIAL

Contents:

- **Passcode Cheatsheet (for teachers already familiar with Lesson Plan)**

- **Lesson Plan (for teachers)**

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- **Review Sheet (for students)**

These draft lesson plans, worksheets, worksheet solution guides, and review sheets are intended to accompany digital activities developed as part of *Thinking Outside the Box: Integrating Dynamic Mathematics to Advance Computational Thinking for Diverse Student Populations*, a National Science Foundation's STEM+C/Core R&D Programs #1543062. These draft versions correspond to those used in classroom research February - March 2017. As drafts, no warrants are made about these materials' completeness or correctness.

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1. Introduce Boolean switches A, B, C, controlling green indicators beneath buttons. Students find which switch or combination of switches illuminates large lightbulb on the right.

Challenge #1

Off

A B C

On
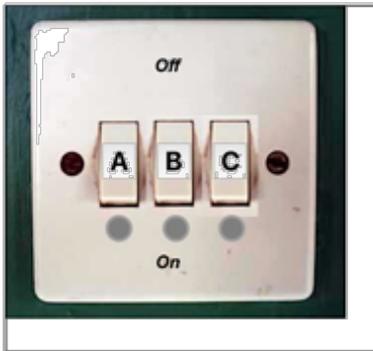
passcode: **2**

2. Same setup, different wiring. Which switches turn on bulb now? ("OR" logic)

Challenge #2

passcode: **3**

3. Another challenge, more difficult... ("AND" logic)

Challenge #3

Explore

Challenge #4

passcode: **4**

4. Final challenge! ("NOT" logic)

passcode:
values

5. Verify your answers against the table of *Boolean expressions* that *control the light* in different challenges

Validate

Name	Expression	Value	Controls Light	
A		false (off)		
B		false (off)		
C		false (off)		
	A OR C	false (off)		Answer to Challenge 2
	B AND C	false (off)		Answer to Challenge 3
	NOT A	true (on)	●	Answer to Challenge 4

(Answer to Challenge 1 is indicated beside rows A, B, C)

passcode:
new

6. Create your own rules for controlling the light, by defining (and naming) new Boolean expressions

AllThreeTurnedOn : A AND (B AND C) false (off)

New Boolean Expressions

A AND B +
A OR B +
NOT A +

Create
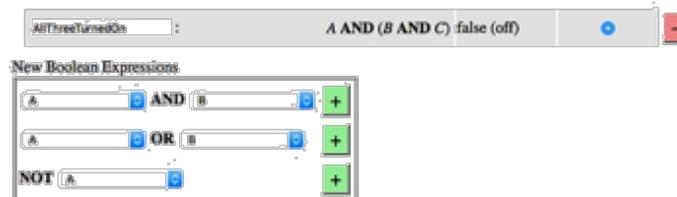
7. Done!

VELA Lesson #12
Three Switches: Boolean Operations

What comes before

Loops, variables and conditionals (Scratch) lesson

What comes after

Boolean operators and expressions (Scratch) lesson

Lesson Summary

Students will be introduced to Boolean operators (AND, OR, NOT). They will explore how these operators work and what the resulting expressions evaluate to (essentially build truth tables) using an example of 3 switches that toggle between 2 states (ON and OFF/ TRUE and FALSE). They will work in pairs to then extend the ideas to create and evaluate Boolean expressions that use these operators either as simple expressions or compound expressions that combine one or more operators.

Intended Outcomes

Students will be able to . . .

- Understand the meaning of the terms Boolean value, Boolean variable, Boolean expression
- Understand that Boolean **variables** hold Boolean values
- Define/describe how AND, OR and NOT work
- Recognize that NOT uses one operand (unary operator), whereas AND and OR require at least two operands (binary operator)
- Evaluate given expressions that use one or more Boolean operators/operations
- Understand how Boolean operations **can** appear and be combined in Boolean expressions to define or model *new* values
- Recognize real-world situations that can be described by Boolean operations resulting in Boolean expressions
- Construct simple and compound expressions involving one or more Boolean operators that express real world scenarios

New Vocabulary Used/Introduced:

Boolean value	TRUE or FALSE
Boolean variable	A variable that contains a Boolean Value
Boolean operation	Mathematical operations (or functions) that create a new Boolean value (output) from one or more other Boolean values (inputs). Also known as **Boolean operators.** AND, OR, and NOT are the most common **Boolean operations.**
Boolean expression	An expression that evaluates to a Boolean Value (TRUE or FALSE)

If you have not yet completed Review sheets for "Loops, Variables and Conditionals (Scratch)", hand them out now during attendance to start the class (5-7 mins)

Prior Learning Connections:

In the Dice activity lesson plan, students have already worked with conditional statements and evaluated numerical expressions to decide whether or not something is True or False (like "is 4 > 3?"). They have worked with the idea of a Boolean condition (e.g. If (arithmetic expression meets a condition) then (take some action))

Procedure:

Activate Prior Knowledge:

Before students open their computers, ask the class what they remember about expressions from the Cats and Ladders activity. Review expressions combining variables holding numeric values with arithmetic operators like addition and subtraction. Then, remind students about Boolean expression in the Dice activity where all expressions had a value of either True or False.

Hook:

Explain to the class that they will be learning about Boolean expressions where Boolean variables are combined using Boolean operators.

Exploration:

Phase 1 - Solving challenges:

Have students open up their laptops to view the VELA 3 switches activity. Point out the three switches labeled A, B, and C that can be turned On or Off. **The green light beneath a switch becomes visible when a switch is turned On.** Let students try it out for themselves as you demonstrate to the class by projecting your screen.

Make sure the class understands that the switches can either be ON or OFF. Since they can only have two values ON or OFF, and the question "Is switch on?" can only be "TRUE" or "FALSE", we call them **Boolean**

- On/ True/ 1
- Off/ False/ 0

A variable that has a Boolean Value is known as a Boolean variable. For example, A, B, C are all Boolean variables in this activity—they can have one of only two possible values. Similarly, think of the answer to the question "is it raining?" It likely also has only two possible values—yes and no, or True and False—and can thus be captured by a Boolean variable, which we might choose to name *isRaining*. **A Boolean variable can hold values that model questions with only two possible answers possibilities—that is, questions whose answers are *yes/no, black/white, on/off, true/false, present/absent, etc*.**

Tell students that what they are currently seeing on the screen is the first of 4 challenge scenarios where students have to figure out which switches or which combinations of switches control the light-bulb. (**Paired activity**)

Point on the screen where it now says "**Challenge #1**"

Point students to the worksheet, and ask each student pair to note which switch or combination of switches controls the light-bulb in this scenario.

Once most students say they have finished noting the answer to Challenge 1 in their worksheets, collect students' responses and write out how one or more switches control the bulb using informal language.

For Challenge 1, help students arrive at the following result: Switch A controls the bulb, but B and C do not. When A is on, the switch is on. When A is off, the switch is off.

If using the **whiteboard**, write so that responses for all 4 challenges fit on the whiteboard.

If using a computer to project and show, open up a **blank word document or a blank powerpoint slide, and type into it**, so that your class can follow as you write down collective thoughts from your class.

Next, ask students to type in "**2"** in the passcode box to advance to **Challenge 2**.

Similarly, for Challenge 2, ask student-pairs to note their answers in the worksheet. Once done, collect answers from the class and summarize on the white-board or on the powerpoint slide or word document where you summarized answers for Q1.

For Challenge 2, help students arrive at the following result: The bulb is on when either Switch A is on, or Switch C is on, or both switches A and C are on. Switch B does not control the bulb.

Next, ask students to type in "**3**" in the passcode box to advance to **Challenge 3.**

After students note their answers to Challenge 3 in the worksheet, again collect answers from the class and summarize them on whiteboard/powerpoint slide/word document.

For Challenge 3, help students arrive at the following result: The bulb is on only when switches B and C are both on.

Next, students can type in "**4**" in the passcode box and proceed to **Challenge 4**.

Similarly, collect answers for Challenge 4 from the class and summarize them on whiteboard/powerpoint slide/word document.

For Challenge 4, help students arrive at the following result: Only Switch A controls the bulb. Switches B and C do not. When Switch A is on, the bulb is off. When Switch A is off, the bulb is on.

Once students are done with all 4 challenges, tell them that we are now going to verify our answers, and learn how to represent our answers as **Boolean operations**.

Phase 2 - Representing challenge answers as Boolean operations:
Ask students to type "**values**" in the passcode box.

Point out 3 columns under Boolean values, displaying names of boolean expressions, their current values, and whether they control the light bulb or not.

First, ask students to focus on the first line where it says that **A** is the "**Answer to Challenge 1**". Ask students to click on the radio button for that row to indicate that A controls the light bulb. Demonstrate how A can have two values: **true (on)** and **false (off).**
Ask students to note how the value of A changes to True and False as the switch is turned On and Off respectively.
Here, A is a **Boolean Variable** since it can only have two values - true (on) and false (off).
Show students that **when A is true, the light bulb is On. When the value of A is false, the light bulb is off.**

Next, point out the line where it says that **A OR C** is the "**Answer to Challenge 2**". Ask students to click the radio button on this line to make A OR C the controller of the light bulb.

Help the class understand that the **light bulb is on when A OR C is true**, and **A OR C is true when either A or C is true or both A and C are true. A OR C is an example of a Boolean expression and OR is a Boolean operator.**

Teaching moment: In real life, if we say that we will be going to the zoo this Saturday or Sunday, it means that we will be going on either Saturday or on Sunday, but not on both days. But, the **Boolean operator OR is true when at least one of its operands is true**. This means it is also true when both operands are true.

Direct students to the worksheet and ask them to fill out **Q5** in pairs. For Q5, fill out the first one or two rows as a class to demonstrate how to fill out a truth table.

Next, ask students to write down how an OR operator works in **Q6 of their worksheet.**

Thereafter, direct students' attention to the line which says that **B AND C** is the "**Answer to Challenge 3**". Here, the expression (B AND C) needs to be set to control the light bulb.

Help the class understand that (B AND C) is True only when both B and C are True. **B AND C is an example of a Boolean expression and AND is a Boolean operator.**

Like before, direct students to fill out the truth table in **Q7 of their worksheets**.

Next, ask students to write down how the AND operator works in **Q8 from the worksheet**.

Finally, ask students to focus on the line which says that **NOT (A)** is the "**Answer to Challenge 4**". Here, (NOT A) needs to be set to control the light bulb.

The light bulb is on when NOT (A) is true. NOT (A) is true when A is false or off.

Like before, direct students to fill out **Q9 and Q10 from their worksheets**.

Explain that AND, OR, and NOT are the most common **Boolean operators. Boolean operations using these operators** create new Boolean values from one or more other Boolean values/variables. Expressions combining boolean variables and boolean operators always result in one of 2 values - [True or On or 1], and [False or Off or 0]. Such expressions are known as **Boolean expressions**.

End this section by discussing <u>connections between boolean expressions and real-world scenarios</u>. Use the board or projector for this discussion.
For each scenario, ask students **what the controlled outcome is, what the controlling variables are, and what the boolean operators used are.**

1. Travis' parents say that he can go out and play with his friends if he has done both - finished his homework and made his bed in the morning

2. We will go on a hike if it is not raining.

3. Keisha can watch a movie if she finishes either her math homework or her computer science project.

4. A car gives a warning beep if
    - Driver's seat-belt is not locked
    - Passenger's seat-belt is not locked
    - Car is being driven
Here, the "outcome" (similar to the lightbulb in the computer activity) is "Car will give a warning beep"
Here, our variables that control the outcome are 'Driver's seat-belt is not locked', 'Passenger's seat-belt is not locked', & 'Car is being driven'
The outcome **"Car will give a warning beep" is TRUE** when **(Driver's seat-belt is not locked OR Passenger's seat-belt is not locked) AND (Car is being driven)**
So.. if **(A OR B) AND C = True** then **"Car will give a warning beep"**

Use this example to transition students to creating new Boolean expressions. Remind students how they have solved compound arithmetic expressions. Similarly, we can also have compound Boolean expressions.

Phase 3 - Creating new expressions that result in new boolean values:
Enter "new" in the passcode box. You will see a button called "Add new value". Clicking on the button will open up a box with AND, OR and NOT boolean operators. Show your students how to use the interface and let them explore on their own for a bit.
Then, ask students if any of them have built compound expressions involving 3 or more Boolean variables. Demonstrate to the class how that can be done by taking an expression like **A AND B AND C**, or **(A OR B) AND C** (car beeping example from Phase 2)
Let us try to create **(A OR B) AND C**.
    - Click the + button next to A OR B. Now, you will see an expression called A OR B in the table of Boolean values. You can give it a name if you want, like X
    - Now click the "Add new value" button again
    - Now, construct an expression using AND by choosing the first operand as A OR B (or whatever name you gave A OR B) and the second operand as C.

Encourage students to explore further on their own by creating other expressions.

Then, ask student pairs to fill out **Q11 from their worksheets.**

_____

Formal (and Important) Terms

These all have precise meanings and also meanings we think students and teachers immediately benefit from knowing in this activity.

- **Boolean value:** TRUE or FALSE.
- **Boolean variable:** A variable that contains a Boolean Value
- **Boolean expression:** An expression that evaluates to a Boolean Value.
- **Boolean operation:** Mathematical operations (or functions) that create a new Boolean value (output) from one or more other Boolean values (inputs). Also known as **Boolean operators.** AND, OR, and NOT are the most common **Boolean operations.**
- **Boolean operand:** The role of a Boolean value or variable when used as an input to a Boolean operation.

Example: If *A* and *B* are both <u>Boolean variables,</u> then *A* OR *B* is a <u>Boolean expression</u> featuring one <u>Boolean operation</u>, OR. *A* and *B* are the <u>Boolean operands</u> to the *OR* operator in that expression. The <u>Boolean value</u> of the expression *A* OR *B*—that is, *true* or *false*—depends on the value of the two variables, *A* and *B*.

Formal (but Less Important) Terms

- **Logical operations and operators: AND, OR, and NOT.** The same as a Boolean operator. As opposed to RELATIONAL OPERATORS (<, >, =).
- **Relational operations and operators:** Mathematical operations (or functions) that create a new Boolean value (output) from one or more values (input) that *do not have to be Boolean.* **=** and ≠ are the most common relational operators, but there are many others (**>**, **<**, is-a-member-of, etc.)

Informal Terms

These terms **Boolean arithmetic** and **Boolean logic** are frequently used to refer to Boolean expressions and operators, or statements and reasoning based on such expressions. Similarly, **Boolean flag** and **Boolean condition** are sometimes used as synonyms for Boolean variables or Boolean expressions.

Names: _____ and

_____

3 Switches Worksheet

Q1. Challenge #1
Which switch or switches control the lightbulb and how?

_____

_____

_____

Q2. Challenge #2
Which switch or switches control the lightbulb and how?

_____

_____

_____

Q3. Challenge #3
Which switch or switches control the lightbulb and how?

_____

_____

_____

Q4. Challenge #4
Which switch or switches control the lightbulb and how?

_____

_____

_____

Q5. Fill in the values of the Boolean expression A OR C based on the given values of the Boolean variables A and C.

A	C	A OR C
False	False	
True	False	
False	True	
True	True	

Q6. Describe in words how OR works_____

_____

_____

Q7. Fill in the values of the Boolean expression B AND C based on the given values of the Boolean variables B and C.

B	C	B AND C
False	False	
True	False	
False	True	
True	True	

Q8. Describe in words how the AND operator works

_____

_____

_____

Q9. Fill in the values of the Boolean expression NOT (A) based on the given values of the Boolean variable A.

A	NOT A
True	
False	

Q10. Describe in words how you think the **NOT** operator works

_____

_____

Q11. Tom's parents lay down the following rules for him:
Rule 1: If homework is done, and chores are complete, Tom can play video games
Rule 2: If there is an exam the next day, Tom does not get to play video games even if he does his homework and chores

Use Boolean operations (NOT, AND, OR) to describe when Tom can play video games and when he cannot.

    a. What is the "outcome" variable (like the lighting up of the light bulb) in this scenario?

_____

    b. What are the boolean variables that control that outcome variable?

_____

_____

_____

    c. Write a boolean expression to represent Rule 1: If homework is done, and chores are complete, Tom can play video games

Tom **can** play video games:

_____

_____

d. Write a boolean expression to represent Rule 2: If there is an exam the next day, Tom does not get to play video games

Tom **can** play video games:

_____

_____

e. Write a combined boolean expression to represent when Tom can play video games.

Tom **can** play video games =

_____

_____

Names: _____ and

_____

3 Switches Worksheet Solutions

Q1. Challenge #1
Which switch or switches control the lightbulb and how?
 Switch A controls the bulb, but B and C do not. When A is on, the switch is on. When A is off, the switch is off.

Q2. Challenge #2
Which switch or switches control the lightbulb and how?
The bulb is on when either Switch A is on, or Switch C is on, or both switches A and C are on. Switch B does not control the bulb.

Q3. Challenge #3
Which switch or switches control the lightbulb and how?
The bulb is on only when switches B and C are both on.

Q4. Challenge #4
Which switch or switches control the lightbulb and how?
Only Switch A controls the bulb. Switches B and C do not. When Switch A is on, the bulb is off. When Switch A is off, the bulb is on.

Q5. Fill in the values of the Boolean expression A OR C based on the given values of the Boolean variables A and C.

A	C	A OR C
False	False	False
True	False	True
False	True	True
True	True	True

Q6. Describe in words how OR works

Q7. Fill in the values of the Boolean expression B AND C based on the given values of the Boolean variables B and C.

B	C	B AND C
False	False	False
True	False	False
False	True	False
True	True	True

Q8. Describe in words how the AND operator works

The AND operator evaluates to True when both its operands are True. A AND B is True when both A and B are True.

Q9. Fill in the values of the Boolean expression NOT (A) based on the given values of the Boolean variable A.

A	NOT A
True	False
False	True

Q10. Describe in words how you think the **NOT** operator works

The NOT operator works on only one operand and returns the opposite value of the operand. NOT(A) is True when A is False.

Q11. Tom's parents lay down the following rules for him:
Rule 1: If homework is done, and chores are complete, Tom can play video games

Rule 2: If there is an exam the next day, Tom does not get to play video games even if he does his homework and chores

Use Boolean operations (NOT, AND, OR) to describe when Tom can play video games and when he cannot.
   a. What is the "outcome" variable (like the lighting up of the light bulb) in this scenario?

Play video games

   b. What are the boolean variables that control that outcome variable?

isHomeworkDone?
areChoresComplete?
examTomorrow?

   c. Write a boolean expression to represent Rule 1: If homework is done, and chores are complete, Tom can play video games
Tom **can** play video games:

isHomeworkDone? AND areChoresComplete?

d. Write a boolean expression to represent Rule 2: If there is an exam the next day, Tom does not get to play video games
Tom **can** play video games:

NOT (examTomorrow?)

e. Write a combined boolean expression to represent when Tom can play video games.

Tom **can** play video games:

isHomeworkDone? AND areChoresComplete? AND (NOT (examTomorrow?))

Name: _____

Review questions - 3 switches activity

1. Perform the following Boolean operations given the values of the Boolean variables X, Y.

X	Y	X OR Y	X AND Y	NOT (X)
True	True			
True	False			
False	True			
False	False			

2. Kate needs to hire a babysitter every Friday throughout the year. For the month of March, she **also** needs a babysitter every Monday. Which Boolean expression indicates the times when Kate needs to hire a babysitter.

    a. Hire a babysitter IF (isFriday?) AND (isMarch? AND isMonday?)

    b. Hire a babysitter IF (isFriday?) AND (isMarch? OR isMonday?)

    c. Hire a babysitter IF (isFriday?) OR (isMarch? AND isMonday?)

    d. Hire a babysitter IF (isFriday?) OR (isMarch? OR isMonday?)