Binary, pixels, logic gates, and packet switching (5 lessons)

Computing, grade 6 - by Gemini 4 Argon - status: written (unreviewed)

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Binary, Pixels, Logic Gates, and Packet Switching

Subject: Computing Grade: 6 Lessons: 5 Time per lesson: 50 minutes Status: written Author: Gemini 4 Argon

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Big idea

Computers store every number, letter, and image using physical two-state switches (`0` and `1`), combine those switches with simple rules (`AND`, `OR`, `NOT`) to make decisions, and send data across networks by splitting messages into numbered packets that can be checked for errors.

What students should be able to do

- Convert whole numbers between `0` and `255` to and from 8-bit binary using repeated-doubling place-value cards (`128, 64, 32, 16, 8, 4, 2, 1`), and explain why adding one more card doubles the total number of patterns.
- Encode and decode short words using a 7-bit/8-bit ASCII lookup table and encode/decode a `8 × 8` bitmap icon, calculating the unit rate in **bits per pixel** and the image's **width-to-height ratio**.
- Complete truth tables for `NOT`, `AND`, and `OR` gates and trace the output of a 2-gate combination circuit for all four possible input pairs.
- Simulate routing a multi-packet message across a 6-node network with a broken link, reassemble out-of-order packets using sequence headers, calculate delivery unit rates (**packets per second** and **bits per second**), and detect a single flipped bit using an **even parity bit**.

What students should already know

- Whole-number addition and subtraction up to `300`, and multiplication/division by `2`.
- Base-10 place value (`ones, tens, hundreds`).
- **No exponent notation (`2^n`) is required.** Lesson 1 builds binary place values directly through repeated doubling (`1, 2, 4, 8, 16, 32, 64, 128`).
- Basic ratio and unit-rate language (such as `3 : 2` or `bits per pixel`), reinforced alongside Grade 6 Mathematics (`units/mathematics/6-ratios/`).

Lesson list

1. Lesson 1: Counting with Switches — Repeated Doubling and 8-Bit Binary: Build a set of 8 doubling dot-cards (`1` through `128`) to represent any number from `0` to `255` using only `ON (1)` and `OFF (0)`.
2. Lesson 2: Letters and Pictures in Bits — ASCII Text and Bitmap Pixels: Decode secret binary text messages and design `8 × 8` 1-bit and 2-bit pixel art while comparing storage unit rates (`bits per character` and `bits per pixel`).

3. Lesson 3: Making Decisions with Switches — NOT, AND, and OR Logic Gates: Model series and parallel switches with human circuit paths and truth tables to design a 3-sensor greenhouse/terrarium alarm rule.
4. Lesson 4: Postcards on the Wire — Packet Switching, Routing, and Throughput Rates: Break a message into numbered 64-bit packets, route around a failed node on a classroom network map, and compute network unit rates (`packets per second` and `bits per second`).
5. Lesson 5: Catching Flipped Bits — Noise, Even Parity Checks, and End-of-Unit Assessment: Add a 9th parity bit to catch single-bit transmission errors, test where 1-bit parity fails, and complete the 5-part unit assessment.

Materials (whole unit)

- **Index cards or half-sheets of paper** (8 cards per student pair for Lesson 1 binary dot-cards; 6 cards per group for Lesson 4 packet postcards).
- **Grid paper (`8 × 8` squares)** or printed `8 × 8` blank grids for Lesson 2 bitmap pixel design.
- **Pencils, markers, and large two-sided paper cards or tokens** (or written/pointed `0`/`1` table charts as an alternative to handling small objects) for flipping bits in Lesson 5.
- **No computers, batteries, or internet connection required** (100% unplugged classroom-ready; optional browser verification extensions noted in Teacher Notes).

Assessment

Each lesson includes 8 worked/practice tasks with complete step-by-step answers (40 lesson tasks total). Lesson 5 concludes with a **20-point End-of-Unit Synthesis Assessment** (5 multi-part problems covering binary conversion, pixel bit-rate ratios, a 2-gate truth table, packet routing/throughput, and even-parity error detection) with a full scoring rubric and worked answer key.

Sources

- Bell, T., Witten, I. H., & Fellows, M. (2015). CS Unplugged: An enrichment and extension programme for primary-aged students (openly licensed CC BY-NC-SA reference for dot-card and parity unplugged pedagogy; all text, numbers, diagrams, and problems in this unit are newly written from scratch under CC0): https://www.csunplugged.org/
- American National Standards Institute (1968/1986). ANSI X3.4 — Coded Character Sets — 7-Bit American National Standard Code for Information Interchange (7-Bit ASCII) (public-domain numerical mapping of standard printable characters `32–126`): https://www.rfc-editor.org/rfc/rfc20
- Postel, J. (Ed.) (1981). RFC 791 — Internet Protocol: DARPA Internet Program Protocol Specification (public-domain specification of packet headers, addressing, and datagram routing): https://www.rfc-editor.org/rfc/rfc791

Known gaps and cautions

- **Unreviewed AI draft:** This unit has not yet been reviewed by a human classroom teacher or tested with Grade 6 students.
- **Simplifications stated explicitly for students:**
- Lesson 2 uses standard 7-bit/8-bit ASCII for English letters (`A–Z`, `a–z`) and notes explicitly that modern software uses **UTF-8 / Unicode** so scripts and emoji from all languages can be represented.

- Lesson 4 models packet headers with three fields (`From`, `To`, `Packet # of Total`) rather than a full 20-byte IPv4 / TCP header.
- Lesson 5 introduces **single-bit even parity** and explicitly shows students why two simultaneous bit flips inside the same byte go undetected, motivating stronger checksums (like CRC and cryptographic hashes) in later grades.

Lesson 1: Counting with Switches — Repeated Doubling and 8-Bit Binary

Time: 50 minutes

Unit: Binary, Pixels, Logic Gates, and Packet Switching | **Next:** Lesson 2: Letters and Pictures in Bits

Goal

Convert whole numbers between `0` and `255` to and from 8-bit binary using repeated-doubling place-value cards (`128, 64, 32, 16, 8, 4, 2, 1`), and explain why adding one more card doubles the number of possible patterns.

Materials

- 8 index cards (or half-sheets of paper) per pair of students.
- Thick dark marker for drawing dots/numbers on one side of each card.
- Chalkboard or whiteboard for class place-value comparison.

Steps

✎ 1. Opening (5 min): Why Only Two States?

Hold up a classroom light switch (or draw a simple switch on the board). Ask: - "In everyday base-10 arithmetic, each digit slot can hold 10 different symbols (*`0`* through *`9`*). Why doesn't a computer wire use 10 different voltage levels (*`0V, 1V, 2V, ..., 9V`*) for each digit?" - Guide students to notice that electrical wires experience tiny fluctuations (heat, static, long cables). Distinguishing `10` close voltage levels is fragile, whereas distinguishing **two clearly separated states** — `OFF (0)` vs. `ON (1)` (or dark vs. bright, unmagnetized vs. magnetized) — is fast and reliable.

✎ 2. Main Activity Part A (15 min): Building the 8 Doubling Cards

Have each student pair make a row of 5 cards first, arranged **right to left** just like base-10 place value: 1. On the rightmost card, write **`1`** and draw `1` dot. 2. Move one slot left: **double** the previous card to write **`2`** (`2` dots). 3. Move one slot left: **double** `2` to write **`4`** (`4` dots). 4. Move one slot left: **double** `4` to write **`8`** (`8` dots). 5. Move one slot left: **double** `8` to write **`16`** (`16` dots).

Now extend the row to a full **byte (8 bits)** by doubling three more times to the left: **`32`**, **`64`**, and **`128`**:

Bit slot (left to right)	Card 8	Card 7	Card 6	Card 5	Card 4	Card 3	Card 2	Card 1
Place value (doubling right to left)	128	64	32	16	8	4	2	1

Explain the rule: - Face-up (`ON`) = **`1`** (add this card's value to your total). - Face-down (`OFF`) = **`0`** (do not add this card's value).

✎ Worked Example 1: Binary to Base-10 (`00101101`)

Suppose the 8 cards read `0 0 1 0 1 1 0 1`:

Card value	128	64	32	16	8	4	2	1
Bit (1 = ON, 0 = OFF)	0	0	1	0	1	1	0	1

Add only the cards switched `ON (1)`: `32 + 8 + 4 + 1 = 45`.

✎ Worked Example 2: Base-10 to 8-Bit Binary (`100`)

To build a target number like **`100`**, always work **from left (`128`) to right (`1`)** using the greedy subtraction check: 1. Does `128` fit into `100`? No (`128 > 100`) → write **`0`**, remainder is still `100`. 2. Does `64` fit into `100`? Yes (`64 <= 100`) → write **`1`**, subtract `100 - 64 = 36` remaining. 3. Does `32` fit into `36`? Yes (`32 <= 36`) → write **`1`**, subtract `36 - 32 = 4` remaining. 4. Does `16` fit into `4`? No → write **`0`**. 5. Does `8` fit into `4`? No → write **`0`**. 6. Does `4` fit into `4`? Yes (`4 <= 4`) → write **`1`**, subtract `4 - 4 = 0` remaining. 7. Does `2` fit into `0`? No → write **`0`**. 8. Does `1` fit into `0`? No → write **`0`**. Result: **`01100100`** (`64 + 32 + 4 = 100`).

✓ 3. Discussion Questions (10 min)

- **Question A:** "Look at the sum of all cards to the right of *`16`*: *`8 + 4 + 2 + 1 = 15`*. Look at all cards to the right of *`64`*: *`32 + 16 + 8 + 4 + 2 + 1 = 63`*. What pattern do you notice?"
- Example good answer: Every card is always **`1`** **more** than the sum of all smaller cards to its right! That means if your remaining target is `64` or more, you must turn on the `64` card because all smaller cards combined only reach `63`. This guarantees every whole number from `0` to `255` has **one and only one** 8-bit binary pattern.
- **Question B:** "How can you tell in one second whether an 8-bit binary number is odd or even?"
- Example good answer: Look only at the rightmost card (`1`). Every other card (`128`, `64`, `32`, `16`, `8`, `4`, `2`) is an even number, so the sum is odd if and only if the `1` bit is `1`.

✓ 4. Student Practice & Closing Check (20 min)

✎ Practice Tasks (1.1 – 1.8)

1. **Task 1.1:** Convert the 8-bit binary number `00010110` to a base-10 number.
2. **Task 1.2:** Convert the 8-bit binary number `10000101` to a base-10 number.
3. **Task 1.3:** Convert the 8-bit binary number `11111111` (all 8 cards turned ON) to a base-10 number.
4. **Task 1.4:** Write the base-10 number **`19`** in 8-bit binary.
5. **Task 1.5:** Write the base-10 number **`75`** in 8-bit binary.

6. **Task 1.6:** Write the base-10 number **200** in 8-bit binary.
7. **Task 1.7 (Pattern Reasoning):** Without converting both numbers to base-10 first, what happens to the value of `00001101` (`13`) when you shift every bit one slot to the left and put a `0` on the right (`00011010`)? Explain why.
8. **Task 1.8 (Capacity & Doubling):** A 4-bit system can represent `16` different numbers (`0` through `15`). How many different numbers can a 5-bit system represent, and what is the largest number it can hold?

Complete Answer Key (Tasks 1.1 – 1.8)

- **Answer 1.1:** `16 + 4 + 2 = 22`.
- **Answer 1.2:** `128 + 4 + 1 = 133`.
- **Answer 1.3:** `128 + 64 + 32 + 16 + 8 + 4 + 2 + 1 = 255` (which is `1` less than the next doubling value, `256`).
- **Answer 1.4:** `19 = 16 + 2 + 1` → **`00010011`**.
- **Answer 1.5:** `75 = 64 + 8 + 2 + 1` → **`01001011`**.
- **Answer 1.6:** `200 = 128 + 64 + 8` → **`11001000`**.
- **Answer 1.7:** Shifting left by one slot **doubles** the number from `13` (`8 + 4 + 1`) to `26` (`16 + 8 + 2`), because every ON bit moves to a card worth twice as much (just as appending a `0` in base-10 multiplies by `10`).
- **Answer 1.8:** Adding a 5th bit (the `16` card) **doubles** the number of patterns from `16` to **`32` different numbers** (`16` patterns with the `16`-card OFF, plus `16` patterns with the `16`-card ON). Because `0` uses one pattern, the range is `0` through **`31`** (`16 + 8 + 4 + 2 + 1 = 31`).

Vocabulary

- **bit (binary digit):** A single two-state switch or symbol that can be either `0` (`OFF`) or `1` (`ON`).
- **byte:** A group of `8` bits treated as a single unit, capable of representing `256` distinct patterns (`0` through `255`).
- **place value:** The numerical value assigned to a digit slot based on its position (`1, 2, 4, 8, 16, 32, 64, 128` from right to left in binary).

Differentiation

- **Extra support:** Start with only the 4 rightmost cards (`8, 4, 2, 1`) with pre-drawn dots (or large paper tokens, pointing, or verbal counting rather than small loose objects) so students can count the dots on each card directly before flipping cards face-up or face-down to build `1` through `15`.
- **Extra challenge:** Ask students how a computer could represent **negative numbers** or **fractions** using 8 bits, or challenge them to add two 8-bit binary numbers (`00010110 + 00001011`) column by column using the carry rule `1 + 1 = 2` (write `0`, carry `1` to the next doubled slot).

⚠ Safety

No physical hazards in this unplugged lesson.

Teacher notes

- **Common misconception 1 (Reading left-to-right vs. right-to-left):** Some students place `1` on the far left and `128` on the far right. Remind them that binary uses the exact same convention as base-10: the **smallest place value (`1`) is always on the far right**, and values grow larger as you move left.
- **Common misconception 2 (Forgetting that `00000000` counts as a pattern):** Students often ask why 8 bits (`256` patterns) maxes out at `255` instead of `256`. Point out that in base-10, two digits give `100` patterns (`00` through `99`), not `100`!

Lesson 2: Letters and Pictures in Bits — ASCII Text and Bitmap Pixels

Time: 50 minutes

Unit: Binary, Pixels, Logic Gates, and Packet Switching | **Previous:** Lesson 1 | **Next:** Lesson 3

Goal

Encode and decode text using an 8-bit ASCII lookup table, represent `8 × 8` images as 1-bit and 2-bit bitmaps, and calculate storage unit rates in **bits per character** and **bits per pixel**.

Materials

- Lesson 1 binary place-value cards (`128, 64, 32, 16, 8, 4, 2, 1`).
- Printed or board-drawn `8 × 8` blank pixel grids (2 grids per student).
- Colored pencils or shading styles (blank, light crosshatch, dark diagonal, solid black) for 2-bit palettes.

Steps

✎ 1. Opening (5 min): If Computers Only Store `0` and `1`, Where Are the Letters?

Write the byte `01001000` on the board. Ask: - "In Lesson 1, we decoded *`01001000`* as the number *`64 + 8 = 72`*. How can a text-messaging app use that exact same byte to display a capital letter instead of the number *`72`*?" - Introduce the idea of a **shared codebook (standard encoding)**: if every keyboard and screen agrees on which number stands for which letter, then storing numbers is enough to store words.

✎ 2. Main Activity Part A (15 min): Decoding and Encoding ASCII Text

Show the class how uppercase English letters are mapped in standard **ASCII** (American Standard Code for Information Interchange):

Character	Base-10 Code	8-Bit Binary	Character	Base-10 Code	8-Bit Binary
(space)	32	00100000	A	65	01000001
!	33	00100001	B	66	01000010
0 (digit)	48	00110000	C	67	01000011
1 (digit)	49	00110001	...	...	...
?	63	00111111	Z	90	01011010

Point out two helpful patterns: 1. Capital **`A` is `65` (`01000001`)**, so the `n`-th letter of the alphabet has code **`64 + n`**! Since `64` is the `01000000` bit, the last 5 bits directly tell you the letter's

position (1 to 26) in the alphabet. 2. Lowercase **a is 97 (01100001)**, which is 65 + 32 — toggling just the 32-bit switches any letter between uppercase and lowercase!

✎ Worked Example 1: Decoding a 3-Byte Word

Decode 01000011 01000001 01010100: - Byte 1 (01000011): 64 + 2 + 1 = 67 (3rd letter) → **C** - Byte 2 (01000001): 64 + 1 = 65 (1st letter) → **A** - Byte 3 (01010100): 64 + 16 + 4 = 84 (20th letter) → **T** Word: **CAT** (3 characters × 8 bits per character = 24 bits).

✎ 3. Main Activity Part B (15 min): Bitmap Grids and Bits-per-Pixel Ratios

Now ask: "How do we turn a grid of tiny squares (**pixels**) into *0*s and *1*s?" - **1-Bit Monochrome (1 bit per pixel):** Each square uses 1 bit: 0 = white (unshaded), 1 = black (shaded). - Example 8 × 8 icon (64 pixels total at 1 bit per pixel = 64 bits = 8 bytes of **raw uncompressed pixel data**, excluding any file headers or metadata): - Row 1: 00111100 - Row 2: 01000010 - Row 3: 10100101 - Row 4: 10000001 - Row 5: 10100101 - Row 6: 10011001 - Row 7: 01000010 - Row 8: 00111100 (Students shade the *1*s on their *8 × 8* grid to reveal a smiling face!) - **2-Bit Four-Color Palette (2 bits per pixel):** What if we want **4 colors** (like an early handheld game console: 00 = White, 01 = Light Gray, 10 = Dark Gray, 11 = Black)? - Each pixel now requires **2 bits**, so the unit rate doubles from 1 bit per pixel to **2 bits per pixel**. - For the same 8 × 8 (64-pixel) grid, raw pixel storage doubles from 64 bits (8 bytes) to **128 bits (16 bytes)** (excluding any metadata or compression).

4. Discussion & Student Practice (15 min)

✎ Practice Tasks (2.1 – 2.8)

1. **Task 2.1:** Using A = 65, find the base-10 ASCII code and 8-bit binary byte for uppercase **E** (the 5th letter) and **M** (the 13th letter).
2. **Task 2.2:** Decode the 4-byte ASCII message: 01000100 01000001 01010100 01000001.
3. **Task 2.3:** Look at the ASCII table: the character '1' has code 49 (00110001), while the number 1 in Lesson 1 was 00000001. Why does a computer distinguish between the text character '1' and the number 1?
4. **Task 2.4 (Unit Rate — Text):** A text file contains 150 characters (including spaces) encoded at a unit rate of 8 bits per character. How many total **bits** and how many **bytes** does the text file require?
5. **Task 2.5 (Bitmap Decoding):** Draw a 4 × 4 grid and shade the 1s for these four 4-bit rows: Row 1 = 0110, Row 2 = 1111, Row 3 = 0110, Row 4 = 0110. What symbol appears?
6. **Task 2.6 (Color Depth Ratio):** An 8 × 8 sprite uses a 16-color palette where each pixel uses 4 bits (0000 through 1111). What is the unit rate in **bits per pixel**, and how many **raw pixel bits** (and **bytes**, excluding headers/compression) are needed for all 64 pixels?
7. **Task 2.7 (Aspect Ratio):** A game banner measures 120 pixels wide by 80 pixels tall. Write the width-to-height ratio 120 : 80 in simplest whole-number form. If you scale the banner to 300 pixels wide while keeping the exact same aspect ratio, how many pixels tall must it be?

8. **Task 2.8 (Metadata Reasoning):** Suppose you receive a raw stream of `64` bits (`0`s and `1`s) for a 1-bit black-and-white picture, but nobody tells you whether the grid is `8 × 8`, `16 × 4`, or `32 × 2`. Why does the receiver need to know the **width and height** (whether stored in a file header, sent by a communication protocol, or fixed by a prior external agreement) to display the pixel bits correctly?

Complete Answer Key (Tasks 2.1 – 2.8)

- **Answer 2.1:** `E` is the 5th letter: `64 + 5 = 69` → **`01000101`**. `M` is the 13th letter: `64 + 13 = 77` (`64 + 8 + 4 + 1`) → **`01001101`**.
- **Answer 2.2:** `01000100` = `64 + 4 = 68` (`D`); `01000001` = `65` (`A`); `01010100` = `64 + 16 + 4 = 84` (`T`); `01000001` = `65` (`A`). Word: **`DATA`**.
- **Answer 2.3:** When `'1'` appears inside a sentence or street address (like `"12 Oak St"`), the screen needs to look up the font glyph for the symbol `'1'` alongside letters and punctuation; when storing a quantity for arithmetic, storing pure binary (`00000001`) lets the processor add and subtract directly.
- **Answer 2.4:** `150 characters × 8 bits/character = 1,200 bits`, which is **`150 bytes`** (`1 byte per character`).
- **Answer 2.5:** Shading the middle two columns on rows 1, 3, and 4 and all four columns on row 2 forms a **cross / plus (+) or sword/tree icon**.
- **Answer 2.6:** Unit rate = **`4 bits per pixel`**. Total storage = `64 pixels × 4 bits/pixel = 256 bits`, which is `256 ÷ 8 =` **`32 bytes`**.
- **Answer 2.7:** Dividing both `120` and `80` by their greatest common factor (`40`) gives a **`3 : 2`** width-to-height ratio. Since `300 ÷ 3 = 100`, the scaled height must be `2 × 100 =` **`200` pixels tall**.
- **Answer 2.8:** Without knowing how many pixels belong in each row (the width—supplied via a file header, a protocol message, or a fixed format agreement), the receiver does not know where to wrap to the next line; wrapping every `16` bits instead of every `8` bits scrambles the picture into unrecognizable stripes.

Vocabulary

- **ASCII:** A standard character-encoding table that assigns numbers (`0` to `127`) to English letters, digits, and punctuation marks.
- **pixel (picture element):** One individual colored square in a grid-based digital image.
- **bitmap:** An image represented as a row-by-row grid of pixel color codes (whose width and height are supplied by a file header, protocol, or format specification).
- **color depth (bits per pixel):** The unit rate measuring how many bits are used to represent the color of each single pixel.

Differentiation

- **Extra support:** Provide a printed alphabet strip listing `A = 65` through `Z = 90` with their 5-bit endings (`00001` to `11010`) so students can focus on matching patterns before doing mental subtraction.
- **Extra challenge:** Introduce **Run-Length Encoding (RLE)** compression: in Row 1 of the smiley face (`00111100`), instead of listing every bit, write `(2 white, 4 black, 2 white)`. Ask students to test which `8 × 8` drawings shrink with RLE and which pattern (such as an alternating checkerboard `01010101`) actually gets larger!

⚠ Safety

No physical hazards in this unplugged lesson.

Teacher notes

- **Important scope note on Unicode / UTF-8:** Make sure students know that 7-bit/8-bit ASCII only had room for English characters. Modern operating systems and web browsers use **UTF-8 (Unicode)**, which stays backwards-compatible with 1-byte ASCII for `0–127` while using `2`, `3`, or `4` bytes per character to represent over `149,000` characters across global writing systems and emoji.

Lesson 3: Making Decisions with Switches — NOT, AND, and OR Logic Gates

Time: 50 minutes

Unit: Binary, Pixels, Logic Gates, and Packet Switching | **Previous:** Lesson 2 | **Next:** Lesson 4

Goal

Complete truth tables for `NOT`, `AND`, and `OR` logic gates, model series and parallel switch paths, and trace the output of a 2-gate combination circuit for all four input pairs.

Materials

- Chalk or masking tape on the classroom floor to draw two circuit pathways (**Series Path** and **Parallel Path**).
- Index cards labeled `0 (OPEN / FALSE)` and `1 (CLOSED / TRUE)` for student gatekeepers.
- Student notebooks or worksheet tables for truth tables.

Steps

✎ 1. Opening (5 min): How Do `0`s and `1`s Make Decisions?

Ask the class: - "Lessons 1 and 2 showed how *0*s and *1*s store numbers, letters, and pictures. But how does a computer actually **decide** something — like turning on a terrarium misting sprayer only when the soil is dry **AND** the lid is closed?" - Explain that inside a processor chip, billions of microscopic electronic switches (**logic gates**) take `0`/`1` inputs and produce a `0`/`1` output according to three fundamental rules: **`NOT`**, **`AND`**, and **`OR`**.

✎ 2. Main Activity Part A (15 min): Acting Out the Three Fundamental Logic Gates

Select student volunteers to act as **Switch Gatekeepers** along chalk paths drawn on the floor (or trace the paths at desks using a tabletop diagram, paper switch cards, or pointing so standing/walking is optional): - **`1` = Gate Closed (Bridge Down / True):** The messenger can walk across. - **`0` = Gate Open (Bridge Up / False):** The path is blocked.

1. The `NOT` Gate (Inverter) — 1 Input

Flips the input bit to its opposite:

Input `A`	Output `NOT A`
`0`	**`1`**
`1`	**`0`**

Everyday example: A refrigerator interior light switch that turns the bulb **ON (1)** when the door is **NOT closed (0)**.

2. The AND Gate (Series Path) — 2 Inputs

Draw two switches A and B **in a single straight line (in series)**. To walk from the battery to the lightbulb, the messenger must cross **both** A and B:

Input A	Input B	Output A AND B
0	0	**0**
0	1	**0**
1	0	**0**
1	1	**1**

Rule: A AND B outputs 1 **only when both inputs are 1**.

3. The OR Gate (Parallel Path) — 2 Inputs

Draw a path that **splits into two side-by-side branches** (Switch A on the top branch, Switch B on the bottom branch) and rejoins before the lightbulb. The messenger can reach the lightbulb if **either** A is closed, **or** B is closed, **or both**:

Input A	Input B	Output A OR B
0	0	**0**
0	1	**1**
1	0	**1**
1	1	**1**

Rule: A OR B outputs 1 **whenever at least one input is 1**.

✎ 3. Main Activity Part B (15 min): Combining Gates in a Terrarium Controller

Connect to the Grade 6 Science unit (Fungi and Decomposition): suppose your class is modeling an **ideal Boolean simulation** of a mushroom decomposition terrarium controller with three idealized binary inputs: - **D (Dry):** 1 if humidity is too low, 0 if moist enough. - **L (Lid Closed):** 1 if the terrarium lid is safely closed, 0 if open. - **M (Manual Override Button):** 1 if a student presses the test-spray button, 0 otherwise.

✎ Worked Example: Tracing (D AND L) OR M

Let's trace when the **Sprayer (S)** turns ON (S = 1) for different sensor readings by adding an intermediate column X = (D AND L) first:

D (Dry)	L (Lid)	M (Manual)	Step 1: X = D AND L	Step 2: S = X OR M
1	0	0	1 AND 0 = 0	0 OR 0 = **0 (OFF — lid is open!)**
1	1	0	1 AND 1 = 1	1 OR 0 = **1 (ON — dry and lid closed)**

D (Dry)	L (Lid)	M (Manual)	Step 1: X = D AND L	Step 2: S = X OR M
0	0	1	0 AND 0 = 0	0 OR 1 = **1 (ON — manual button pressed)**

4. Discussion & Student Practice (15 min)

✎ Practice Tasks (3.1 – 3.8)

1. **Task 3.1:** Evaluate `1 AND 0`, `1 OR 0`, and `NOT 0`.
2. **Task 3.2:** Evaluate `(1 OR 0) AND (NOT 1)`. Show the intermediate value of each parentheses group first.
3. **Task 3.3:** Complete all 4 rows of the truth table for the circuit `Output = (NOT A) AND B` (where `(A, B)` takes values `(0,0)`, `(0,1)`, `(1,0)`, `(1,1)`).
4. **Task 3.4:** Complete all 4 rows of the truth table for the circuit `Output = NOT (A OR B)`.
5. **Task 3.5 (Safety Bug Analysis in Our Boolean Simulation):** In the simulated mushroom terrarium controller `S = (D AND L) OR M`, notice Row 3 of the worked example (`D=0, L=0, M=1`): if the lid is **open (`L = 0`)** and someone presses the **Manual button (`M = 1`)**, the sprayer output is still `1`! Rewrite the Boolean formula using `D`, `L`, and `M` so that in this ideal logic model the sprayer output is `1` when dry **or** when the manual button is pressed, **but ONLY if the lid input `L` is closed (`L = 1`)**.
6. **Task 3.6 (Comparing Circuits):** Compute all 4 rows of `(NOT A) AND (NOT B)` and compare the output column to Task 3.4 (`NOT (A OR B)`). What do you discover?
7. **Task 3.7 (Bitwise Masking):** Computers often apply an `AND` gate to two 4-bit numbers **column by column**. Compute `1101 AND 0110` bit by bit.
8. **Task 3.8 (Ratio of True Outputs):** Out of the `4` possible input rows in a 2-input truth table (`00, 01, 10, 11`), what is the ratio of `1` (TRUE) outputs to total rows for an `AND` gate vs. an `OR` gate?

Complete Answer Key (Tasks 3.1 – 3.8)

- **Answer 3.1:** `1 AND 0` = **0**; `1 OR 0` = **1**; `NOT 0` = **1**.
- **Answer 3.2:** First group: `(1 OR 0)` = 1. Second group: `(NOT 1)` = 0. Final gate: `1 AND 0` = **0**.
- **Answer 3.3 (`(NOT A) AND B`):**
- `(0, 0)`: `NOT 0` = 1 → `1 AND 0` = **0**
- `(0, 1)`: `NOT 0` = 1 → `1 AND 1` = **1**
- `(1, 0)`: `NOT 1` = 0 → `0 AND 0` = **0**
- `(1, 1)`: `NOT 1` = 0 → `0 AND 1` = **0** (Only row *`(0, 1)`* outputs *1*.)
- **Answer 3.4 (`NOT (A OR B)`):**
- `(0, 0)`: `0 OR 0` = 0 → `NOT 0` = **1**
- `(0, 1)`: `0 OR 1` = 1 → `NOT 1` = **0**
- `(1, 0)`: `1 OR 0` = 1 → `NOT 1` = **0**
- `(1, 1)`: `1 OR 1` = 1 → `NOT 1` = **0**
- **Answer 3.5:** Put `D OR M` inside parentheses first, then require `AND L`: **`S = (D OR M) AND L`**. In this **ideal Boolean model**, whenever `L = 0` (lid open), `(D OR M) AND 0 = 0`, so the logic output stays `0` while `L = 0`. (Note that in a real physical device, a stuck lid sensor or faulty valve could still cause a malfunction even when the Boolean formula is correct!)
- **Answer 3.6:** For `(NOT A) AND (NOT B)`: `(0,0) -> 1 AND 1 = 1`; `(0,1) -> 1 AND 0 = 0`; `(1,0) -> 0 AND 1 = 0`; `(1,1) -> 0 AND 0 = 0`. The output column (`1, 0, 0, 0`) is **identical** to `NOT (A OR B)` in Task 3.4! ("Neither A nor B is ON" means the exact same thing as "A is OFF and B is OFF".)

- **Answer 3.7:** Column by column from left to right: `1 AND 0 = 0`, `1 AND 1 = 1`, `0 AND 1 = 0`, `1 AND 0 = 0` → **`0100`**.
- **Answer 3.8:** An `AND` gate outputs `1` in **`1 : 4`** (`1` out of `4` rows, or `25%`), whereas an `OR` gate outputs `1` in **`3 : 4`** (`3` out of `4` rows, or `75%`).

Vocabulary

- **logic gate:** A physical or digital switch circuit that takes one or more binary inputs (`0` or `1`) and produces a single binary output according to a fixed rule.
- **truth table:** A complete table listing every possible combination of input bits and the resulting output bit.
- **series circuit (`AND`):** Switches wired one after another along a single path so all switches must be closed (`1`) for current to flow.
- **parallel circuit (`OR`):** Switches wired on side-by-side branches so closing any one branch (`1`) allows current to flow.

Differentiation

- **Extra support:** Have students physically write the `0` or `1` output above each gate wire on a printed circuit diagram before filling in the table row.
- **Extra challenge:** Introduce the **Exclusive OR (`XOR`)** gate, which outputs `1` when `A` and `B` are **different** (`01` or `10`), and outputs `0` when both are the same (`00` or `11`). Ask students to build `A XOR B` using only `AND`, `OR`, and `NOT` gates: `(A OR B) AND NOT (A AND B)`.

⚠ Safety

Keep floor pathways clear of backpacks and chairs during the human-circuit walkthrough.

Teacher notes

- **Common misconception ("Everyday English OR vs. Logical OR"):** In everyday conversation, "You can have soup OR salad" often means one or the other, not both (`XOR`). Emphasize that in mathematics and computing, **`OR` always means "at least one (including both)"** (`1 OR 1 = 1`).

Lesson 4: Postcards on the Wire — Packet Switching, Routing, and Throughput Rates

Time: 50 minutes

Unit: Binary, Pixels, Logic Gates, and Packet Switching | **Previous:** Lesson 3 | **Next:** Lesson 5

Goal

Simulate splitting a message into numbered packets, route packets around a failed network link, reassemble out-of-order packets using header sequence numbers, and calculate network unit rates (**packets per second** and **bits per second**).

Materials

- 6 index cards ("Packet Postcards") per group of 6 students.
- Yarn or string pieces connecting 6 student desks as a 6-node router mesh (`Node A` through `Node F`).
- Scissors or a red `"LINK DOWN"` card to simulate a cut fiber-optic cable during the activity.

Steps

✎ 1. Opening (5 min): One Giant Scroll vs. Numbered Postcards

Ask the class: - "Suppose you want to mail a 300-page book to a friend, but the postal tube can only hold 1 page at a time, and 20 other classmates are also sharing the same highway. What happens if one person reserves the entire highway for 10 minutes to send their whole book in one piece?" - Contrast **circuit reservation** (everyone else waits in line; if a tree falls across the road halfway through, the whole book fails) with **packet switching** (chopping the data into small numbered blocks called **packets** that take turns sharing the links and can detour around a broken road).

✎ 2. Main Activity (20 min): The 6-Node Classroom Router Mesh

Arrange 6 desks (`A, B, C, D, E, F`) with yarn links matching this network map:

```
   [Node B] -------- [Node D]
   /      \          /      \
[Node A]   (link)  (link)   [Node F]
   \      /          \      /
   [Node C] -------- [Node E]
```

Links available: - `A–B`, `A–C` - `B–C`, `B–D` - `C–D`, `C–E` - `D–F`, `E–F`

Step-by-Step Simulation

1. **Sender (`Node A`)** wants to send the 16-character message `"FUNGI GROW FAST!"` to **Receiver (`Node F`)**, but each packet payload can hold **at most `4` characters** (`32 bits`).
2. `Node A` splits the message into `4` packets and fills out a **Header** on each card:
3. **Packet 1:** `From: A | To: F | Packet: 1 of 4 | Payload: "FUNG"`
4. **Packet 2:** `From: A | To: F | Packet: 2 of 4 | Payload: "I GR"`
5. **Packet 3:** `From: A | To: F | Packet: 3 of 4 | Payload: "OW F"`
6. **Packet 4:** `From: A | To: F | Packet: 4 of 4 | Payload: "AST!"`
7. **Round 1 (Normal Routing — `1` Hop per Step):** Assume a synchronized step-by-step scenario where each link hop takes **1 step (1 second)** and `Node F` logs simultaneous arrivals from `Node D` before `Node E`. `Node A` sends Packet 1 along `A -> B -> D -> F` (`3` steps) and Packet 2 along `A -> C -> E -> F` (`3` steps), so Packets 1 and 2 arrive at `Node F` first (logged as `Packet 1, Packet 2`).
8. **Round 2 (Sending Packets 3 & 4 + Link Failure!):** Next, `Node A` sends **Packet 3** to `Node B` and **Packet 4** directly to `Node C`. Just as Packet 3 arrives at `Node B`, place the red `"LINK DOWN"` card on link **`B–D`**!
9. Does `Node B` throw Packet 3 away? **No!** `Node B` inspects its remaining working links, sees `B–C` is still up, and reroutes Packet 3 along `B -> C -> E -> F` (`4` hops total from `A`). Meanwhile, **Packet 4** travels directly along `A -> C -> E -> F` (`3` hops total, with no queue delay at `C` or `E` because it is 1 step ahead of rerouted Packet 3).
10. **Out-of-Order Arrival at `Node F` (in This 1-Second-per-Hop Scenario):** In this scenario where every hop takes 1 second, Packet 4 completes its 3-hop path (`A -> C -> E -> F`) one step before rerouted Packet 3 completes its 4-hop detour (`A -> B -> C -> E -> F`). (Note: On real networks, arrival order depends on link delays, bandwidth, and router queues—not hop count alone!) Thus `Node F` receives the cards in the order: **Packet 1, Packet 2, Packet 4, Packet 3** (`"FUNGI GRAST!OW F"` if read blindly!).
11. `Node F` uses the **`Packet # of 4`** header field to sort them back into `1, 2, 3, 4` → **`"FUNGI GROW FAST!"`**.

3. Connecting to Grade 6 Ratios & Unit Rates: Network Throughput (10 min)

Work through a concrete rate calculation on the board: - Suppose each packet carries **`32` bits of header** + **`32` bits of payload** = **`64` bits per packet**. - If a router link transmits **`300` packets in `6` seconds**: 1. **Packet rate (unit rate):** `300 packets ÷ 6 seconds` = **`50 packets per second`**. 2. **Bit rate (throughput):** `50 packets/second × 64 bits/packet` = **`3,200 bits per second`**. 3. **Header overhead ratio:** In every `64`-bit packet, `32` bits are header and `32` bits are payload (`32 : 64 = 1 : 2`, or `50%` header overhead). If we increase the payload to `192` bits while keeping the same `32`-bit header (`224` bits total), the header overhead drops to `32 : 224` = **`1 : 7`**!

✓ 4. Student Practice & Closing Check (15 min)

✎ Practice Tasks (4.1 – 4.8)

1. **Task 4.1:** A `20`-character message (`"MEET AT THE LIBRARY!"`) is split into packets that hold at most `4` characters per payload. How many packets are needed, and what is the exact `4`-character payload of **Packet 3 of 5**? (Count spaces as characters!)
2. **Task 4.2:** Receiver `Node F` receives five packets in the arrival order:

3. `Packet 4 of 5: "RKS!"`
4. `Packet 2 of 5: "ING "`
5. `Packet 5 of 5: " :)"`
6. `Packet 1 of 5: "ROUT"`
7. `Packet 3 of 5: "WO"` Reassemble the original message in order.
8. **Task 4.3:** What would happen at `Node F` if `Packet 3 of 5` was accidentally dropped on the floor and never arrived? How does the header `"Packet # of 5"` help `Node F` know specifically which piece to request again?
9. **Task 4.4 (Hop Count on the Network Map):** Using the 6-node map (`A–B, A–C, B–C, B–D, C–D, C–E, D–F, E–F`), what is the minimum number of link hops from `A` to `F` when all links are working? List all `3`-hop paths from `A` to `F`.
10. **Task 4.5 (Rerouting Around Failure):** If **both** link `B–D` and link `C–E` fail at the same time on the 6-node map, is there still a working path from `A` to `F`? If so, write the exact node sequence and count its hops.
11. **Task 4.6 (Unit Rate — Packets per Second):** A classroom switch forwards `420` packets in `14` seconds. What is its unit rate in **packets per second**? At that same rate, how many packets will it forward in `25` seconds?
12. **Task 4.7 (Unit Rate — Bits per Second):** Each packet on a sensor network is `80` bits long (`16` header bits + `64` payload bits). If the sensor transmits `40` packets per second, what is the total transmission rate in **bits per second**? How many of those bits per second are **actual sensor payload**?
13. **Task 4.8 (Header-to-Total Ratio):** In Task 4.7 (`16` header bits and `64` payload bits, `80` bits total per packet), write the ratio of **payload bits to total bits** in simplest whole-number form.

Complete Answer Key (Tasks 4.1 – 4.8)

- **Answer 4.1:** `20 characters ÷ 4 characters/packet = 5` **packets**. Splitting into 4-character blocks: Packet 1 = `"MEET"`, Packet 2 = `" AT "`, **Packet 3 = `"THE "`**, Packet 4 = `"LIBR"`, Packet 5 = `"ARY!"`.
- **Answer 4.2:** Sorting by sequence number `1, 2, 3, 4, 5`: `"ROUT" + "ING " + "WO" + "RKS!" + " :)"` = **`"ROUTING WORKS! :)"`**.
- **Answer 4.3:** Because `Node F` sees packets `1, 2, 4, 5` of `5`, it immediately detects that **`Packet 3` is missing** and only needs to ask `Node A` to re-send **Packet 3**, rather than re-sending the entire message.
- **Answer 4.4:** The minimum hop count is **`3` hops**. There are **three** `3`-hop paths from `A` to `F`:
- `A -> B -> D -> F`
- `A -> C -> D -> F`
- `A -> C -> E -> F`
- **Answer 4.5: Yes!** Even with both `B–D` and `C–E` broken, `Node C` connects to `Node D` via `C–D`. So a packet can travel **`A -> C -> D -> F`** (`3` hops) or **`A -> B -> C -> D -> F`** (`4` hops).
- **Answer 4.6:** Unit rate: `420 ÷ 14 =` **`30 packets per second`**. In `25` seconds: `30 × 25 =` **`750 packets`**.
- **Answer 4.7:** Total rate: `40 packets/sec × 80 bits/packet =` **`3,200 bits per second`**. Actual payload rate: `40 packets/sec × 64 payload bits/packet =` **`2,560 payload bits per second`**.
- **Answer 4.8:** Payload to total is `64 : 80`. Dividing both by `16` gives **`4 : 5`** (`4` out of every `5` bits sent are payload).

Vocabulary

- **packet:** A small, fixed-limit chunk of data paired with a header so it can travel independently across a shared network.
- **header:** Metadata attached to the front of a packet listing its sender address, destination address, and sequence number (`Packet k of N`).
- **payload:** The actual slice of user data (text, image bits, sensor reading) carried inside a packet.
- **router:** A network node that inspects a packet's destination address and forwards it along a working link toward its destination.
- **throughput (bit rate):** The unit rate measuring how many bits pass through a network link per second (`bits per second`).

Differentiation

- **Extra support:** Give each student desk a printed sign (`Node A` through `Node F`) and have students slide the index cards along the yarn strings—or trace the routes on a shared tabletop map/diagram by pointing or dictating moves so standing, walking, or handling yarn is optional.
- **Extra challenge:** Assign different **link delays** to each yarn piece (for example, `C–D` takes `1` second, while `B–D` takes `4` seconds) and ask students to find the path with the **lowest total travel time** even when that path has more hops!

⚠ Safety

Ensure yarn links are taped across desk tops rather than stretched across floor walkways where students could trip.

Teacher notes

- **Scope note on TCP/IP:** Explain briefly that on the real Internet, **IP (Internet Protocol)** handles addressing and hop-by-hop routing (like the `From` and `To` fields on our cards), while **TCP (Transmission Control Protocol)** handles the sequence numbering (`Packet k of N`) and requesting re-transmission when a packet is lost.

Lesson 5: Catching Flipped Bits — Noise, Even Parity Checks, and End-of-Unit Assessment

Time: 50 minutes

Unit: Binary, Pixels, Logic Gates, and Packet Switching | **Previous:** Lesson 4

Goal

Add an even-parity check bit to 8-bit bytes, detect single-bit transmission errors, explain why two simultaneous bit flips in the same byte escape 1-bit parity, and complete the 5-part End-of-Unit Assessment.

Materials

- Large two-sided paper cards or tokens (`Light = 1`, `Dark = 0`), 9 cards per pair (or a printed 9-box row where students can point, dictate, or write `0` and `1` instead of handling small objects).
- Printed or board-copied End-of-Unit Assessment (20 points total; 20 minutes at the end of this 50-minute lesson, or administered in a separate quiz period).

Steps

✎ 1. Opening (5 min): What If Static Flips a `0` to a `1`?

Ask the class: - "Suppose a hospital or spacecraft sends the 8-bit number *`00000101`* (*`5`* milligrams or *`5`* degrees), and a burst of radio static on the wire flips the leftmost bit from *`0`* to *`1`* (*`10000101`* = *`133`*!). How can the receiver tell that a bit was flipped without already knowing the secret number?"

✎ 2. Main Activity (15 min): The Even-Parity Check Bit

Demonstrate how adding **one extra check bit** (a **9th bit** called the **Even Parity Bit**) catches any single-bit flip (or any odd number of bit flips):

The Even-Parity Rule

Before sending an 8-bit data byte, the sender counts how many **`1`s** are in the 8 data bits: - If the number of `1`s in the 8 data bits is already **even** (`0, 2, 4, 6, or 8`), set the 9th **Parity Bit = `0`** so the total number of `1`s across all 9 bits stays **even**. - If the number of `1`s in the 8 data bits is **odd** (`1, 3, 5, or 7`), set the 9th **Parity Bit = `1`** so the total number of `1`s across all 9 bits becomes **even**.

✎ Worked Example 1: Computing the Parity Bit

8 Data Bits	Count of 1s in Data	Even or Odd?	9th Bit (Even Parity Bit)	Complete 9-Bit Frame Sent	Total 1s Sent
01000001 ('A')	2 ones	Even	**0**	01000001 **0**	2 (Even)
01000011 ('C')	3 ones	Odd	**1**	01000011 **1**	4 (Even)

✎ Worked Example 2: Checking Incoming Frames at the Receiver

When the receiver gets a 9-bit frame, it counts the total number of 1s across **all 9 bits**: - Received Frame X: 01001001 0 → Count of 1s = 3 (**Odd!**). Since every valid frame was sent with an **even** number of 1s, an odd total signals that **an odd number of bits (1, 3, 5...) flipped** during transmission: **ERROR DETECTED — discard and request re-send!** - **Crucial limitation ("No Error Detected" ≠ Proof of Zero Errors):** What if lightning flips **two** (or 4, 6, 8) bits inside the same 9-bit frame? Changing an even count by +2, 0, or -2 keeps the total **even**, so a single parity bit **cannot detect an even number of bit flips**. Therefore, a passing (even) parity check means **no error was detected**, not absolute proof that zero bits changed!

✎ 3. Student Practice Tasks (5.1 – 5.8) (10 min)

1. **Task 5.1:** Find the Even Parity Bit (0 or 1) to append to the 8-bit data byte 00110101.
2. **Task 5.2:** Find the Even Parity Bit (0 or 1) to append to the 8-bit data byte 10110101.
3. **Task 5.3:** A receiver uses even parity and receives these four 9-bit frames. Which ones have a detected error?
4. Frame A: 01010101 0
5. Frame B: 11001010 1
6. Frame C: 00000000 0
7. Frame D: 10000000 0
8. **Task 5.4:** What if the **Parity Bit itself** (the 9th bit) gets flipped by static during transmission while the 8 data bits are untouched? Will the receiver still detect an error? Explain why.
9. **Task 5.5:** Assuming at most **one** bit flipped in a 9-bit frame, explain why a single 9th parity bit can tell you **that** a bit flipped, but cannot tell you **which** of the 9 bits flipped.
10. **Task 5.6 (2D Grid Parity Puzzle):** Arrange three 4-bit data rows into a grid with an even **Row Parity bit** at the right end of each row and an even **Column Parity bit** at the bottom of each data column:
11. Row 1: 1 0 1 0 | 0
12. Row 2: 0 1 1 0 | 1
13. Row 3: 1 1 0 0 | 0
14. Col Parity: 0 0 1 0 Assume that **at most one bit** in the entire diagram flipped during transmission, and in fact **exactly one data bit** inside the 3 × 4 data grid flipped. Check the row sums and column sums to pinpoint the exact (Row, Column) of the flipped bit.

15. **Task 5.7 (Error Rate Ratio):** Out of `500` transmitted packets, `15` packets fail their parity check and must be re-sent. Write the error rate as a simplified ratio (`failed : total`) and as a rate **per `100` packets** (percentage).
16. **Task 5.8 (Overhead Comparison):** Adding `1` parity bit to every `8` data bits creates `9` total bits per byte. What is the ratio of **check bits to data bits** (`1 : 8`) and **data bits to total bits** (`8 : 9`)?

Complete Answer Key (Tasks 5.1 – 5.8)

- **Answer 5.1:** `00110101` has `4` ones (already even) → Parity Bit = **`0`** (`00110101 0`).
- **Answer 5.2:** `10110101` has `5` ones (odd) → Parity Bit = **`1`** (`10110101 1`, making `6` ones total).
- **Answer 5.3:**
- Frame A (`01010101 0`): `4` ones (Even) → **Passes check (no error detected)**.
- Frame B (`11001010 1`): `5` ones (Odd) → **ERROR DETECTED (odd number of bit flips)**.
- Frame C (`00000000 0`): `0` ones (`0` is an even number!) → **Passes check (no error detected)**.
- Frame D (`10000000 0`): `1` one (Odd) → **ERROR DETECTED (odd number of bit flips)**.
- **Answer 5.4: Yes!** Flipping any single bit among the 9 bits — including the 9th parity bit itself — changes the total count of 1s by `+1` or `-1`, turning an even total into an odd total.
- **Answer 5.5:** Under the single-bit-flip assumption, flipping any one of the 9 bit positions changes the total parity from even to odd in the exact same way, so an odd total tells the receiver that a bit flipped (or, more generally, that an odd number of bits flipped), but not which slot (`1` through `9`) changed.
- **Answer 5.6:** Count the 1s in each row (including its right-hand Row Parity bit):
- Row 1 (`1 0 1 0 | 0`): `2` ones (Even — passes check).
- **Row 2 (`0 1 1 0 | 1`):** `3` ones (**Odd — error detected in Row 2!**).
- Row 3 (`1 1 0 0 | 0`): `2` ones (Even — passes check). Now count the 1s in each data column (including its bottom Column Parity bit):
- Column 1 (`1, 0, 1 | 0`): `2` ones (Even — passes check).
- Column 2 (`0, 1, 1 | 0`): `2` ones (Even — passes check).
- **Column 3 (`1, 1, 0 | 1`):** `3` ones (**Odd — error detected in Column 3!**).
- Column 4 (`0, 0, 0 | 0`): `0` ones (Even — passes check). Because Row 2 and Column 3 both fail their even-parity check, the single flipped bit lies at their intersection: **`(Row 2, Column 3)`** (changing that `1` back to `0` restores both Row 2 and Column 3 to `2` ones).
- **Answer 5.7:** `15 : 500` simplifies (dividing by `5`) to **`3 : 100`**, which is **`3` failed packets per `100` packets (`3%`)**.
- **Answer 5.8:** Check bits to data bits = **`1 : 8`**; data bits to total transmitted bits = **`8 : 9`**.

End-of-Unit Synthesis Assessment (20 Points Total — 20 Minutes)

Instructions for Students

Answer all 5 problems (`4` points each = `20` points total). Show your place-value additions, intermediate gate values, or unit-rate steps clearly.

✎ Problem 1: Doubling Cards & 8-Bit Binary (4 points)

- **(a) [1 pt]** List the 8 binary place-value cards in order from left (`8`th bit) to right (`1`st bit).

- **(b) [1 pt]** Convert the 8-bit binary byte `01011010` to a base-10 number.
- **(c) [2 pts]** Convert the base-10 number **`150`** into an 8-bit binary byte. Show which place-value cards are switched ON (`1`).

✎ Problem 2: ASCII Characters & Bitmap Pixel Ratios (4 points)

- **(a) [2 pts]** In standard ASCII, uppercase `'A'` is `65` (`01000001`). Decode the 2-byte word `01001000 01001001`.
- **(b) [2 pts]** A small `10 × 10` game icon (`100` pixels total) is upgraded from a 2-color palette (`1 bit per pixel`) to an 8-color palette (`3 bits per pixel`). Counting **raw uncompressed pixel data** (excluding any headers), how many **bits** did the icon take before the upgrade, how many **bits** does it take after the upgrade, and what is the ratio of old raw pixel size to new raw pixel size?

✎ Problem 3: Logic Gates & Truth Table (4 points)

A solar battery charger turns ON (`Output = 1`) according to the logic circuit: `Output = S AND (NOT F)` where **`S`** = `1` when Sunlight is detected (`0` when dark), and **`F`** = `1` when the Battery is already Full (`0` when not full). - **(a) [3 pts]** Write out the 4-row truth table for `(S, F)` = `(0,0)`, `(0,1)`, `(1,0)`, `(1,1)`, showing the intermediate column `NOT F` and the final `Output` column. - **(b) [1 pt]** Explain in plain English which single row turns the charger ON and why.

✎ Problem 4: Packet Switching & Network Unit Rates (4 points)

- **(a) [2 pts]** Three packets arrive at a receiver in the order:
- `Packet 3 of 3: "ONE!"`
- `Packet 1 of 3: "WELL"`
- `Packet 2 of 3: " D"` Write the reassembled message and explain why packets from the same message can arrive out of order on a packet-switched network.
- **(b) [2 pts]** A network link transfers `450` packets in `9` seconds. Each packet is `100` bits long (`20` header bits + `80` payload bits). Find the link's rate in **packets per second** and its total throughput in **bits per second**.

✎ Problem 5: Even-Parity Error Detection (4 points)

- **(a) [1 pt]** What Even Parity Bit (`0` or `1`) should be attached to the 8-bit byte `11010011`?
- **(b) [2 pts]** A receiver using even parity receives Frame 1 (`10101010 0`) and Frame 2 (`11100011 0`). Which frame has a detected error? Show your count of `1`s for each frame.
- **(c) [1 pt]** Explain why even parity fails to detect an error if exactly **two** bits flip inside the same 9-bit frame.

End-of-Unit Assessment Answer Key & Scoring Guide (20 Points)

- **Problem 1 (4 pts):**
- **(a) [1 pt]:** `128, 64, 32, 16, 8, 4, 2, 1`.

- **(b) [1 pt]:** `64 + 16 + 8 + 2 =` **`90`**.
- **(c) [2 pts]:** `150 = 128 + 16 + 4 + 2` → **`10010110`** (`1` pt for correct card decomposition, `1` pt for exact 8-bit string).
- **Problem 2 (4 pts):**
- **(a) [2 pts]:** Byte 1 (`01001000`) = `64 + 8 = 72` (8th letter = `'H'`). Byte 2 (`01001001`) = `64 + 8 + 1 = 73` (9th letter = `'I'`). Decoded word: **`"HI"`**.
- **(b) [2 pts]:** Before upgrade: `100 pixels × 1 bit/pixel = 100 bits`. After upgrade: `100 pixels × 3 bits/pixel = 300 bits`. Ratio of old to new storage = **`1 : 3`**.
- **Problem 3 (4 pts):**
- **(a) [3 pts]:**
  - `(S=0, F=0)` → `NOT F = 1` → `0 AND 1 =` **`0`**
  - `(S=0, F=1)` → `NOT F = 0` → `0 AND 0 =` **`0`**
  - `(S=1, F=0)` → `NOT F = 1` → `1 AND 1 =` **`1`**
  - `(S=1, F=1)` → `NOT F = 0` → `1 AND 0 =` **`0`**
- **(b) [1 pt]:** Row `(S=1, F=0)` turns the charger ON (`1`) because there is sunlight (`S=1`) **and** the battery is **not** full (`F=0`, so `NOT F = 1`).
- **Problem 4 (4 pts):**
- **(a) [2 pts]:** Reassembled message (`1, 2, 3`): **`"WELL DONE!"`**. Packets can arrive out of order because different packets may take different router paths (with different hop counts or congestion delays) around busy or broken links.
- **(b) [2 pts]:** Packet rate: `450 packets ÷ 9 seconds =` **`50 packets per second`**. Total throughput: `50 packets/sec × 100 bits/packet =` **`5,000 bits per second`**.
- **Problem 5 (4 pts):**
- **(a) [1 pt]:** `11010011` has `5` ones (odd) → Even Parity Bit = **`1`**.
- **(b) [2 pts]:** Frame 1 (`10101010 0`) has `4` ones (even → **passes check, no error detected**). Frame 2 (`11100011 0`) has `5` ones (odd → **ERROR DETECTED in Frame 2**).
- **(c) [1 pt]:** Flipping two bits changes the number of `1`s by `+2`, `0`, or `-2`, which keeps an even total **even**, so the receiver sees an even count and cannot tell that two bits changed.

Vocabulary

- **noise / interference:** Unwanted electrical or radio disturbances that can accidentally flip a `0` bit to a `1` (or `1` to `0`) during transmission.
- **even parity bit:** An extra check bit (`0` or `1`) appended to a group of data bits so the total number of `1`s across the entire frame is always an even number.

Differentiation

- **Extra support:** Allow students to keep their 8 physical place-value cards (`128, 64, 32, 16, 8, 4, 2, 1`) on their desk during the assessment.
- **Extra challenge:** Have students complete the 2D `3 × 4` grid parity puzzle (Task 5.6) where they intentionally flip one data coin while their partner looks away, and see if their partner can find the exact flipped coin in one try using only row and column parity!

⚠ Safety

No physical hazards in this unplugged lesson.

Teacher notes

- **Zero-is-even reminder:** Remind students before Task 5.3 that `0` **is an even number**, so an all-zero byte `00000000` already has an even count of `1`s (`0` ones) and receives a `0` parity bit (`00000000 0`).