Lesson 04: Marble Maze Box - Building Models from Indirect Evidence (High-Inquiry Version)

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Lesson Title: Marble Maze Mystery: What Could Be Inside?
Intended Grade Level(s): Grades 4-12 (adaptable)
Content Area: Content-Agnostic Spatial Reasoning & Scientific Modeling

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I. Planning

Lesson Focus / Goals

State the big idea(s) of the lesson. Focus on conceptual understanding. Avoid vague objectives. Specify the knowledge and skills students should demonstrate.

The lesson aims to provide the following for students: - Build and revise models of hidden structures based on indirect evidence - Experience the difference between data collection and model-building - Understand that models are provisional explanations, not discovered truths - Defend model features using evidence and respond to challenges - Recognize that multiple models can be consistent with the same evidence

Learning Objectives

Write clear, measurable objectives. Include both procedural and conceptual goals. Consider potential misconceptions students might have.

By the end of the lesson, students will be able to: - Generate a plausible model of the maze interior based on collected evidence - Use specific observations to justify features of their model - Identify which features of their model are well-supported vs. uncertain - Compare competing models and evaluate which explains the evidence better - Revise models when confronted with new evidence or challenges - Articulate what they can and cannot know from the available data

Potential Misconceptions: - Students might think there's only ONE correct model that they need to find - Students might conflate "good data collection" with "doing inquiry" - Students might think the model IS the maze, rather than a representation - Students might seek teacher validation rather than evidence-based justification - Students might think uncertainty means failure rather than honest scientific stance

Standards Alignment

Note: This is a content-agnostic lesson that places math and science students on equal footing. However, the reasoning processes naturally align to core practices in both disciplines.

Standards for Mathematical Practice (Common Core): - MP6 – Attend to precision.
Students record observations precisely and distinguish observation from inference when building models. - **MP7** – Look for and make use of structure.
Students identify patterns in marble movement to infer and model internal maze structure.

NGSS Science and Engineering Practices: - Planning and Carrying Out Investigations – Students design their own testing procedures to collect data systematically. **- Analyzing and Interpreting Data** – Students record observations and use them to construct explanatory models. **- Developing and Using Models** – Students create models to represent hidden structures based on indirect evidence.

II. Implementation

Materials Needed

List all physical and digital resources, manipulatives, and technology needed. For each item listed, provide a brief justification/explanation for its inclusion.

The following materials are used in the lesson: - **Marble maze boxes** (1 per pair) - sealed boxes with internal maze structures. IMPORTANT: Boxes should have DIFFERENT internal structures (not identical) to prevent answer-sharing and emphasize model uniqueness - **Open-ended data recording sheets** (not pre-structured with positions) - **Model-building sheets** with space for: initial model, evidence support, revisions, uncertainties - **Chart paper** for pairs to display their models publicly - **Sticky notes** for peer questions/challenges - **Optional: Additional testing materials** if students want to design new tests - **The actual boxes** (kept sealed until very end, if revealed at all)

Preparation: Build 6-8 marble maze boxes with VARIED internal structures (some simple, some complex). Do NOT prepare an answer key. Prepare model-building sheets that scaffold evidence-based reasoning. Plan for ambiguity.

Lesson Flow

(Before-During-After)

Organize your plan using the Before–During–After framework. Include approximate timing, key questions, and anticipated student responses.

Note for instructors: Phase 2 (Model Presentation & Challenge) and Phase 3 (Model Revision & Uncertainty Mapping) are the core inquiry moves that distinguish this from data collection activities. Some reflective prompts in the After section are optional or extensible depending on time and context. The epistemic priority is ensuring students construct, defend, and revise models based on evidence.

Before: (Launch – 8 min)

1. Show sealed marble maze box
2. Pose the challenge: "Inside this box is a maze. There's a marble inside. Your job is to build a MODEL of what the maze might look like—WITHOUT opening the box."
3. Frame epistemically: "You can't see inside. So whatever model you create will be based on INDIRECT EVIDENCE. That's how scientists work with things they can't directly observe—planets, cells, atoms, ecosystems."
4. Demonstrate one type of test (tilting) but DON'T prescribe the procedure:
   - Hold box flat, tilt to one side
   - "Listen—did the marble roll? How far?"
   - "Feel—did it stop suddenly or gradually?"
5. Open it up: "What other tests could you do? What information would help you figure out what's inside?"
   - Take 2-3 student suggestions (shaking, tilting different directions, listening for bounces, etc.)
6. Key move: "Here's the challenge—you need to build a model that EXPLAINS your observations. Not just collect data, but use it to create a representation."
7. Set expectations:
   - "Different pairs might create different models—that's okay"
   - "Your model should fit your evidence"
   - "Be ready to defend WHY you drew it that way"

During: (Explore – 25 min) Phase 1: Collect Evidence & Build Initial Model (10 min) - Distribute boxes (1 per pair) and model-building sheets - Pairs design their own testing approach - As they collect evidence, they sketch a DRAFT model - Teacher circulates with questions: - "What does that observation tell you? What could it mean?" - "Could there be a different explanation for that sound?" - "Which parts of your model are you confident about? Which parts are guesses?" - No enforcement of procedure—students decide how to investigate - Recording should link observations → model features ("We heard X, so we think Y")

Phase 2: Model Presentation & Challenge (8 min) - Pairs post their models on chart paper with key evidence listed - Gallery walk: Other pairs examine models and leave sticky note questions: - "Why did you put a wall here?" - "What evidence supports this opening?" - "Could it be shaped differently and still fit your data?" - Pairs read challenges and prepare defenses

Phase 3: Model Revision & Uncertainty Mapping (7 min) - Pairs return to their models - Add labels: "Confident (strong evidence)" vs. "Uncertain (weak evidence/guess)" - Option to revise based on peer questions or additional tests - Some pairs might request to do more tests—allow this if time permits - Emphasize: "Scientific models always have uncertainties. That's honest, not wrong."

After: (Meta-Discourse on Modeling – 10 min) Compare Models (4 min) - Display 2-3 different models side-by-side - Ask: "These models are different. Does that mean someone is wrong?" - Guide toward: "If they both explain the evidence, they're both plausible models" - Probe: "What new test could help us choose between these models?"

Surface the Nature of Models (3 min) - "What's the difference between the model and the actual maze?" - Model = our representation based on evidence - Actual maze = physical reality we can't access (yet) - "Could your model be wrong even if it fits all your evidence?" - Yes! Other structures might produce same patterns - This is the nature of indirect inference

Connect to Scientific Practice (3 min) - "Where else do scientists build models of things they can't directly see?" - Atoms, black holes, Earth's core, protein folding, climate systems, evolutionary history - "What makes a good scientific model?" - Explains available evidence - Makes testable predictions - Honest about uncertainties - Can be revised with new data

The Reveal Decision (Optional) - Teacher decides: Open boxes or NOT? - Case for opening: Students see how close they got, experience satisfaction - Case for NOT opening: Preserves epistemic authenticity ("Science often doesn't get to peek inside") - Middle ground: Open SOME boxes but not all, or open next class period - **If boxes are opened, use strong framing:** - "Your model was good not because it matched perfectly, but because you justified it with evidence" - "Model quality is judged by reasoning, not accuracy of match" - "Notice what you couldn't have known from your evidence alone—that's the limit of indirect inference" - Explicitly de-center accuracy: "Even if your model differs from the actual maze, your scientific thinking was sound"

III. Assessment

Formative Assessment

Describe how you will check for understanding during and after the lesson.

During Phase 1 (Model-Building): - Observe whether pairs move beyond data collection to interpretation - Listen for evidence-based reasoning: "We think X because we observed Y" - Note which pairs treat models as provisional vs. seeking "the right answer" - Check if students link specific observations to specific model features

During Phase 2 (Challenges): - Monitor quality of peer questions: Do they probe evidence? - Observe how pairs respond to challenges: defensive? evidence-based? curious? - Note whether students can identify weak vs. strong evidence

During Phase 3 (Revision): - Check if pairs distinguish "confident" from "uncertain" model features - Observe willingness to revise vs. commitment to initial model - Listen for epistemically honest language: "We're not sure about this part"

Exit Ticket: Students answer: 1. "Draw one feature of your model and explain which observation(s) support it" 2. "What's one part of your model you're UNCERTAIN about? Why?" 3. "If you could do ONE more test, what would it be and what would it tell you?"

Self-Assessment: "Rate your confidence in your model: Low / Medium / High. What would increase your confidence?"

IV. Reflection & Next Steps

After teaching: Note what worked well and what didn't. Identify topics or skills to revisit. Record surprising student thinking. Suggest changes for next time.

I will aim to answer the following questions after the lesson has been taught: - Did students build models that genuinely explained their evidence, or just draw mazes? - How comfortable were students with uncertainty and multiple possible models? - Did students defend model features with evidence, or seek teacher validation? - What language did students use: "the answer" vs. "our model" vs. "one possibility"? - During challenges, did pairs engage in argumentation or just describe? - Which pairs revised models? What prompted revision? - Did students distinguish between data quality and interpretation quality? - How did students respond if I chose NOT to open boxes? Frustration? Understanding? - Did the meta-discourse about modeling land? Can students transfer to other contexts?

Note: Please attach student handouts and any other printed materials that students will need to complete the lesson.

Student Model-Building Sheet

Names: ______________________________ & ______________________________
Date: ______________________________

Marble Maze Investigation: Building a Model from Indirect Evidence

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Part 1: Collecting Evidence

What tests did you conduct? What did you observe?

Test/Action	What We Observed	What This Might Mean
Example: Tilted left	Marble rolled quickly	Maybe open channel on left side

Part 2: Initial Model

Draw your model of what might be inside the box:

[Large blank square for model diagram]

Key observations that support this model:

1.
2.
3.

Part 3: Challenges from Peers

Questions or challenges other pairs asked about our model:

1.
2.

Our response / How we defended our model:

Part 4: Model Confidence & Revision

Label your model with: - = Very confident (strong evidence) - = Somewhat confident (some evidence) - ? = Uncertain (guess / weak evidence)

Would you revise anything based on peer questions or new thinking?

What parts of the maze can you NOT figure out from your evidence?

Exit Ticket

1. Draw ONE feature of your model below and explain which observation(s) support it:

[Small box for diagram]

Evidence:

2. What's one part of your model you're UNCERTAIN about? Why?

3. If you could do ONE more test, what would it be and what would it tell you?

4. Self-Assessment - How confident are you in your model?

Low confidence Medium confidence High confidence

What would increase your confidence?

V. Further Revision Ideas

These are additional inquiry-enhancing moves suggested through analysis of the lesson's revision capacity. While not included in this version, they represent growth opportunities for continued development.

Allow Student-Designed Tests (Dimension 3)

- Remove all procedural guidance about HOW to test
- Challenge: "Figure out what's inside. You can test however you want."
- Students decide: What tests? In what order? How many?
- Debrief test design choices: "Why did you choose those tests? What did you learn about experimental design?"

- This fully centers problem-before-method and reveals student reasoning about investigation

Introduce Noise or Contradictory Data (Dimension 2 & 9)

- Build one box where marble sometimes sticks unpredictably
- Students must grapple with: "Our tests gave different results. What do we do?"
- Surfaces real scientific challenges: measurement error, repeatability, confidence intervals
- Extends ceiling significantly: How do you model with imperfect data?

Compare Model Predictions (Dimension 5 & 7)

- Before opening boxes, ask: "Based on your model, predict what will happen if I tilt it THIS new way"
- Test the prediction publicly
- If prediction fails: "What does that tell you about your model?"
- This shifts from descriptive modeling to predictive/testable modeling
- Deepens causal reasoning: models should explain AND predict

Never Open the Boxes (Dimension 8 & 9)

- Keep epistemic authenticity intact
- Close with: "You'll never know if you were exactly right. That's science."
- Emphasize: The quality of your model isn't measured by matching reality, but by how well it explains evidence and makes predictions
- Harder pedagogically but philosophically powerful
- Surfaces beliefs about certainty and truth in science

Add "Model Lineage" Documentation (Dimension 10)

- Track model evolution: Initial model → Revision 1 → Revision 2 → Final model
- Label why each revision was made: "Changed this because of peer question" or "New test showed X"
- Makes the revision process visible and valued
- Connects to how scientific models evolve over time (plate tectonics, atomic models, etc.)

Cross-Box Comparison (Dimension 1 & 10)

- If boxes have different internal structures (as recommended), compare models across pairs
- "How are your models different? Why? Did you have different evidence or interpret the same evidence differently?"

- Surfaces that context matters: what works for one system may not work for another
- Builds flexibility in thinking

Capacity Analysis Summary

Why This Lesson Has Very High Revision Capacity:

This lesson is **methodologically sound but epistemically overdetermined** in its LOW version. Its constraint signature: - **Lesson 01 (WODB):** authority & closure - **Lesson 02 (Mystery Graphs):** interpretation vs. explanation - **Lesson 03 (Headbandz):** efficiency vs. agency - **Lesson 04 (Marble Maze): procedure vs. epistemic uncertainty**

Key Insight: "Good inquiry doesn't come from better procedures, but from better questions about what evidence can (and cannot) tell us."

Core Message: The measuring is fine. **Inquiry lives in modeling, not measuring.**

Very High/High-Capacity Dimensions for Novice Revision:

1. **Curiosity & Genuine Puzzlement** (VERY HIGH) - The sealed box is inherently engaging; uncertainty is real and persistent; inquiry is suppressed by premature closure (answer key); revision is largely subtractive (delay reveal)

2. **Low Floor / High Ceiling** (HIGH) - Entry is immediate and sensory; ceiling capped by fixed procedure and answer key; novices can allow additional tests, refinement, ambiguity

3. **Context-Rich / Phenomena-Based** (HIGH) - Physical, hidden, meaningful phenomenon; authentic sense data; novices don't need to ADD context, only HONOR it epistemically

4. **Causal Explanation** (HIGH) - Cause-and-effect is central (tilt → movement); inference explicitly named; novices can ask students to justify WHY features explain data, compare alternative models

5. **Integration of Big Ideas** (HIGH) - Observation vs. inference, modeling from indirect evidence are foundational; lesson already gestures at these; novices can foreground modeling as provisional and connect to other contexts

6. **Collaboration & Discourse** (MEDIUM-HIGH) - Pairs already work together; shared data invites comparison; adding structured argumentation and public model comparison is high payoff with modest shifts

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Medium Capacity Dimensions:

7. **Openness & Multiple Pathways** (MEDIUM-HIGH) - Hidden maze COULD support multiple models, but lesson enforces single answer; allowing competing models is graspable because task already feels uncertain
8. **Student Agency** (MEDIUM) - Students collect data but don't decide what matters, what counts as good model, when sufficient; constrained by procedure and teacher ownership; revisable without new materials but requires releasing control
9. **Problem Before Method** (MEDIUM) - Problem is compelling but method fully front-loaded; requires loosening procedural control, allowing student-designed tests; pedagogically harder for novices but very revealing
10. **Connection-Making** (MEDIUM) - Treated as one-off investigation; novices can connect to astronomy, geology, medical imaging, etc.; optional but available

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Why This Is a Particularly Powerful Low Anchor:

Three key teaching virtues:

1. **Cleanly separates data from interpretation** - The distinction is named in LOW version but not yet LIVED; HIGH version makes this experiential
2. **Surfaces beliefs about certainty in science** - Students (and teachers) often assume data lead to THE answer; this lesson exposes that assumption when answer key is removed
3. **Reveals that inquiry lives in questions about evidence** - Procedure-following feels like "doing science" but isn't inquiry; inquiry emerges when we ask: "What CAN and CANNOT this evidence tell us?"

Pedagogical Leverage: Candidates learn that strong procedures don't equal inquiry. The transformation happens when students move from "following steps to find the answer" to "building and defending models from uncertain evidence."