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AI as Instructional Design Partner: Scaffolding Teachers in Phenomenon-Based Science Lesson Plan Development

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ABSTRACT

Phenomenon-based learning (PhBL) offers a powerful approach for achieving the three-dimensional learning goals outlined in contemporary science education standards, yet many teachers lack time and expertise to design comprehensive PhBL lessons that effectively integrate disciplinary core ideas, crosscutting concepts, and science practices. This article presents a research-informed framework of structured prompts that enable teachers to leverage artificial intelligence (AI) tools systematically throughout the six stages of PhBL lesson design: phenomenon selection, introduction planning, anticipating student observations and questions, extracting prior knowledge and initial models, designing investigation sequences, and developing summary tools and consensus explanations. Drawing on established PhBL frameworks, NGSS [1] principles, and the authors' extensive implementation experience, each prompt incorporates essential pedagogical features including attention to student misconceptions, grade-appropriate complexity, curriculum alignment, and integration of three-dimensional learning. By providing teachers with practical, ready-to-use prompts accompanied by implementation guidance, this framework democratizes access to high-quality PhBL instructional design and demonstrates how AI can serve as an effective partner in creating engaging, standards-aligned science instruction that supports deep student understanding of natural phenomena.

Keywords:
Phenomenon-based learning (PhBL), Artificial intelligence in education, Prompt engineering, Three-dimensional science learning, AI-assisted lesson planning

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1.INTRODUCTION

Lorem The emergence of generative artificial intelligence (GenAI) tools, such as ChatGPT, Gemini, and Claude, is fundamentally reshaping the production, application, and sharing of knowledge across disciplines, with a particularly significant impact on education. GenAI systems generate content, including text, images, and multimedia, in response to user prompts, offering educators unprecedented opportunities to streamline lesson planning, personalize instructional materials, and create tailored assessments for diverse learner needs [2], [3]. Yet despite scholarship cataloging GenAI's educational impacts, definitive evidence regarding how teachers evaluate, adapt, and responsibly use of AI-generated content remains rare, particularly in the context of contemporary pedagogical approaches like phenomenon-based learning (PhBL), with few studies, such as [4], explicitly bridging GenAI and PhBL design principles [5].

Phenomenon-based learning represents a transformative shift in curriculum design, positioning real-world phenomena as the foundation for student inquiry and interdisciplinary understanding. Designing effective PhBL lesson plans, however, demands significant pedagogical expertise and time investment, requiring teachers to identify engaging phenomena, craft driving questions, and scaffold learning experiences that integrate multiple disciplines. When educators encounter GenAI informally without structured training, they often develop fragmented or superficial understandings of its capabilities and limitations. Without targeted AI literacy training, teachers may misuse GenAI, trust unreliable outputs, perpetuate bias, or misalign AI-generated content with educational standards and learning objectives [6], [7].

This gap is particularly critical because both phenomenon-based learning and strategic GenAI implementation are relatively new to many educators. As classrooms become increasingly influenced by algorithmic tools, teachers must develop both the pedagogical knowledge to design robust PhBL units and the technical literacy to use GenAI responsibly and effectively. The solution lies not in using GenAI superficially for quick content generation, but in leveraging it strategically through deliberate prompt engineering, which is the practice of designing effective prompts to elicit high-quality outputs from GenAI systems [8]. This article addresses that need by providing educators with a step-by-step framework for designing phenomenon-based learning lesson plans using AI-assisted tools paired with carefully crafted prompts at each stage. By combining PhBL pedagogy with strategic prompt design, teachers can harness GenAI's potential while maintaining instructional integrity and avoiding superficial implementation. As [9] emphasize, overly simple one-shot prompts often produce ambiguous results, reinforcing the need for thoughtful and iterative prompt construction. To fulfill these gaps and challenges, the purpose of this article is threefold: (1) to present a comprehensive, research-informed framework of structured prompts that guide science teachers through the six stages of phenomenon-based lesson design using generative AI tools; (2) to demonstrate how pedagogical principles, three-dimensional learning criteria, and contextual specificity can be embedded into prompt engineering to produce high-quality, standards-aligned instructional outputs; and (3) to support the development of teachers' GenAI literacy by providing them with practical tools and implementation guidance that build their capacity to use AI responsibly and effectively in science instruction.

This article makes three distinct contributions to the emerging intersection of GenAI and phenomenon-based science education. First, while existing studies have explored either

GenAI-assisted lesson planning or PhBL implementation separately, very few have addressed their integration, and none, to our knowledge, have provided a structured framework that leverages AI specifically for phenomenon selection and the complete design of PhBL learning units. Second, unlike prior PhBL resources that offer teachers pre-designed phenomena and ready-made lesson plans, this framework adopts a capacity-building approach—teaching educators *how* to use AI tools to design their own PhBL units, rather than providing finished products. Third, by embedding pedagogical principles, three-dimensional learning criteria, and contextual specificity directly into each prompt, this framework transforms AI from a generic content generator into a pedagogically grounded instructional design partner, addressing the well-documented challenges of superficial AI use in education.

2.LITERATURE REVIEW

2-1. Introduction and Foundations of Phenomenon-Based Learning

Phenomenon-based learning puts real-world situations, not school subjects, at the center of instruction. Instead of teaching science, math, or language arts in isolation, teachers pose meaningful questions about events or issues that happen in the world and guide students to explore them from different angles. A phenomenon might be something like rising temperatures in your city, how local ecosystems change after a storm, or why certain areas have better access to clean water. The goal is for students to investigate these phenomena by asking questions, testing ideas, and building explanations together.

Phenomenon-based learning is not built on a single method. It draws from many ideas like social constructivism, situated cognition, and emergent learning, all of which emphasize learning by doing and learning with others [10], [11]. Trauth and Mulvena [12] outline six clear stages that thoroughly structure PhBL in science classrooms: introducing a compelling phenomenon; capturing students' observations and questions on a driving question board; developing an initial model; sequencing investigations to deepen understanding; prompting students to track their learning in summary tables; and developing a class consensus model and explanation. This process helps students build knowledge over time and from multiple sources rather than relying solely on textbooks. Readers interested in a more detailed breakdown of these stages are encouraged to consult Saberi and Nouri [13], who delve into Trauth and Mulvena's framework (2021) and demonstrate each step by testing a real-world phenomenon.

As Adipat [4] explains, students make sense of these complex topics by drawing on multiple disciplines and developing their own understanding. Since investigations start with real-world observations rather than predefined answers, they stay open-ended and flexible. Fisher et al. [14] argue that this way of learning mirrors how thinking works outside of school: it starts messy, follows curiosity, and values the process as much as the result.

The literature suggests several benefits of PhBL. Adipat [15] conducted a quasi-experimental study with Thai preservice teachers and found that participants who engaged in AI-supported PhBL activities demonstrated significant gains in interdisciplinary understanding and English-speaking skills compared to those receiving traditional instruction. Saberi and Nouri [11] report that PhBL encourages preservice teachers to integrate the three dimensions of the Next Generation Science Standards and it profoundly covers these dimensions (disciplinary core ideas, science and engineering practices, and cross-cutting concepts) while simultaneously considering the nature of science. Cross-disciplinary collaboration and real-life relevance are said to increase student engagement, motivation and metacognitive awareness, especially when tasks allow for creative problem-solving and student choice [16]. Fujii [17] notes that collaborative lesson planning, a hallmark of Japanese Lesson Study, helps teachers design lessons that anticipate students' reasoning and encourages reflective dialogue around instructional decisions.

2-2. Challenges in Designing and Implementing PhBL

Although PhBL promises more authentic and engaging learning, the literature identifies substantial barriers to its widespread adoption. Teachers often lack training and confidence in designing interdisciplinary inquiries and managing open-ended investigations [15]. Saberi and Nouri [11] highlight shortages of high-quality phenomena and curricular materials aligned with science standards, as well as a dearth of assessment instruments that measure learning across multiple dimensions. Penuel et al. [18] attempted to develop proximal transfer tasks that align with PhBL by embedding new phenomena distinct from those used in class; while students showed growth on these tasks, the authors noted that establishing equivalence across different phenomena was challenging. Time constraints and institutional pressures can push teachers towards pre-planned content rather than emergent inquiry. For example, in Japan's Lesson Study, Fujii [17] observed that careful planning and post-lesson reflection are critical but time-consuming.

2-3. GenAI in Education and GenAI Literacy

Advances in artificial intelligence are reshaping educational practice. Reiss [19] suggests that GenAI can enrich student learning by personalizing instruction and supplementing teacher efforts, yet warns that overreliance on GenAI risks diminishing the social nature of learning. Bozkurt et al. [20] similarly identify personalized learning and adaptive systems as major themes in GenAI-in-education research, but highlight that ethical considerations have been largely neglected. Several authors call for comprehensive GenAI literacy so that educators and learners can use these tools critically. Ng et al. [2] conceptualize GenAI literacy as encompassing four domains: knowing how GenAI works, using and applying GenAI, evaluating and creating with GenAI, and addressing ethical issues. Allen and Kendeou [3] extend this by proposing the ED-AI Lit framework, which emphasizes knowledge, evaluation, collaboration, contextualization, autonomy and ethics as key components of GenAI literacy. These frameworks stress that GenAI education should not be limited to technical skills but should also cultivate critical thinking and ethical reasoning.

Teacher education programs are beginning to address GenAI literacy. MacDowell et al. [21] describe a course for preservice and in-service teachers that introduced the Student Artificial Intelligence Literacy (SAIL) framework and asked participants to collaboratively author an open-access textbook on GenAI. The course promoted socio-emotional competencies and inclusive design while providing hands-on experiences with GenAI tools. Teachers reported increased confidence in navigating GenAI, suggesting that experiential and reflective learning can develop agency. Nevertheless, many educators remain uncertain about GenAI integration. Zhai [22] notes that teachers' engagement with GenAI falls along a continuum from passive observation to innovation and co-creation; moving along this continuum requires ongoing professional development and institutional support.

2-4. Generative AI and Prompt Engineering

GenAI tools such as ChatGPT can produce text, images and code on demand, opening new possibilities for educational design. However, effective use of these tools hinges on the ability to craft precise prompts. Korzynski et al. [23] argue that prompt engineering constitutes a new digital competence: by strategically framing inputs, educators can elicit more accurate and creative outputs from language models. They propose guidelines for prompt construction, such as including context, constraints and desired outcomes, and emphasize that proficiency in prompt engineering will be valuable across industries. Dang et al. [9] echo this, noting that simple one-shot prompts may lead to ambiguous or misleading responses; they call for user-interface designs that support iterative refinement and feedback.

2-5. Generative AI and lesson planning

Empirical studies highlight both the benefits and limitations of GenAI in lesson planning. ElSayary [24] conducted a qualitative study where preservice teachers used GenAI tools to design lesson plans. Participants appreciated the efficiency and breadth of ideas generated but often found the outputs superficial or misaligned with their instructional contexts; successful planning required iteratively revising prompts and critically evaluating GenAI suggestions. Van den Berg and du Plessis [25] produced several ChatGPT-generated lesson plans and concluded that these resources can serve as a starting point but must be adapted for accuracy, cultural relevance and differentiation. Similarly, MacDowell et al. [21] found that students initially relied heavily on AI-generated content but gradually shifted toward co-creation and critical evaluation after guided practice. Collectively, these findings suggest that GenAI can assist teachers by reducing routine workload and sparking creativity, yet human judgment remains indispensable.

2-6. Integrating GenAI with PhBL

The intersection of GenAI and PhBL offers opportunities to address some of the challenges identified earlier. Adipat [15] demonstrated that AI-enhanced PhBL improved preservice teachers' interdisciplinary understanding and speaking skills, partly because GenAI tools facilitated access to diverse resources and enabled personalized feedback. Teachers used GenAI to model questioning strategies, generate phenomenon-related scenarios and scaffold vocabulary development. However, the author cautioned that students needed additional training and practice to fully benefit from GenAI integration and emphasized that GenAI should enhance rather than replace teacher guidance.

Saberi and Nouri [11] note that PhBL approaches demand rich phenomena and well-crafted tasks; GenAI can help by brainstorming interdisciplinary links. While not focused on PhBL specifically, Fujii [17] and Farhang et al. [26] remind us that lesson planning is a collaborative, reflective process; GenAI can provide a starting framework, but teachers must negotiate goals, adapt content and anticipate misconceptions. Similarly, Reiss [19] envisions GenAI systems that bridge school and home learning, offering continuous support as students investigate real-world problems. Thus, integrating GenAI into PhBL has the potential to reduce design burdens, expand resources and personalize learning, yet its success depends on teacher agency, critical evaluation and alignment with pedagogical principles.

Teachers' roles will evolve as GenAI becomes embedded in PhBL. Zhai [24] argues that teachers may shift from observers to adopters, collaborators and innovators, gradually moving from passive use of AI-generated materials to co-creating content and personalizing instruction. Movement along this trajectory requires institutional support, clear policies and professional development.

2-7. Ethical and Practical Considerations in GenAI Using

The ethical implications of GenAI in education permeate the literature. Bibi et al. [27] conducted a mixed-methods study with educators, students, parents and policymakers, finding widespread concerns about data privacy, algorithmic bias and exacerbated inequalities. Many participants lacked trust in GenAI's fairness and emphasized the need for transparency and accountability. Bozkurt et al. [20] similarly warn that ethical issues are often sidelined in GenAI-in-education research and call for clear policies and codes of conduct. Reiss [19] cautions that GenAI may erode social learning opportunities and urges educators to learn from past technology adoption failures. According to Ng et al. [2] and Allen and Kendeou [3], AI literacy programs must include opportunities to interrogate bias, understand how algorithms make decisions and explore the societal implications of GenAI.

Equity and access remain pressing concerns. Chardonnens [16] notes that while AI-driven feedback can personalize learning for Generation Z, over-reliance may reduce students' planning and self-regulation skills. MacDowell et al. [21] underscore the importance of inclusive design and socio-emotional considerations, arguing that GenAI tools should be culturally responsive and support learners with diverse needs. According to Saberi and Nouri [11] warn that many PhBL resources are developed in Western contexts, according to Chardonnens [16], generative AI could help localize content, but only if prompts account for language and cultural differences. Teacher professional development must therefore prepare educators to adapt GenAI outputs, address bias and advocate for equitable access. Bibi et al. [27] propose an ethical framework emphasizing privacy, equity and accountability, urging policymakers to establish regulations and provide institutional support. Ultimately, GenAI integration should enhance, not undermine, human flourishing.

3.METHODOLOGY

This article adopts a framework development approach, situated within the tradition of conceptual and design-oriented research in education [28]. This study synthesizes established theoretical foundations—including Trauth and Mulvena's (2021) six-stage PhBL model, NGSS three-dimensional learning principles [1], and current research on prompt engineering and GenAI in education—to develop a novel, practical framework for AI-assisted PhBL lesson design. The framework development followed three phases: (1) a review of the literature on PhBL implementation challenges, GenAI capabilities in educational contexts, and prompt engineering principles; (2) iterative design and refinement of structured prompts aligned with each of the six stages of PhBL, informed by the authors' extensive experience in PhBL instruction in both K–12 and preservice teacher education settings; and (3) evaluation of prompt outputs against pedagogical criteria including standards alignment, grade-level appropriateness, scientific accuracy, and attention to student misconceptions. This approach is consistent with other published framework articles in science education that contribute practical tools grounded in research and theory without requiring empirical validation in the initial publication (e.g., [2], [3]).

4.RESULTS

AI-Assisted Prompt Engineering for Phenomenon-Based Science Lesson Design: A Step-by-Step Framework

Drawing on established PhBL frameworks ([12], [13]), NGSS three-dimensional learning principles [1], and the authors' extensive experience in designing and implementing PhBL instruction in both K-12 and preservice teacher education contexts, we have developed a comprehensive set of structured prompts that guide teachers through each stage of PhBL lesson design. These prompts are carefully crafted to incorporate essential pedagogical features: alignment with learning standards, grade-appropriate complexity, attention to student misconceptions, and integration of disciplinary core ideas, crosscutting concepts, and science practices. The following sections present these research-informed prompts sequentially, corresponding to the six key stages of PhBL implementation, providing teachers with practical tools to leverage AI effectively in creating high-quality, phenomenon-based science instruction.

4-1. Phenomenon Selection

The first and most critical step in designing phenomenon-based science instruction is selecting an appropriate phenomenon that will anchor the entire learning unit. Unlike traditional topic-based instruction, PhBL requires identifying an observable event in the natural or designed world that students can see, experience, or witness through media, rather than focusing on an abstract scientific concept. For instance, "water rising in an inverted jar over a burning candle" is a phenomenon, while "air pressure" is merely a concept used to explain it. An effective phenomenon must be engaging and question-provoking, aligned with learning objectives, accessible for investigation, capable of eliciting diverse hypotheses, and preferably relevant to students' lived experiences [12], [29]. Teachers often struggle to identify phenomena meeting all these criteria while also aligning with curriculum standards. The following prompt supports teachers in this initial phase by leveraging AI's capacity to search resources, analyze curriculum alignment, and generate multiple tailored phenomenon options. The prompt provides essential context about PhBL, clearly defines what constitutes a "phenomenon," specifies key selection criteria (detailed within the prompt), and requests AI to propose several high-potential phenomena with pedagogical rationales based on the teacher's specific grade level, content standards, and learning objectives.

Note. Content enclosed in brackets *[like this]* represents placeholders where teachers input their specific contextual information such as target grade level, curriculum topics, learning objectives, and student characteristics to receive customized, context-appropriate AI responses.

Initial Prompt for AI-Assisted Phenomenon Selection

I am a *[grade level]* science teacher designing a phenomenon-based learning (PhBL) lesson plan. PhBL is an instructional approach where students investigate real-world scientific phenomena through six key stages: (1) introducing the phenomenon, (2) creating questions-observations-interpretations tables, (3) developing initial models, (4) exploring the phenomenon, (5) completing summary tables, and (6) constructing consensus models and explanations. The goal is to help students integrate disciplinary core ideas, crosscutting concepts, and science and engineering practices while developing deeper understanding of how and why phenomena occur.

Definition of phenomenon in this context:

A scientific phenomenon is an observable event that occurs in the universe that we can use our science knowledge to explain or predict. It is something students can see, experience, or observe (directly or through media) that raises questions and requires scientific explanation—NOT just a topic or concept to be taught.

Examples:

- ✓ Water rising in an inverted jar over a burning candle (phenomenon)
- ✗ Air pressure, combustion, gas laws, thermal expansion (concepts/topics)
- ✓ A metal container collapsing after being washed with hot water (phenomenon)
- ✗ Phase changes (condensation), thermal expansion and contraction, air pressure (concepts/topics)

I will provide you with:

- Grade level: *[specify grade]*
- Curriculum topic: *[from textbook]*
- Learning objectives: *[from textbook/teacher guide]*
- Student context: *[optional: location, prior knowledge, cultural background]*

My first request is: Help me brainstorm and select an appropriate phenomenon.

The ideal phenomenon should be:

✓ Engaging and curiosity-provoking for students at this grade level

✓ Aligned with the specified learning objectives and curriculum standards

✓ Observable (directly or through video/images) and concrete—something that actually happens

✓ Question-generating, prompting students to ask "why?" and "how?"

✓ Connected to students' real-world experiences or local context

✓ Capable of eliciting diverse student hypotheses and explanations

✓ Explainable through multiple scientific concepts (interdisciplinary when possible)

✓ Appropriate in complexity for the students' developmental level

✓ Accessible in terms of materials/resources needed for investigation

✓ Safe for classroom exploration

Based on the curriculum information I provide, please:

1. Conduct a comprehensive search and analysis
2. Suggest 5-7 high-potential phenomena (observable events, NOT just topics) with brief descriptions
3. For each phenomenon, explain why it fits the criteria above
4. Indicate which disciplinary core ideas and crosscutting concepts each phenomenon addresses

Here is my curriculum information: *[Teacher inputs their specific content here]*

After receiving AI-generated phenomenon suggestions, teachers should critically evaluate each option against their specific classroom context, resource availability, and pedagogical goals to select the most appropriate phenomenon. If initial suggestions do not fully meet their needs, teachers can refine the AI output through iterative prompting by providing additional constraints, clarifying specific curriculum connections, or requesting modifications until they arrive at an optimal phenomenon for their instructional design.

4-2. Step 1: Introducing the Phenomenon

Once a phenomenon has been selected, the next critical decision involves determining how to introduce it to students in a way that captures attention, sparks curiosity, and launches meaningful investigation. The introduction serves as the "anchoring moment" that frames the entire PhBL unit, making its design crucial for student engagement and cognitive activation [12]. Teachers have multiple options for presenting phenomena such as live demonstrations, video recordings, image sequences, narrative scenarios, or combinations of approaches. Each option offers distinct advantages depending on the phenomenon's nature, available resources, and student characteristics. The following prompt guides teachers in designing an effective introduction by first specifying their selected phenomenon, then requesting AI to generate several diverse presentation strategies.

Prompt for Introducing the Phenomenon

I have selected the following phenomenon for my PhBL lesson plan: *[Phenomenon description]*
Target grade level: *[grade]*
Learning objectives: *[objectives]*
I need your help to design an engaging and effective way to introduce this phenomenon to my students. The introduction is the "anchoring" moment that will drive the entire unit, so it must capture students' curiosity and launch the investigation.
Requirements for the introduction:
✓ Capture immediate attention and spark curiosity
✓ Be observable—students can see, hear, or experience clear details
✓ Naturally raise authentic questions without giving away explanations
✓ Connect to real-world context (preferably relatable to students' lives)
✓ Be appropriate for classroom safety and time constraints
✓ Leave room for student wonder and investigation
Possible presentation methods:
- Narrative/storytelling approach (real or realistic scenario)
- Live classroom demonstration/experiment
- Video showing the phenomenon occurring
- Sequence of images (before/during/after)
- Virtual simulation or animated GIF
- Combination of methods
Please provide:
1. 3-4 specific introduction strategies for this phenomenon, using different presentation methods
2. For each strategy, describe:

- How to present it step-by-step
- What we will show or do
- Why this approach is engaging for this grade level
- Estimated time needed

3. Recommended strategy with rationale

Additionally, suggest:
- Opening narrative or script I could use to frame the phenomenon
- Specific prompts to guide student observation (e.g., "Look carefully at...", "What do you notice about...")

My phenomenon details:
[Teacher provides specific information]

Teachers should review the AI-generated introduction strategies, considering practical constraints such as available materials, class time, safety considerations, and their students' prior experiences, before selecting or adapting the most suitable approach for their classroom context.

4-3. Step 2: Anticipating Student Observations and Questions

After determining how to introduce the phenomenon, teachers must prepare for the diverse observations and questions students will generate during initial exposure. This anticipatory work is essential for effectively facilitating the Questions-Observations-Interpretations (QOI) table, which serves as a core PhBL tool for capturing student thinking [12]. Teachers need to distinguish between genuine observations (directly perceivable details) and inferences (interpretations or explanations), as students frequently conflate the two. Additionally, predicting the range of student questions helps teachers identify which inquiries will be most productive as "driving questions" for investigation. The following prompt requests AI to generate comprehensive lists of anticipated observations and questions based on the specific phenomenon introduction, highlight observation-inference distinctions, and suggest facilitation strategies for guiding productive classroom discourse.

Prompt for Anticipating Student Observations and Questions

Now that I have decided how to introduce the phenomenon, I need to anticipate what students will observe and what questions they will ask. This preparation helps me facilitate meaningful discussion and guide students toward productive investigation.

My phenomenon introduction:
[Teacher describes exactly how they will present the phenomenon - narrative, demo, video, images, etc.]
[Attach any images/videos that will be shown]

Target grade level: *[grade]*

Why anticipation matters:
Understanding possible student observations and questions helps me:
- Prepare to capture diverse student thinking on the Questions-Observations-Interpretations (QOI) table
- Recognize the difference between observations and inferences students make
- Identify which questions will drive meaningful investigation
- Plan how to guide discussion toward productive inquiry paths

Please provide:

1. ANTICIPATED OBSERVATIONS
What specific, observable details will students likely notice when experiencing this phenomenon?
- List 10-15 diverse observations across different levels (surface to detailed)
- Important: Distinguish between true observations (what can be directly seen/heard/measured) and inferences (interpretations/explanations)
- Include common instances where students might state inferences as observations
- Note details students might overlook but should be prompted to notice

2. ANTICIPATED QUESTIONS
What questions will this phenomenon naturally raise for students at this grade level?
- List 12-18 authentic student questions (use student-appropriate language)
- Include various question types: "Why...?", "How...?", "What would happen if...?", "What caused...?"
- Mark which 2-3 questions are most productive as "driving questions" for investigation
- Note any off-topic or unproductive questions that might arise

3. OBSERVATION vs. INFERENCE GUIDANCE
- Provide 3-4 examples of statements students might make, labeled as observation or inference
- Suggest prompts I can use to help students distinguish between the two (e.g., "Is that something you can see directly, or is that your explanation for what you see?")
Present your analysis in a format I can use during class facilitation.

Teachers should use these AI-generated predictions as a preparatory guide, recognizing that actual student responses may vary, and remain responsive to unexpected observations or questions that emerge during classroom implementation.

4-4. Step 3: Developing Initial Models (Prior Knowledge Extraction)

After collecting student observations and identifying driving questions, teachers must anticipate the initial explanatory models and hypotheses students will propose based on their existing knowledge, prior to any formal instruction. This stage is critical for understanding what prior conceptions (both accurate and inaccurate) students bring, identifying common misconceptions, and designing investigations that specifically address student-generated ideas [11]. Teachers provide AI with the selected driving question(s) and phenomenon context, and the prompt requests comprehensive analysis of anticipated student hypotheses, underlying prior knowledge, prevalent misconceptions, and the cognitive resources that can support conceptual development. This preparation enables teachers to facilitate productive group dialogue and design targeted investigations in Step 4.

Prompt for Developing Initial Models

After introducing the phenomenon and collecting student observations and questions, we identified the following as our main driving question(s): [Teacher states the question(s) the class will focus on]
Now I need to anticipate the initial models, hypotheses, and explanations students will propose based on their prior knowledge—BEFORE we conduct any investigations or provide instruction.
Target grade level: *[grade]*
Phenomenon*: [brief description]*

Driving question: *[the question]*
Purpose of this stage: Extracting students' initial ideas helps me:
- Understand what prior knowledge students bring (correct and incorrect)
- Identify common misconceptions that need addressing
- Recognize naive or intuitive theories students hold
- Design investigations that specifically test student-generated hypotheses
- Plan instruction that builds on or challenges existing mental models
Please provide:
1. ANTICIPATED INITIAL MODELS/HYPOTHESES
What explanations will students likely propose to answer the driving question?
- List 5-8 diverse initial hypotheses students might suggest (use student language)
- Include both scientifically accurate and inaccurate ideas
- Note which ideas are most common for this age group
- Indicate which hypotheses reflect common misconceptions
2. PRIOR KNOWLEDGE ANALYSIS
- What relevant concepts have students studied in previous grades that they'll draw upon?
- What every day experiences or observations inform their thinking?
- What "intuitive physics/chemistry/biology" might lead them astray?
3. COMMON MISCONCEPTIONS
- What are the well-documented misconceptions about this phenomenon or related concepts?
- Why are these misconceptions compelling or persistent?
- What makes the scientifically accurate explanation counterintuitive?
4. COGNITIVE RESOURCES
- What correct prior knowledge can serve as a foundation for building new understanding?
- What analogies or familiar experiences might students use (helpful or misleading)?
5. INITIAL MODEL EXAMPLES
Provide 2-3 example student statements like:
- "I think *[X happens]* because *[student's reasoning] ..."*
- Label each as: scientifically accurate, partially correct, or misconception
This analysis will help me facilitate productive group dialogue and design targeted investigations for Step 4.

Teachers should use these predictions to prepare for diverse student thinking during class discussions, recognizing that initial models represent valuable starting points for inquiry rather than deficits to be corrected immediately.

4-5. Step 4: Exploring the Phenomenon (Designing Investigations)

Step 4 represents the most substantive phase of PhBL, where students actively test their initial hypotheses through carefully sequenced investigations. Teachers must design a coherent progression of research activities such as hands-on experiments, data analysis, video observations, simulations, or readings, that systematically address student-generated hypotheses and guide conceptual development toward scientific understanding [12]. This requires selecting 2-4 common initial student models from Step 3 and crafting activities that help students use if-then-therefore reasoning to make testable predictions, gather evidence, and iteratively revise their thinking. Teachers provide AI with their selected hypotheses, available resources, and time constraints, and the prompt requests a detailed investigation sequence specifying: which hypothesis each activity addresses, how to structure predictive models, what evidence students will encounter, expected outcomes, conceptual connections to DCIs and CCCs, and necessary materials. This comprehensive design ensures that investigations build systematically from student ideas toward scientific explanations.

Prompt for Exploring the Phenomenon

Based on the anticipated initial models from Step 3, I have identified the most common student hypotheses that will guide our investigation. Now I need to design a coherent sequence of research activities that will help students test, revise, and refine their thinking.
Selected initial student hypotheses to address: *[Teacher lists 2-4 main hypotheses students are likely to propose]*
Target grade level: *[grade]*
Phenomenon: *[brief description]*
Driving question: *[the question]*
Available class time: *[e.g., 3-4 class periods]*
Available resources: *[lab equipment, technology, budget constraints, etc.]*
Purpose of this stage: Design activities that help students:
- Test their initial hypotheses using evidence
- Use if-then-therefore reasoning to make predictions
- Collect data that confirms, refines, or refutes their models
- Iteratively revise their thinking based on new evidence
- Build understanding of scientific concepts and crosscutting concepts

I need your help to design:
1. INVESTIGATION SEQUENCE: Create a coherent progression of 4-6 research activities that:
- Address each major student hypothesis systematically
- Build in complexity (simple → complex)
- Lead students toward the scientific explanation step-by-step
- Integrate multiple types of evidence

2. FOR EACH INVESTIGATION/ACTIVITY, provide:
a) Hypothesis being tested: Which student idea does this address?
b) Predictive model structure:
- Help students frame testable predictions using: "If *[hypothesis],* and *[we do X]*, then [we predict Y], therefore *[conclusion]"*
- Provide example prediction statements

c) Activity type and description:
- Hands-on experiment (with procedure)
- Data analysis activity
- Video observation (suggest specific video or describe what to look for)
- Interactive simulation (suggest tools like PhET)
- Reading/article analysis
- Image sequence analysis
- Real-world case study
- Or combination

d) Evidence students will gather: What will they observe/measure/discover?
e) Expected outcome: Will this evidence support, refute, or complicate their hypothesis?
f) Conceptual development: What scientific concept(s) does this activity illuminate?
g) Crosscutting concept connection: Which CCC is emphasized? (patterns, cause-effect, systems, scale, energy-matter, structure-function, stability-change)
3. RESOURCES AND MATERIALS: For each activity, specify or suggest:

- Videos (describe content or provide links)
- Images/photos/GIFs (describe what to show)
- Simulations or virtual labs
- Reading materials or articles (describe topic/level)
- Experiment materials (if hands-on)
- Graphic organizers or data collection templates

Design this investigation sequence to be practical, engaging, and conceptually coherent—leading students from their initial ideas toward scientific understanding.

Teachers should review the AI-generated investigation sequence for practical feasibility, adapting activities to match available resources, time constraints, and student readiness levels, while maintaining the conceptual coherence of the progression from initial ideas to scientific understanding.

4-6. Combined Steps 5 & 6: Summary Table and Consensus Model

After completing the investigation sequence, students must synthesize their learning by organizing findings (Step 5) and constructing a scientifically accurate consensus explanation (Step 6). The summary table serves as a scaffold for tracking conceptual progression by documenting what students did, observed, and learned at each investigation stage, and how evidence shifted their thinking from initial models toward scientific understanding [12]. This organizational tool then supports development of the final consensus model, where students integrate evidence and reasoning to answer the driving question comprehensively. Teachers provide AI with their investigation sequence and learning objectives, and the prompt requests two interconnected products: (1) a complete, grade-appropriate summary table showing the progression from initial ideas through investigations to scientific concepts, and (2) a rigorous yet accessible scientific explanation that addresses the driving question, explicitly connects to the three dimensions of NGSS (DCIs, CCCs, SEPs), addresses initial misconceptions, and includes real-world applications. These products serve both as teaching tools for facilitating class discussion and as reference materials for student learning consolidation.

Prompt for Summary Table and Consensus Model

I have completed Step 4 (Exploring the Phenomenon) with the following investigation sequence:

[Teacher briefly summarizes the activities/investigations conducted]

Phenomenon: *[description]*

Driving question: *[the question]*

Target grade level: *[grade]*

Learning objectives: *[curriculum goals]*

Now I need two interconnected products to help students synthesize their learning and reach scientific understanding:

PART A: SUMMARY TABLE (Step 5)

Throughout our investigations, students have been documenting what they learn at each stage. Now I need a complete, organized summary table that consolidates all learning from this PhBL unit.

- ➢ Purpose:

- Provide students with an exemplar of how to organize their findings

- Show connections between initial ideas, investigations, evidence, and conclusions

- Serve as a reference tool for constructing the final consensus model

Please create a comprehensive summary table with these columns:

| Investigation Stage | What We Did | What We Observed/Found | How This Changed Our Thinking | Scientific Concept(s) Learned |

- ➢ **Requirements**:

- Include ALL major investigations from Step 4

- Use grade-appropriate, student-friendly language

- Show the progression from initial ideas → revised thinking → scientific understanding

- Highlight key evidence that led to conceptual shifts

- Connect to relevant Disciplinary Core Ideas (DCIs) and Crosscutting Concepts (CCCs)

- Be detailed enough to support student review and discussion

- Format should be clear and visually organized

PART B: CONSENSUS MODEL & SCIENTIFIC EXPLANATION (Step 6)

Based on the investigations and summary table, students now need to construct a final consensus model and explanation that answers the driving question scientifically.

I need you to provide:

1. CONSENSUS MODEL EXPLANATION: Write a comprehensive scientific explanation of the phenomenon that:

- Directly answers the driving question

- Is scientifically accurate and evidence-based

- Uses grade-appropriate language while maintaining scientific rigor

- Integrates relevant scientific vocabulary naturally

- Length: [specify, e.g., 2-3 paragraphs for middle school]

2. CONCEPTUAL BREAKDOWN: After the explanation, identify and briefly describe:

a) Disciplinary Core Ideas (DCIs) addressed:

- List relevant physics, chemistry, biology, or earth science concepts

- Explain how each connects to the phenomenon

b) Crosscutting Concepts (CCCs) integrated:

- Identify which CCCs are central (patterns, cause-effect, systems, scale, energy-matter, structure-function, stability-change)

- Explain their role in understanding the phenomenon

c) Science and Engineering Practices (SEPs) used:

- Which practices did students engage in during this unit?

3. **REAL-WORLD CONNECTIONS**: Suggest 2-3 everyday examples or applications that:

- Connect this phenomenon to students' lives
- Demonstrate the same scientific principles
- Could be used to deepen understanding

4. **COMMON MISCONCEPTIONS ADDRESSED**: Explicitly state:

- What students likely believed initially (from Step 3)
- What the scientific evidence showed instead
- Why the misconception is compelling but incorrect

5. **EXTENSION OPPORTUNITIES**: Suggest 1-2 ways to deepen learning:

- Related phenomena to explore
- Simulations (e.g., PhET) that reinforce concepts
- Engineering design challenges that apply the science

Format the output so it is:

- Ready for classroom use (can be shared with students directly or adapted minimally)
- Aligned with *[specify standards if applicable, e.g., NGSS MS-PS3-4]*
- Appropriate for the cognitive level of *[grade]* students
- Scientifically rigorous yet accessible

This will serve as both a teaching tool for me and a learning reference for students as we conclude the PhBL unit.

Teachers should adapt the AI-generated summary table and consensus explanation to match their students' language proficiency and conceptual readiness, using these materials as flexible guides for facilitating final synthesis discussions rather than as scripts to be followed verbatim.

5. Limitations and Future Directions

Many schools and teachers have uneven access to AI tools. In under-resourced schools, limited devices or slow internet can prevent teachers from trying AI in lesson planning. These limitations mean that the benefits of AI are not reaching all classrooms equally. Teachers also differ widely in their comfort with AI technology. We cannot assume all teachers are confident or experienced in using digital tools. In reality, many educators have had little or no formal training with AI and may not feel prepared to use it in instruction. Without guidance, teachers may struggle to write effective prompts, check AI-generated content, or integrate AI into lesson planning in a meaningful way. This shows the need for professional development to build teachers' AI skills.

Another major limitation comes from the AI systems themselves. Generative AI sometimes "hallucinates," meaning it produces information that sounds correct but is inaccurate or misleading. It may also oversimplify scientific ideas or introduce biased examples based on the data it was trained on. Because of this, teachers must review AI-generated suggestions carefully. AI should support, not replace, the teacher's judgment, especially when accuracy and scientific reasoning are essential.

Equity issues also need attention. The digital divide means some schools and communities have far fewer technological resources than others. If only well-equipped schools can take advantage of AI-assisted lesson design, existing inequalities may grow. Language and cultural barriers play a role as well, since many AI tools perform best in English and may reflect Western cultural norms. This means teachers may need to adapt AI-generated content to match students' languages, cultures, and lived experiences so that instruction is truly inclusive.

Looking ahead, several steps can help address these challenges:

1. More research is needed to study how AI-supported lesson design works across diverse contexts—urban and rural schools, high-needs districts, and teachers with different levels of experience. This research can highlight what additional support teachers need and which parts of the framework work best in different environments.
2. Teacher training is essential. Professional development should focus on building AI literacy, including how to create effective prompts, evaluate AI output, and use AI responsibly in science lesson planning. Supporting teachers in learning these skills will help ensure they use AI with confidence and care.
3. Supportive policies are needed to guide safe and fair AI use in schools. District leaders can create guidelines that promote responsible use while protecting student data and ensuring equitable access. Policies can also encourage funding for technology in under-resourced schools and support the development of culturally responsive AI tools. Clear policies can help teachers use AI in ways that are safe, ethical, and aligned with educational goals.

By addressing access, training, and policy needs, the education community can help ensure that AI becomes a helpful partner for all teachers (not just those in well-resourced settings) and that it enhances learning without replacing the essential role of educators.

6. CONCLUSION

The central argument of this article is straightforward: without strategically designed prompts grounded in pedagogical principles, generative AI can easily be used superficially in lesson planning. This article has presented a set of purposefully crafted prompts covering the six stages of phenomenon-based learning unit design that demonstrate an alternative approach. In this approach, AI amplifies teacher expertise rather than replacing it. Beyond classroom teachers, this framework has practical applications for: (a) teacher educators who can use the prompts as training tools in preservice and in-service professional development programs; (b) curriculum developers who can adapt the framework for creating PhBL materials at scale; (c) school administrators who need practical examples of responsible AI integration in instruction; and (d) researchers who can use the framework as a basis for empirical studies on prompt engineering and AI-assisted lesson planning.

Prompt engineering is not simply about asking AI questions; it is about framing questions in ways that produce educationally sound outputs. As Korzynski et al. [23] established, prompt engineering is a new digital competence involving strategic framing of inputs to bring out accurate and creative outputs. The prompts presented here exemplify this principle. They are not generic requests; they are *pedagogically purposeful* prompts designed to maintain alignment with PhBL principles and learning standards at every stage of lesson design.

These prompts succeed where generic (general and common) AI requests fail because they embed multiple layers of pedagogical specificity. Each prompt begins by defining the PhBL framework, distinguishing phenomena from topics, and articulating clear pedagogical goals. This contextual specificity prevents the generic, misaligned outputs that teachers receive when asking AI to simply "write a lesson plan." Rather than relying on AI's general knowledge, the prompts require teachers to provide critical contextual information: curriculum topic, learning objectives, grade level, student context, and available resources. This ensures that AI suggestions are grounded in the teacher's specific instructional reality, not in abstract best practices.

Beyond context, each prompt articulates explicit criteria and characteristics for success at that particular stage of lesson design. For instance, the phenomenon selection prompt specifies eight criteria the phenomenon must meet (engagement, alignment with standards, observability, safety, accessibility, interdisciplinary potential, and developmental appropriateness). The introduction design prompt clarifies why the introduction is an "anchoring" moment and defines requirements for capturing curiosity, raising authentic questions, and connecting to real-world contexts. By making these criteria explicit, the prompts enable teachers to evaluate AI suggestions against pedagogically informed standards rather than accepting output uncritically. According to Kerr and Kim [30], while generative AI can support lesson planning by enhancing efficiency and creativity, it still requires careful teacher guidance and structured prompting to overcome its limitations in pedagogical depth and accuracy.

Crucially, the prompts guide teachers to anticipate student thinking before AI generates suggestions. Teachers must consider grade-level development, identify prior knowledge students bring, anticipate common misconceptions, and consider diverse learner needs. This anticipatory work forces deliberate pedagogical thinking and ensures that subsequent AI suggestions build on grounded understanding of students, not assumptions. Finally, by requiring specification of learning standards and grade level within each prompt, these frameworks prevent the misalignment problems that researchers have identified when AI generates lesson materials without standards guidance. Together, these characteristics transform prompt engineering from a casual query into a structured, educationally grounded design practice.

We envision that by engaging repeatedly with these carefully structured prompts, teachers will develop not just technical facility with AI tools, but genuine GenAI literacy. Through this process, they will learn to write effective prompts, evaluate AI outputs critically, understand how prompt quality shapes content quality, and anticipate when AI suggestions may misalign with pedagogical goals. Over time, this iterative practice of prompt refinement and critical evaluation builds the evaluative and ethical reasoning capacities that AI literacy frameworks emphasize. In this way, strategic prompt engineering becomes both a practical lesson design tool and a vehicle for developing the critical AI competencies teachers need as generative AI becomes embedded in educational practice.

Throughout this article and in every prompt, the teacher's role is explicitly centered. ElSayary [24] found that successful AI-assisted lesson planning required iterative refinement and critical evaluation; passive acceptance of AI output led to weak designs. The prompts embed this critical stance by positioning the teacher as curator, evaluator, and final decision-maker. The teacher (not AI) determines which phenomenon engages their students, which introduction strategy captures their particular group's curiosity, and which student hypotheses merit investigation. Adipat [15] cautioned that GenAI should "augment rather than replace teacher guidance." These prompts operationalize that principle. They support teachers in planning investigations and anticipating student thinking, but orchestration of in-the-moment instruction, recognition of emerging ideas, and responsive scaffolding remain uniquely the teacher's role [21]. Teachers also remain responsible for equity and ethics including culturally responsive adaptation, inclusive design, and advocacy for equitable access.

Strategic prompt engineering grounded in pedagogical principles offers a path toward responsible, effective AI integration in phenomenon-based learning. The prompts in this article demonstrate that GenAI can assist with the legitimate burdens of lesson design. These include generating phenomena ideas, anticipating student questions, designing investigation sequences, all without displacing the teacher's essential role as pedagogical expert, curriculum designer, and advocate for equitable learning. When teachers use carefully structured prompts that require contextual information, specify grade-level and standards alignment, and guide anticipation of student thinking, they harness AI's generative capacity while maintaining instructional integrity and teacher agency. This is collaboration, not substitution.

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