



ORIGINAL RESEARCH PAPER

Reimagining Physics Education in Iran: From Memorization to Meaningful Learning*Fatemeh Arbabifar *,1**1Department of Physics Education, Farhangian University, P.O. Box 14665-889, Tehran, Iran.***ABSTRACT****Keywords:***Rote learning, inquiry-based learning, active learning, curriculum reform, pedagogical strategies***1. Corresponding author:***f.arbabifar@cfu.ac.ir*

Physics education in Iran has traditionally emphasized rote memorization and exam preparation, often at the expense of conceptual understanding and scientific reasoning. This teacher-centered model limits student engagement and intellectual growth. This paper advocates for a shift toward a learner-centered approach that fosters student agency, critical thinking, and meaningful engagement with physics. It aims to reimagine classrooms as spaces for inquiry, collaboration, and cognitive development. Drawing on pedagogical research and classroom evidence, the paper critiques the limitations of conventional instruction and proposes a human-centered framework informed by Self-Determination Theory, Constructivism, and Cognitive Load Theory. It emphasizes inclusive learning environments, explicit instruction in thinking skills, and active learning strategies. A sample lesson on Bernoulli's Principle demonstrates how abstract concepts can be taught through experiential, inquiry-based methods. By aligning teaching practices with students' psychological needs and cognitive capacities, educators can enhance motivation, deepen understanding, and prepare learners to think scientifically. This framework supports curriculum reform in Iran, equipping students with the skills to explore creatively, reason critically, and engage meaningfully with the world of science

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INTRODUCTION

Despite decades of curricular reform, physics education in Iran remains predominantly traditional, characterized by rote memorization, algorithmic problem-solving, and exam-oriented instruction [1]. This pedagogical model has led to a systemic disconnect between students' procedural proficiency and their conceptual understanding of physics. Empirical observations and interviews with high-achieving students in national entrance exams reveal a troubling pattern: while they demonstrate technical competence in solving textbook problems, they often lack the ability to contextualize physical principles, articulate their historical development, or relate them to everyday phenomena. This suggests a deeper epistemological issue—physics is taught as a set of abstract rules rather than as a coherent, inquiry-driven discipline. International research has consistently shown that active learning strategies—such as peer instruction, diagnostic assessment, and collaborative problem-solving—can significantly improve conceptual understanding and student engagement [2–6]. Studies by Hake [7] and Freeman et al. [8] provide robust evidence that interactive engagement yields higher learning gains across STEM disciplines. These findings have informed global efforts to shift physics education toward constructivist models that emphasize reasoning, reflection, and conceptual change. However, while the efficacy of active learning is well-documented, there is limited research on how these approaches can be adapted to culturally specific contexts like Iran, where entrenched pedagogical norms and systemic constraints pose unique challenges. Existing literature tends to focus on Western implementations, leaving a gap in understanding how conceptual reform can be localized within Iranian educational structures. This study addresses that gap by critically examining the structural and cultural barriers to reform in Iran's physics education system and proposing context-sensitive strategies for transformation.

The paper begins by articulating a human-centered philosophy of physics education rooted in inquiry and conceptual coherence. It then identifies key principles for designing collaborative learning environments, fostering student motivation, and supporting teachers in transitioning from authoritative instruction to facilitative practice. The final sections offer practical guidance for lesson design and present a classroom-ready example—a physics lesson on Bernoulli's Principle—that embodies the proposed framework.

Throughout this paper, terms such as *human-centered framework*, *inclusive learning environments*, and *alignment with cognitive development* are used to describe the proposed transformation in physics education. To ensure conceptual clarity and theoretical grounding, it is important to define these terms and connect them to established educational theories. A human-centered framework refers to an instructional approach that prioritizes students' psychological needs, autonomy, and personal agency. This concept is rooted in Self-Determination Theory (SDT) [9], which emphasizes the importance of autonomy, competence, and relatedness in fostering intrinsic motivation and meaningful learning. Inclusive learning environments are informed by Constructivist theory [10] which posits that learners construct knowledge through social interaction and personal experience. Inclusivity in this context means recognizing diverse backgrounds, prior knowledge, and learning styles, and creating equitable opportunities for all students to engage in scientific inquiry. Alignment with cognitive development draws from Cognitive Load Theory [11], which highlights the importance of managing the complexity of instructional content to avoid overwhelming students' working memory. In physics education, this involves scaffolding abstract concepts, using visual representations, and sequencing tasks to support progressive understanding.

By explicitly linking these pedagogical principles to SDT, Constructivism, and Cognitive Load Theory, this paper provides a robust theoretical foundation for its proposed reforms and clarifies the rationale behind its instructional strategies.

Cultivating a Human-Centered Approach to Physics Education

Creating a positive and enriching atmosphere in the physics classroom requires far more than delivering equations and scientific facts. It demands the intentional cultivation of a space where intellectual curiosity, emotional safety, and meaningful human connection can thrive. In this context, the physics teacher plays a pivotal role—not only as a facilitator of conceptual understanding but as a model of scientific thinking, ethical behavior, and inclusive values.

To align classroom practice with the deeper goals of physics education, educators must reflect on questions that go beyond pedagogy:

- **Do I embody the habits of mind I hope my students will adopt?** A physics teacher's conduct—whether in reasoning through a problem or engaging in classroom dialogue—serves as a living example. Precision, integrity, and enthusiasm for discovery should be evident not just in instruction, but in everyday interactions [12].
- **Do I genuinely care about my students—not only as learners, but as individuals?** Effective physics education begins with empathy. When students feel seen and respected, they are more likely to engage with complex ideas. Recognizing their emotional and personal needs builds trust and fosters motivation, especially in a subject often perceived as abstract or intimidating [13].
- **Am I doing everything within my capacity to support their learning?** Professional commitment in physics teaching means continuously refining instructional strategies, responding thoughtfully to questions, and offering diverse opportunities for exploration—whether through experiments, simulations, or real-world applications. This dedication reflects a teacher's responsibility to nurture both understanding and confidence [14].
- **Do I see all my students, or only a select few?** Equity in physics education requires that every student—regardless of prior achievement or background—be acknowledged and supported. Each learner deserves access to the tools of scientific inquiry and the chance to experience the joy of discovery.

By engaging honestly with these questions, physics educators can begin to transform their classrooms into spaces where physics is not only taught, but lived—where students are empowered to question, investigate, and connect the laws of nature to the world around them. In such environments, physics becomes more than a subject; it becomes a lens through which students learn to think critically, act ethically, and imagine boldly.

Humanistic Foundations for a Collaborative and Reflective Physics Classroom

A meaningful physics education is not limited to the transmission of scientific content—it is a human-centered endeavor that nurtures curiosity, intellectual courage, and mutual respect. In this view, learning is not merely cognitive but deeply relational, shaped by the emotional and social dynamics of the classroom. Two essential components of such an environment are the teacher's epistemic stance and the norms that guide classroom interactions. Together, they create the cognitive and emotional conditions in which students begin to think and act like physicists. To foster deep engagement, scientific

reasoning, and collaborative inquiry, the physics classroom must be intentionally designed—both physically and socially—as a space that encourages dialogue, reflection, and shared responsibility for learning [15]. Within this humanistic framework, students are not passive recipients of knowledge but active participants in a community of inquiry. The following principles offer a foundation for cultivating such a space—one where students learn physics by engaging with ideas, with each other, and with the broader human experience of making sense of the natural world. The following principles offer a humanistic framework for cultivating a physics classroom where students not only learn scientific concepts but also develop the reflective, inquisitive, and collaborative mindset of physicists.

1. Seating in a Circle

Arranging students in a circle or semi-circle can significantly enhance the dynamics of physics instruction by breaking down traditional hierarchical structures and fostering a sense of equality among participants. Unlike rows of desks that position the teacher as the central authority, circular seating promotes a more democratic and dialogic atmosphere. In this layout, students are more likely to make eye contact, listen actively, and engage in thoughtful exchanges with both peers and the instructor. This physical reconfiguration is especially powerful during conceptual discussions [16], whether exploring the nuances of energy conservation, debating the implications of quantum paradoxes, or unpacking the philosophical foundations of relativity. It encourages students to voice their ideas, question assumptions, and build on each other's insights. The classroom becomes a community of inquiry, where learning is co-constructed through dialogue rather than passively received. In physics, where abstract concepts often require deep reflection and multiple perspectives, such an environment can be transformative.

2. Reading Aloud in Turn

Having students read aloud from physics textbooks, problem statements, or excerpts from scientific papers fosters a sense of shared ownership over the learning material. This practice transforms passive reading into an active, communal experience, where students engage with the language of science and build confidence in expressing complex ideas verbally. It also enhances scientific literacy by helping learners internalize terminology, structure, and reasoning patterns common in physics discourse. For example, reading a passage about Newton's laws aloud can prompt spontaneous questions, peer clarification, and deeper discussion. A student might pause to ask, "What exactly does 'net force' mean in this context?"—opening the door for collaborative exploration. This approach not only supports comprehension but also cultivates a classroom culture where inquiry is vocal, visible, and shared.

3. The Teacher as a Model of Thinking

Rather than assuming the role of an all-knowing authority, the physics teacher should embody the stance of a thoughtful inquirer—someone who models how to approach complex problems, ask meaningful questions, and navigate uncertainty with intellectual curiosity. By thinking aloud while analyzing a puzzling circuit diagram or grappling with conflicting experimental data, the teacher makes scientific reasoning visible and accessible. This approach humanizes the discipline, showing students that science is not a static body of facts but a dynamic process of exploration, revision, and evidence-based judgment [17]. When students witness their teacher engaging authentically with challenges, they are more likely to adopt similar habits of mind—becoming more reflective, persistent, and open to learning through trial and error. In this way,

the physics classroom becomes a laboratory not just for scientific content, but for cultivating scientific character.

4. Clear Rules and Norms

To support this inquiry-driven model of teaching, the classroom must also be governed by clear and consistent norms that promote respectful and intellectually safe discourse. Norms such as taking turns to speak, respecting differing hypotheses, and grounding arguments in evidence are essential for fostering a collaborative learning environment. In physics, where understanding often emerges through debate, experimentation, and the refinement of ideas, these norms provide the scaffolding for productive engagement. When students know that their contributions will be heard without interruption, that alternative viewpoints are welcomed, and that claims must be supported by data or reasoning, they are more likely to participate authentically. These practices not only foster mutual respect but also mirror the epistemic values of scientific inquiry. By embedding such norms into the daily rhythm of instruction, educators cultivate a space where curiosity thrives, critical thinking is valued, and learning becomes a shared endeavor.

5. Avoiding Excessive Praise

While encouragement plays a vital role in student motivation, excessive or vague praise can undermine authenticity and inadvertently discourage intellectual risk-taking. In physics education—where grappling with complex concepts and making mistakes is part of the learning journey—feedback should be specific, constructive, and growth-oriented [18]. Rather than offering generic affirmations like “Good job,” teachers can provide targeted comments such as: “*Your explanation of projectile motion was clear—can you now apply it to a real-world example, like a basketball shot or a rocket launch?*” This kind of feedback affirms what the student has done well while inviting deeper thinking and application. It reinforces the idea that learning is an ongoing process and that mastery involves refinement, not just correctness. By striking a balance between encouragement and challenge, educators help students build genuine confidence—rooted in effort, understanding, and the willingness to stretch beyond their comfort zones.

6. The Teacher’s Willingness to Express Uncertainty

When teachers openly share moments of confusion—such as grappling with a counterintuitive result in a lab experiment—they model intellectual humility and curiosity. This invites students to embrace uncertainty as a natural part of scientific exploration and to see learning as a shared journey. In a lesson on wave-particle duality, a student questions how light’s behavior can be predicted. Rather than offering a fixed answer, the teacher acknowledges the complexity of quantum mechanics and admits their own uncertainty. This response fosters a collaborative learning environment where students feel safe to ask challenging questions and view science as an evolving exploration rather than a set of final truths [19].

7. Drawing Attention to Metacognitive Processes

Encouraging students to reflect on how they approach problem-solving cultivates metacognitive awareness—an essential skill in mastering physics. Rather than focusing solely on arriving at the correct answer, students are prompted to examine their thinking processes: How did they classify the evidence? What assumptions guided their choices? Did they revise their hypotheses in light of new information? In physics, this reflective practice can be integrated through targeted questions such as: “How did you decide which formula to apply in this situation?” or “What assumptions are embedded in your model, and how might they affect your results?” These prompts help students become more

conscious of their reasoning strategies, recognize patterns in their thinking, and develop a deeper understanding of the conceptual foundations behind the calculations. Over time, metacognitive reflection empowers learners to become more independent, adaptive, and critical thinkers—qualities essential not only in physics but in scientific inquiry more broadly [20].

8. Taking Responsibility for Ideas

Students should be encouraged to take ownership of their scientific claims—articulating their reasoning, defending their ideas with evidence, and remaining open to revision or rejection when confronted with stronger arguments or contradictory data. In the context of physics, this might involve presenting a hypothesis about motion, energy transfer, or wave behavior, and then testing it through experimentation or peer critique. This process nurtures intellectual integrity and resilience, two foundational traits of scientific thinking. When students learn to detach their ego from their ideas, they become more willing to engage in constructive debate, accept uncertainty, and refine their understanding based on evidence. Rather than viewing mistakes as failures, they begin to see them as opportunities for growth. Cultivating this mindset in physics classrooms helps students develop the habits of mind necessary for authentic inquiry and prepares them to think like scientists—curious, critical, and committed to truth [21].

Fostering Motivation in the Physics Classroom

Creating genuine motivation in a science class—particularly in physics, where abstract concepts and mathematical reasoning often dominate—requires more than external rewards or imposed expectations. Research consistently shows that motivation is an intrinsic force, activated when learners encounter the right conditions[22]. In physics education, cultivating these conditions is essential for deep engagement and sustained effort.

One of the most powerful motivators is **the presence of meaningful challenges**. When students face problems that stretch their thinking—such as analyzing a counterintuitive result in a mechanics experiment or reconciling conflicting data in a thermodynamics lab—they are prompted to invest greater cognitive effort[23]. However, the challenge must be carefully calibrated: tasks that are too easy lead to boredom, while those that are too difficult can cause frustration and disengagement. The optimal zone lies in presenting problems that are just beyond the learner’s current level of mastery, encouraging persistence and growth through productive struggle[24].

Equally important is **the sense of autonomy**. When students feel they have agency in their learning—choosing which phenomena to investigate, selecting methods of experimentation, or proposing their own models—they are more likely to engage with curiosity and commitment [25]. Autonomy fosters ownership, making learning more personal and meaningful. In physics, this might involve allowing students to design their own experiments to test Newton’s laws or explore real-world applications of electromagnetism based on their interests [26].

Another key factor is **the integration of creativity and imagination** into the learning process. Physics is often perceived as rigid and formulaic, yet it is fundamentally a creative endeavor—requiring visualization, modeling, and conceptual innovation [27]. Encouraging students to think imaginatively, such as by constructing analogies for

quantum behavior or designing hypothetical scenarios involving gravitational anomalies, transforms learning into a dynamic and enjoyable experience [28]. This not only deepens understanding but also nurtures intrinsic motivation by making the subject feel alive and open-ended [29].

In sum, motivation in physics education flourishes when students are challenged appropriately, granted autonomy, and invited to engage creatively. By designing learning environments that honor these principles, educators can inspire students not just to learn physics—but to love the process of discovering how the universe works [30].

Engaging Students in the Physics Classroom

To foster meaningful and engaging learning experiences in physics education, instructors must move beyond conventional, lecture-based teaching methods. Traditional instruction—often centered on formula memorization and procedural problem-solving—can limit students’ ability to connect with the deeper principles of physics and its relevance to the real world. In contrast, a human-centered approach to teaching physics emphasizes intellectual curiosity, active participation, and conceptual understanding [31]. By integrating creative and student-responsive strategies, educators can transform the physics classroom into a space of inquiry, dialogue, and discovery. These methods not only help students grasp abstract scientific ideas but also encourage them to think critically, ask meaningful questions, and relate physics to their everyday experiences. Such approaches are particularly effective in making physics more accessible, inclusive, and intellectually stimulating for diverse learners. Table 1 outlines seven practical strategies that can be implemented to enrich physics instruction. Each method is designed to capture students’ attention, promote deeper engagement, and foster a collaborative learning environment. From using real-life problems to incorporating visual data and thought-provoking questions, these techniques offer educators a flexible toolkit for designing dynamic and impactful physics lessons.

Table 1 – Effective strategies for enhancing learning experiences in physics education

Strategy	Illustrative Example in Physics Class
Contradictory Events	A physics teacher, usually dressed casually, enters the classroom wearing a lab coat, safety goggles, and holding a glowing plasma ball to introduce the topic of electromagnetism.
Use of Charts	While teaching about energy efficiency, the teacher presents a chart comparing the electricity consumption of various household appliances over a month.
Use of Images	To introduce the concept of wave-particle duality, the teacher displays a dramatic photo of Albert Einstein alongside a diagram of the double-slit experiment.
Real-Life Problems	The teacher asks: “If you drop your phone from a moving bus, where will it land? Why?”—prompting students to apply concepts of inertia and relative motion.
Thought-Provoking Questions	The lesson begins with: “What would happen if the speed of light were suddenly reduced by half?”—encouraging students to explore implications across physics and technology.
Emphasis	While explaining Newton’s Third Law, the teacher says, “This is crucial—every action has an equal and opposite reaction,” and uses hand gestures to reinforce the concept.

Naming Students	During a discussion on thermal expansion, the teacher asks, “Why do train tracks have gaps between them?” then pauses and says, “Fatemeh, what do you think?”
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Teacher Challenges in Physics Education: Shifting from Control to Engagement

In many physics classrooms, teachers often gravitate toward instructional strategies that offer maximum control—such as lecturing, assigning silent desk work, or tightly managing classroom interactions. While these methods may create a sense of order, they frequently run counter to the conditions necessary for meaningful learning. Physics, by nature, demands active engagement, conceptual exploration, and critical thinking—none of which flourish in passive, teacher-centered environments.

Students benefit most from dynamic, student-centered approaches that invite participation, inquiry, and collaboration. When learners are given opportunities to experiment, discuss, and reflect, they begin to construct their own understanding of physical phenomena [32]. Yet many educators report frustration when attempting to shift toward more interactive methods. A common concern is: “*I tried asking questions, but students either didn’t respond or seemed disengaged.*” This reaction underscores the need to explicitly teach thinking skills and to use open-ended questions that stimulate curiosity and dialogue [33].

Open-ended questions—such as “*What do you think would happen if we removed friction from this system?*” or “*Why might two observers disagree on the measurement of time in relativity?*”—encourage students to explore ideas, articulate reasoning, and engage in deeper cognitive processes [34]. These strategies help overcome classroom passivity and foster a culture of intellectual risk-taking.

Teaching Thinking Skills: Building Confidence and Motivation: Teaching thinking skills is not just a pedagogical technique—it’s a transformative practice that empowers students to see themselves as capable thinkers. In physics, where abstract reasoning and problem-solving are central, developing these skills is especially vital [35]. When students learn how to analyze evidence, evaluate assumptions, and construct logical arguments, they begin to take pride in their intellectual abilities.

Experience shows that once students become familiar with thinking routines—such as identifying patterns, questioning models, or distinguishing scientific reasoning from pseudoscience—they naturally begin to support their claims with evidence and enjoy the process of intellectual exploration [36]. This sense of competence fuels motivation: the more students feel intelligent and capable, the more invested they become in learning. Moreover, as students’ thinking skills mature, they derive satisfaction from identifying cognitive challenges and inconsistencies. They begin to approach physics not as a set of formulas to memorize, but as a field of inquiry where their minds are actively engaged [37].

Creating the Right Conditions for Thinking in Physics Classrooms: Fostering critical thinking in physics requires more than instructional strategies—it demands a classroom environment that is emotionally safe, intellectually open, and socially supportive [38]. Students must feel respected, valued, and free to express their ideas without fear of judgment. This psychological safety is the foundation for active participation and deep thinking. To cultivate such an

environment, teachers should begin by presenting relevant and thought-provoking information in an open-ended manner. Instead of delivering facts, lessons should invite inquiry—for example, introducing a paradox in thermodynamics or a puzzling result from a quantum experiment. This approach sparks curiosity and encourages students to explore rather than simply absorb. Inclusivity is also key. All student contributions—regardless of accuracy or sophistication—should be welcomed and treated as valuable. This practice encourages diverse perspectives and fosters richer discussions, which are essential for developing critical thinking [39].

Furthermore, a collaborative spirit should be actively nurtured. Physics classrooms should emphasize teamwork, mutual support, and shared problem-solving rather than competition. Avoiding comparisons between students helps maintain a positive atmosphere where everyone feels capable of growth and contribution [40].

Assessment practices should align with this philosophy. Instead of relying solely on grades or high-stakes tests, teachers should focus on formative assessments that highlight students' reasoning and conceptual understanding. Constructive feedback—such as *“Your explanation of energy transfer is solid; can you now consider how entropy plays a role?”*—promotes reflection and deeper engagement [41].

Essential Teaching Practices for Effective Engagement in Physics Classrooms

Effective physics instruction goes far beyond the mere transmission of formulas and facts. It is a dynamic, student-centered process shaped by the teacher's behaviors, beliefs, classroom organization, communication style, and responsiveness to learners' needs. In a subject as conceptually rich and cognitively demanding as physics, these foundational practices are essential for fostering deep engagement, critical thinking, and inclusive participation [42].

1. Teacher Behaviors and Beliefs: Modeling Enthusiasm and Respect

A teacher's energy, curiosity, and genuine passion for physics are contagious. When educators demonstrate excitement about scientific inquiry and show respect for students' ideas, they cultivate a classroom culture grounded in trust, motivation, and intellectual openness. It is vital that all students feel seen and heard—especially in physics, where abstract concepts can intimidate or alienate learners. Inclusive questioning strategies, such as cold-calling with support or using random name generators, ensure that participation is equitable and that diverse voices contribute to the learning process [43].

2. Organization: Structuring for Efficiency and Engagement

A well-organized physics classroom maximizes instructional time and minimizes distractions. Lessons should begin promptly, with materials and equipment prepared in advance—especially for labs and demonstrations. Warm-up activities, such as quick conceptual questions or mini-problems, can activate prior knowledge and set the tone for inquiry. Students should also be trained to manage routine tasks independently, such as setting up lab stations or submitting assignments, so that the classroom runs smoothly and predictably [41].

3. Communication: Clarity, Coherence, and Connection

Clear and expressive communication is the backbone of effective physics teaching. Teachers must articulate complex ideas in accessible language, use coherent transitions

between topics, and emphasize key concepts through tone, repetition, and visual cues. For example, when introducing the concept of conservation of energy, a teacher might use analogies, diagrams, and verbal emphasis to reinforce understanding. Strong communication also builds emotional connection, helping students feel supported and engaged [39].

4. Focus and Attention: Making Physics Tangible

Maintaining student attention in physics requires making abstract ideas concrete. Teachers should regularly incorporate tangible objects (e.g., springs, pendulums), visual aids (e.g., circuit diagrams), models, simulations, and multimedia tools such as PowerPoint slides or educational videos. Writing key equations and concepts on the board reinforces visual learning and helps students track the lesson's progression. These tools anchor attention and support conceptual clarity [42].

5. Feedback: Guiding Growth with Precision and Positivity

Feedback in physics should be specific, timely, and focused on performance. Rather than vague praise, teachers can offer targeted comments such as: *“Your explanation of projectile motion was clear—can you now apply it to a real-world scenario?”* Constructive feedback highlights strengths, identifies areas for improvement, and provides actionable steps forward. Delivered with a positive emotional tone, it reinforces effort and builds confidence without fostering complacency [40].

6. Monitoring: Maintaining Momentum and Correcting Misconceptions

Active monitoring is essential—especially during student work time, labs, or group activities. Even when seated or less mobile, teachers must remain observant and responsive. In physics, where misconceptions can easily take root (e.g., misunderstanding force vectors or misapplying formulas), timely intervention is critical. Monitoring allows teachers to address errors, clarify reasoning, and maintain a productive learning environment [41].

7. Questioning: Stimulating Thought and Dialogue

Strategic questioning is a powerful tool in physics education. Thoughtful questions serve multiple purposes:

- Sustain attention and focus during instruction.
- Engage shy or reluctant students.
- Reinforce and revisit key concepts.
- Assess understanding in students' own words.

For example, asking *“Why does the acceleration remain constant in free fall?”* or *“What assumptions are built into this energy model?”* encourages deeper thinking and invites students to articulate their reasoning. Questioning transforms passive listening into active dialogue [39].

8. Review: Bridging Past and Present Learning

Reviewing prior knowledge is essential for helping students connect new concepts to existing mental frameworks. In physics, this might involve revisiting Newton's laws before introducing momentum, or recalling wave properties before exploring

interference. Reviews can occur at the beginning of a lesson to activate prior knowledge, or at the end to consolidate learning. Effective review strengthens retention, reinforces understanding, and prepares students for future inquiry.

Structuring Physics Lessons for Deep Learning: Key Components of Instructional Design

Effective physics instruction requires thoughtful planning that aligns content, pedagogy, and assessment in a coherent framework. To move beyond fragmented teaching and foster meaningful learning experiences, educators must design lessons with intentional structure [43]. Table 2 outlines five essential components of instructional design that serve as a foundation for building engaging and outcome-driven physics lessons.

Each component plays a distinct role in shaping the learning experience:

- **Topic** refers to the central concept or skill that students are expected to master. In physics, this might range from understanding Newton's laws to exploring wave interference or thermodynamic systems. Clearly defining the topic ensures that instruction remains focused and conceptually coherent [44].
- **Learning Objectives** articulate what students should be able to do by the end of the lesson. These goals must be specific, measurable, and aligned with broader curricular standards. For example, an objective might state: "*Students will be able to apply Bernoulli's Principle to explain pressure differences in fluid flow.*" Well-crafted objectives guide both teaching and assessment [45].
- **Learning Activities** are the heart of the instructional process. These include experiments, simulations, group discussions, and problem-solving tasks that actively engage students and support the stated objectives. In physics, hands-on activities—such as building simple circuits or modeling projectile motion—help bridge theory and practice [43].
- **Assessment** provides evidence of student understanding. Whether through quizzes, oral presentations, lab reports, or practical demonstrations, assessment should reflect the depth and scope of the learning objectives. It also offers feedback for both students and teachers to refine learning strategies [46].
- **Alignment** ensures that all instructional elements—objectives, activities, and assessments—work in harmony. Misalignment can lead to confusion or superficial learning. For instance, if the objective focuses on conceptual understanding but the assessment only tests memorization, the instructional impact is diminished [47].

By integrating these components into lesson planning, physics educators can create structured, purposeful, and engaging learning experiences that promote both conceptual mastery and scientific thinking. By applying the framework presented in **Table 2**, physics educators can design lessons that are engaging, focused, and effective—transforming the classroom into a space where scientific thinking and discovery thrive [43].

Table 2 – Core components of physics lesson design

Component	Description (Physics-Focused)
Topic	Identify the central physics concept or skill to be taught—such as Newton’s Second Law, conservation of energy, or wave interference.
Learning Objectives	Define clear, measurable goals that specify what students should understand or be able to do. Example: <i>“Students will be able to apply Bernoulli’s Principle to real-world fluid systems.”</i>
Learning Activities	Design hands-on and inquiry-based tasks that support the objectives. These may include lab experiments, simulations (e.g., PhET), group problem-solving, or conceptual debates.
Assessment	Use varied tools—quizzes, lab reports, oral explanations, or demonstrations—to evaluate students’ grasp of concepts and their ability to apply them in new contexts.
Alignment	Ensure that activities and assessments directly reflect and reinforce the learning objectives. Every task should contribute meaningfully to the intended learning outcomes.

Illustrative Case: Designing a Conceptual Physics Lesson on Bernoulli’s Principle

Within a human-centered framework for physics education—one that values curiosity, experiential learning, and epistemic growth—lesson design must go beyond content delivery to create opportunities for meaningful engagement. The following lesson on Bernoulli’s Principle exemplifies this approach by integrating cognitive activation, hands-on inquiry, and reflective assessment. It serves as an illustrative case of concept-based instructional design aimed at fostering scientific thinking in middle and high school learners. Grounded in the core idea that faster-moving fluids exert lower pressure, this lesson introduces Bernoulli’s Principle through accessible materials and experiential activities [48]. Students begin by activating prior knowledge related to force, motion, and pressure, then engage in simple experiments using paper strips and a fan. These activities make invisible fluid dynamics visible, allowing students to infer relationships between airflow and pressure through direct observation. The instructional sequence follows a constructivist arc: from guided exploration to formal conceptualization. After observing the upward movement of the paper strip, students are introduced to Bernoulli’s Principle and asked to demonstrate their understanding through diagramming, verbal explanation, and targeted questioning. These formative assessments prioritize conceptual clarity and encourage students to articulate their reasoning rather than memorize definitions.

To extend learning beyond the classroom, students complete a homework task that invites them to design or illustrate a real-world application of Bernoulli’s Principle. This final component reinforces the principle while cultivating scientific imagination and relevance. By aligning with the humanistic principles outlined earlier—modeling scientific thinking, fostering collaborative inquiry, and valuing student agency—this lesson bridges theory and practice. It demonstrates how thoughtfully designed instruction can transform abstract physics concepts into lived experiences that deepen understanding and spark curiosity.

Table 3 – A sample lesson plan

Section	Description
Subject	<i>Physics – Bernoulli’s Principle.</i> Exploring fluid dynamics and the relationship between velocity and pressure in gases and liquids.
Grade Level	<i>Middle School / High School.</i> Adaptable for students aged 12–18, with scaffolding for different levels of prior knowledge.
Learning Objective	Students will understand and be able to explain that as the speed of a fluid increases, the pressure it exerts decreases, and vice versa. They will apply this concept to real-world examples of lift and flow.
Materials Needed	<ul style="list-style-type: none"> - Paper strips (lightweight) - Fan or hairdryer (to generate airflow) - Diagrams of airflow over surfaces (e.g., airplane wing) - Whiteboard and markers for group discussion and modeling
Prior Knowledge	Students should have a basic understanding of: <ul style="list-style-type: none"> - Newton’s laws of motion - The concept of force and pressure - Directional motion and effects of applied forces
Activities	<ol style="list-style-type: none"> 1. Begin with a review of force and motion using everyday examples (e.g., pushing a swing). 2. Demonstrate push/pull forces and discuss directionality. 3. Blow across a paper strip and observe its lift. 4. Repeat the demonstration and ask students to hypothesize why the paper rises. 5. Introduce the concept of pressure and how it changes with speed. 6. Present Bernoulli’s Principle with diagrams and real-world applications (e.g., airplane wings, sports balls).
Key Concept	Faster-moving air exerts lower pressure. This pressure difference creates lift, which explains how objects like paper strips rise and how airplane wings generate upward force.
Evaluation Methods	<ul style="list-style-type: none"> - Students draw and label diagrams showing airflow and pressure zones. - Write a short explanation of Bernoulli’s Principle in their own words. - Answer guided questions linking speed and pressure. - Participate in a group discussion analyzing real-life examples.
Homework / Extension	Students will design a simple experiment or create a sketch that demonstrates Bernoulli’s Principle in action. Examples may include: <ul style="list-style-type: none"> - Airplane wing cross-section - Shower curtain movement - Spinning soccer ball - Chimney draft effect

CONCLUSION

The prevailing model of physics education in Iran—marked by rigid curricula and an overreliance on memorization—continues to inhibit the development of scientific reasoning, intellectual autonomy, and meaningful engagement with physical phenomena

[49]. This paper has proposed a shift toward a learner-centered paradigm grounded in conceptual understanding, epistemic inquiry, and collaborative learning. Drawing on insights from cognitive science, motivational theory, and research-based pedagogy, the proposed framework advocates for instructional design that cultivates scientific habits of mind—such as evidence-based reasoning, metacognitive reflection, and interdisciplinary synthesis. These principles align with global trends in STEM education that emphasize deep learning, transferable competencies, and inclusive pedagogical practices. To translate this vision into actionable reform, several recommendations are offered:

- **For policymakers:** Support curriculum redesign that embeds conceptual coherence, historical context, and inquiry-based learning as core components of physics education.
- **For curriculum designers:** Develop modular resources and lesson sequences that integrate diagnostic assessment, collaborative problem-solving, and real-world applications.
- **For teacher educators:** Provide professional development focused on modeling scientific thinking, facilitating classroom discourse, and designing cognitively rich learning environments.

The sample lesson on Bernoulli's Principle serves as an illustrative case, demonstrating how abstract concepts can be taught through experiential learning, formative assessment, and reflective dialogue. It operationalizes the framework in a way that is both pedagogically sound and adaptable to diverse classroom contexts. Future research should empirically test the effectiveness of this framework across varied educational settings in Iran. Longitudinal studies could examine its impact on students' conceptual growth, scientific identity formation, and engagement with physics beyond the classroom. Comparative analyses with international models may also yield insights into culturally responsive adaptations of active learning strategies. Reimagining physics education in Iran is not merely a pedagogical challenge—it is a cultural and intellectual opportunity. By embracing a human-centered approach, educators can empower students to become thoughtful inquirers, capable of reasoning critically, collaborating meaningfully, and contributing to the evolving narrative of scientific understanding.

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