High School Students Expectations in Learning Physics: A Review of Traditional, Constructivist, And Emerging Approaches

R.V.S. Aparna[1],

Head Master, Zilla Parishad High School, Kalavalapudi, Venkatagiri, Tirupathi District, Andhra Pradesh, India

---***---

Abstract - Students expectations and beliefs about learning physics play a critical role in shaping their engagement, persistence, and achievement. Over the past three decades, research in Physics Education has demonstrated that epistemological beliefs whether students see physics as a set of formulas to memorize or as a coherent system to be understood strongly influence learning outcomes. Traditional lecture-based instruction often reinforces surface-level learning, whereas constructivist pedagogies encourage students to actively build conceptual understanding. More recently, digital and hybrid approaches, including simulations, flipped classrooms, and AI-driven platforms, have further reshaped student expectations of learning physics. This review synthesizes research from classic frameworks such as Hammer's epistemological dimensions and the Maryland Physics Expectations (MPEX) survey, alongside newer instruments like the CLASS and E-CLASS. Comparative evidence across traditional, constructivist, and technology-enhanced pedagogies is presented, with attention to cross-cultural studies, gender and equity considerations, and the role of teacher professional development. The paper highlights persistent challenges in assessing student expectations and emphasizes the need for longitudinal, international, and interdisciplinary research. By critically analysing trends from the 1990s to 2020s, this review underscores the ongoing shift toward more student-centered, globally relevant physics education, and outlines future directions for research and practice.

Key Words: Physics Education Research, Constructivism, Student Expectations, High School Physics, Digital Pedagogy, MPEX, CLASS, E-CLASS

1. INTRODUCTION

High school physics represents a pivotal stage in science education, often serving as students' first sustained engagement with formal scientific reasoning and problem-solving. However, students enter physics classrooms with diverse expectations about what learning science entails. Many view physics as a subject dominated by rote memorization of equations, while others expect it to provide a framework for making sense of the physical world. Epistemological beliefs significantly affect not only how students approach learning but also their eventual performance and long-term interest in STEM fields.

Physics Education Research (PER) has long recognized that teaching methods strongly influence these expectations. Traditional lecture-based instruction tends to reinforce passive learning and a fragmented view of physics knowledge. In contrast, constructivist pedagogies—such as Modelling Instruction, Workshop Physics, and Peer Instruction—encourage active engagement, inquiry, and real-world connections. More recently, the integration of digital tools, online simulations, flipped classrooms, and adaptive learning systems has created new possibilities for reshaping student beliefs about physics as a dynamic, exploratory discipline.

Several instruments have been developed to measure and analyse student expectations, including Hammer's epistemological framework (1994), the Maryland Physics Expectations (MPEX) survey (Redish et al., 1998), the Colorado Learning Attitudes about Science Survey (CLASS; Adams et al., 2006), and the Experimental Physics Attitudes Survey (E-CLASS; Zwickl et al., 2014). Collectively, these tools have revealed both progress and persistent challenges in aligning student expectations with expert-like views of science.

Three decades of research on high school student expectations in physics, comparing traditional, constructivist, and technology-enhanced approaches. It expands on prior reviews by integrating cross-cultural perspectives, highlighting equity and inclusion issues, and examining the role of teacher professional development. In doing so, it aims to provide a comprehensive synthesis of past findings and propose future directions for globally relevant and research-informed physics pedagogy.

2. THEORETICAL FRAMEWORK

2.1 Epistemological Beliefs and Student Expectations

Student expectations in physics are deeply rooted in their epistemological beliefs views about the nature of knowledge and learning. Hammer (1994) identified three critical dimensions

Independence: whether students see learning as passive reception from authority or active construction of knowledge.

Coherence: whether knowledge is viewed as fragmented facts or as a connected conceptual system.

Concepts: whether physics is perceived as a collection of formulas or as reasoning grounded in physical principles.

These dimensions highlight the tension between rote and conceptual learning. They remain foundational for analyzing how pedagogy influences student expectations.

2.2 Maryland Physics Expectations (MPEX) Framework

Building on Hammer's work, Redish, Saul, and Steinberg (1998) expanded the framework into six clusters, forming the Maryland Physics Expectations (MPEX) Survey:

Independence – passive vs. active learning.

Coherence – fragmented facts vs. integrated concepts.

Concepts – equations vs. conceptual reasoning.

Reality Link – abstract formulas vs. real-world connections.

Math Link – mathematics as calculation vs. representational tool.

Effort – memorization vs. reflection and inquiry.

The MPEX survey became one of the most widely used instruments for capturing how instruction shapes student attitudes and expectations.

2.3 Expansion of Measurement Tools

Since MPEX, several other instruments have emerged, broadening the analysis of student expectations in physics education:

CLASS (Colorado Learning Attitudes about Science Survey) (Adams et al., 2006)
Designed to measure shifts in students' beliefs about physics across multiple dimensions, CLASS has been widely validated across institutions and cultural contexts. Unlike MPEX, it includes student affect (enjoyment and personal interest).

VASS (Views About Science Survey) (Halloun & Hestenes, 1998)
Focuses on epistemological beliefs about science and science learning, including student views of authority, effort, and real-world applicability.

E-CLASS (Colorado Learning Attitudes about Science Survey for Experimental Physics) (Zwickl et al., 2014)
Specifically measures student attitudes toward experimental physics, including views on uncertainty, collaboration, and experimental design.

Other Emerging Tools

ASSIST (Approaches and Study Skills Inventory for Students) used in some PER studies.

Motivation and identity-based surveys that connect expectations with self-efficacy and belonging (Hazari et al., 2010).

2.4 Strengths and Limitations of Current Frameworks

Strengths: Instruments like MPEX and CLASS provide validated, large-scale measures of expectations and allow longitudinal tracking of change.

Limitations:

Focus mainly on cognitive/epistemological beliefs, less on socio-cultural contexts.

Less emphasis on digital learning environments, which have become central post-2010.

Limited validation outside the US, though recent studies are adapting these tools cross-culturally (e.g., in China, India, and Europe).

Taken together, these frameworks offer a powerful but incomplete picture of how students perceive physics. The need remains for culturally adaptive, technology-sensitive tools that capture both cognitive and affective dimensions of learning.

3 INSTRUCTIONAL APPROACHES ON STUDENT EXPECTATIONS

3.1 Traditional Physics Instruction

The 20th century, high school and introductory university physics instruction was dominated by the lecture–demonstration–problem solving model. These courses emphasized:

Transmission of knowledge from teacher to student.

Heavy reliance on textbooks and algorithmic problem sets.

Summative assessments that reward procedural fluency over conceptual reasoning (Arons, 1990).

Students taught under this model frequently adopt surface learning strategies, focusing on memorization and pattern-matching rather than deep conceptual understanding (Biggs, 2003). Research consistently shows that traditional instruction leaves many misconceptions intact (McDermott, 1993; Crouch & Mazur, 2001).

Recent critiques highlight additional problems:

Limited engagement: Large classes and lecture-heavy formats discourage student participation (Freeman et al., 2014).

Equity gaps: Traditional methods often amplify performance gaps across gender, race, and socioeconomic status (Kost-Smith et al., 2010).

Resistance to change: Despite decades of research, traditional lecture remains prevalent, partly due to institutional inertia and teacher preparation constraints (Henderson & Dancy, 2007).

3.2 Constructivist Approaches

In response, constructivist pedagogies emerged in the 1980s–1990s, emphasizing active engagement, inquiry, and conceptual reasoning. Notable innovations include:

Modelling Instruction (Hestenes, 1996): Students build and test conceptual models of physical systems.

Workshop Physics (Laws, 1997): Lab-centered, hands-on investigations replace lectures.

Constructing Physics Understanding (CPU) Project (Goldberg & Bendall, 1995): Emphasizes peer discussion and real-world contexts.

Peer Instruction (Mazur, 1997; Crouch & Mazur, 2001): Uses conceptual multiple-choice questions and peer discussion during lectures.

Evidence shows that constructivist approaches consistently promote:

Expert-like expectations on MPEX/CLASS surveys (Redish et al., 1998; Adams et al., 2006).

Higher learning gains, especially on the Force Concept Inventory (Hake, 1998).

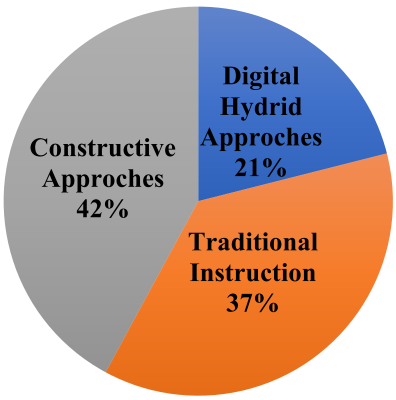
Increased retention of underrepresented groups in physics (Brewe et al., 2010).

Limitations:

Implementation fidelity: Teachers often adopt elements of active learning without full restructuring, limiting impact (Dancy & Henderson, 2010).

Math link cluster: Gains in conceptual reasoning do not always extend to mathematical modeling skills (Redish, 1996).

Fig 1. Research Focus on Instructional Aprroches in Education (1990 - 2020)



3.3 Digital and Hybrid Approaches

Since the mid-2000s, the landscape of physics pedagogy has been transformed by digital tools and blended learning models. Innovations include:

PhET Interactive Simulations (Perkins et al., 2006): Visual, interactive simulations that strengthen reality links.

Flipped Classrooms: Lectures are delivered as videos; classroom time is used for problem-solving and discussion (Deslauriers et al., 2011).

Virtual Labs and AR/VR: Provide remote or immersive experiences of physical experiments, especially critical during COVID-19 (Zacharia & Olympiou, 2011).

AI and Adaptive Learning Systems: Intelligent tutoring systems like MasteringPhysics personalize feedback and track misconceptions (Lin et al., 2016).

These approaches have shown promising results:

Enhanced student engagement and self-regulation (Lo & Hew, 2017).

Improved conceptual gains, especially when simulations are combined with guided inquiry (Wieman et al., 2008).

Increased accessibility for students in resource-limited contexts through online platforms.

Nevertheless, digital approaches raise new questions:

How do they influence student expectations compared to face-to-face constructivist methods?

Do they risk reinforcing passive behaviours if used without active guidance?

What are the equity implications of differential access to technology?

3.4 Comparative Findings

Traditional methods reinforce fragmented, rote expectations.

Constructivist methods foster conceptual and real-world connections, though challenges remain with math integration.

Digital approaches have the potential to amplify constructivist benefits and broaden access, but require careful design to avoid superficial engagement.

4 CROSS-CULTURAL PERSPECTIVES

Research on student expectations in physics has been conducted in the United States, yet educational contexts vary significantly across the globe. Cross-cultural studies reveal that expectations are shaped not only by pedagogy but also by curriculum design, cultural attitudes toward authority, and the role of examinations in education systems.

Asia:Studies in China and Japan suggest that students often view physics as formula-driven due to exam-oriented systems. For example, Bao et al. (2009) found Chinese students outperform U.S. students on algorithmic problem-solving but lag in conceptual understanding. In India, limited classroom resources and large class sizes create challenges for implementing constructivist methods, though pilot studies of Peer Instruction and PhET simulations show promise (Singh & Hake, 2007).

Europe: Research in Germany and Finland has emphasized the role of inquiry-based curricula in promoting conceptual coherence. Cross-cultural CLASS studies show that European students tend to enter courses with more favourable expectations than their U.S. counterparts (Gire et al., 2015).

Developing Contexts: In African countries, resource limitations constrain active learning, but innovative adaptations such as low-cost experiments and blended online modules demonstrate the potential to foster expert-like beliefs even in low-resource settings (Akuma & Callaghan, 2019).

Table 1. Comparison of Instructional Approaches on Student Expectations

Dimension	**Traditional Instruction**	**Constructivist Approache**	**Digital/Hybrid Approaches**	**References**
Independence	Passive note-taking, teacher centered	Active exploration, student-centered	Self-paced online + collaborative in class	Lo & Hew (2017)
Coherence	Fragmented facts and formulas	Emphasis on conceptual connections	Visual simulations strengthen conceptual links	Wieman et al. (2008)
Concepts	Focus on equations/procedures	Conceptual reasoning emphasized first	Simulations + inquiry deepen conceptual focus	Perkins et al. (2006)
Reality Link	Weak connection to real-world	Strong use of real-life contexts	VR/AR environments make physics experiential	Zacharia & Olympiou (2011)
Math Link	Heavy reliance on algebraic manipulation	Math as representational tool, but still underdeveloped	Adaptive tools scaffold math-physics integration	Lin et al. (2016)
Effort	Memorization-driven	Inquiry, reflection, collaboration	Engagement through gamification, adaptive tasks	Freeman et al. (2014)

Implication: Instruments like MPEX and CLASS, originally designed for Western contexts, require careful adaptation and validation across diverse educational systems. Without this, cross-cultural comparisons risk misinterpreting student expectations.

5 EQUITY, GENDER, AND INCLUSION

Equity in physics education is a persistent concern. Expectations are not uniform across all learners; they are shaped by gender, socioeconomic status, prior preparation, and cultural identity.

Gender: Studies show women often report lower self-efficacy and less favorable expectations on CLASS surveys compared to men, even when performance differences are small (Kost-Smith et al., 2010). Constructivist and collaborative learning environments, however, have been shown to reduce these gaps (Brewe et al., 2010).

Socioeconomic Background: Students from under-resourced schools may enter physics with limited exposure to laboratory work, leading to weaker reality links and fragmented views of science. Digital platforms can mitigate these gaps by providing access to virtual labs, but inequities in technology access (the “digital divide”) remain a barrier.

Underrepresented Minorities: Research in U.S. contexts (Hazari et al., 2010) highlights how identity, recognition, and mentorship shape expectations. Students who feel alienated from physics culture often see physics as inaccessible, reinforcing surface learning approaches. Inclusive teaching practices and culturally relevant pedagogy can counteract this trend.

Intersectionality:
Equity challenges are rarely one-dimensional. For instance, gender and socioeconomic disadvantages often overlap, compounding barriers to developing expert-like expectations.

Implication: Efforts to reform physics pedagogy must explicitly address equity and inclusion. Constructivist and digital approaches should be designed with diverse learners in mind, ensuring that reforms do not inadvertently privilege already advantaged groups.

6 ROLE OF TEACHERS AND PROFESSIONAL DEVELOPMENT

Student expectations in physics are not shaped in isolation; they are closely tied to the instructional practices and epistemological beliefs of teachers. Teachers’ own views of physics—whether they see it as a body of formulas to be transmitted or as a coherent system to be explored—strongly influence the learning environment they create.

6.1 Teacher Epistemologies

Research suggests that teachers often mirror the same epistemological tensions seen in students. Many physics teachers, particularly in traditional systems, emphasize procedural fluency and problem-solving over conceptual coherence (Lising & Elby, 2005). Without explicit professional development, teachers may inadvertently reinforce rote learning, even when constructivist curricula are adopted.

6.2 Teacher Preparation and Fidelity of Implementation

The success of constructivist and digital pedagogies depends heavily on teacher training and fidelity of implementation.

Partial adoption problem: Dancy & Henderson (2010) observed that instructors often adopt isolated techniques (e.g., peer discussion) without embracing the underlying constructivist philosophy, leading to limited impact on student expectations.

Training barriers: Teachers cite time constraints, curricular demands, and lack of institutional support as barriers to fully implementing reform-based strategies (Henderson & Dancy, 2007).

Professional development models: Intensive workshops, mentoring, and learning communities have been shown to improve teacher buy-in and effectiveness (Desimone, 2009).

6.3 Teacher-Student Alignment

Recent studies highlight the importance of aligning teacher and student epistemologies. For example:

Modelling Instruction programs often succeed because they explicitly train teachers in model-based reasoning before classroom implementation (Brewe, 2008).

Digital learning platforms are most effective when teachers integrate them with inquiry-based pedagogy rather than treating them as stand-alone tools (Lin et al., 2016).

6.4 International Perspectives on Teacher Development

In developing countries, resource limitations mean that professional development often focuses on low-cost strategies, such as guided peer instruction and context-based learning modules (Akuma & Callaghan, 2019).

In Europe and East Asia, systemic reforms have integrated inquiry-based methods into teacher training, with evidence that students develop more favorable expectations as a result (OECD, 2019).

6.5 Implications

Effective reform in physics education requires equipping teachers not only with new tools but also with a shift in epistemological stance.

Teacher professional development must be sustained, collaborative, and context-sensitive to foster lasting improvements in student expectations.

7 CRITICAL ANALYSIS

This review highlights a consistent theme across three decades of physics education research: student expectations are malleable and deeply shaped by pedagogy, context, and teacher beliefs. Traditional, constructivist, and digital/hybrid approaches have distinct impacts, yet several persistent challenges remain.

7.1 Shifts in Pedagogy and Expectations

The transition from traditional lecture-based instruction to constructivist methods has demonstrably shifted student expectations toward more expert-like beliefs, particularly in areas of independence, conceptual reasoning, and reality link. More recent digital innovations—such as PhET simulations, flipped classrooms, and adaptive learning platforms—have further extended these gains by offering interactive, visual, and personalized learning environments.

However, challenges persist in the math link cluster, where students continue to struggle to connect mathematical formalism with conceptual understanding. This suggests that even constructivist and digital approaches must place greater emphasis on mathematical modeling as a representational tool rather than as an isolated skill.

7.2 Cross-Cultural Gaps

Most expectation surveys and reforms have been developed in U.S. and European contexts. Yet cross-cultural studies indicate that expectations are strongly shaped by broader educational systems. In exam-oriented cultures such as China and India, students often excel in procedural tasks but show weaker conceptual coherence. Without adaptation, instruments like MPEX and CLASS risk mischaracterizing student beliefs in non-Western settings. Global validation and cultural contextualization of these frameworks are urgently needed.

7.3 Equity and Inclusion

Persistent inequities highlight that student expectations are not uniform across populations. Gender gaps, socioeconomic disparities, and the underrepresentation of minority groups shape how students perceive physics and their ability to succeed in it. Constructivist and digital methods have the potential to reduce these gaps, but only when implemented with explicit equity goals. For instance, flipped classrooms can promote inclusion if all students have access to technology, but they risk widening divides if the "digital gap" is not addressed.

7.4 Teacher Role and Professional Development

A recurring finding is that the **teacher remains the most critical mediator** of student expectations. Reforms fail when teachers adopt only surface-level techniques without deeper epistemological shifts. Sustained professional development—through workshops, mentoring, and collaborative learning communities—is essential for aligning teacher beliefs with reform goals. Without this, even well-designed curricula may not translate into improved student expectations.

7.5 Methodological and Assessment Limitations

Although tools like MPEX, CLASS, and E-CLASS have provided invaluable insights, they face limitations:

They capture attitudes and expectations, but less often connect these with long-term learning trajectories or career choices.

Most are survey-based, raising concerns about self-report biases.

Few incorporate socio-cultural or identity-based factors, despite growing evidence of their importance.

Longitudinal studies are rare, making it difficult to assess the persistence of expectation shifts beyond the immediate course

7.6 Synthesis

Taken together, the literature reveals both progress and gaps:

Progress: Constructivist and digital pedagogies foster more favourable student expectations.

Gaps: Cultural adaptation, equity concerns, teacher preparation, and assessment limitations.

Table. 2 . Cross-Cultural Studies on Physics Expectations

Country/Region	Instrument Used	Key Findings on Expectations	References
U.S.	MPEX, CLASS	Students often view physics as fragmented; constructivist teaching improves independence	Adams et al. (2006)
China	FCI + surveys	High procedural proficiency, weaker conceptual reasoning.	Bao et al. (2009)
India	Peer Instruction pilots, PhET	Large classes limit constructivist adoption, but localized tools improve expectations.	Singh & Hake (2007)
Europe (Germany, Finland)	CLASS	Students enter with stronger expert-like expectations	Gire et al. (2015)
Africa (South Africa, Uganda)	Modified CLASS	Resource limitations challenge constructivist adoption	Akuma & Callaghan (2019)

8. FUTURE DIRECTIONS

Important advances in understanding student expectations in physics, but also highlights persistent challenges and opportunities for innovation. Future research and pedagogical reforms should prioritize the following areas:

8.1 Longitudinal and Lifespan Research

Most studies examine expectation shifts over the course of a single semester or academic year. Longitudinal research is needed to track how expectations evolve:

From high school into university physics.

Across STEM pathways and career trajectories.

In relation to persistence in physics and broader STEM disciplines.

Such research would clarify whether expert-like expectations cultivated in high school endure into advanced study or dissipate under traditional higher education environments.

8.2 Cross-Cultural Validation and Global Comparisons

Physics education is increasingly global, yet existing frameworks (MPEX, CLASS, E-CLASS) were primarily developed in U.S. contexts. Future work should:

Adapt and validate instruments for cultural relevance in Asia, Africa, Latin America, and Europe.

Explore how systemic features (e.g., exam-driven curricula, resource limitations) interact with student expectations.

Encourage international collaborations to build comparative datasets that reveal both universal and context-specific patterns.

8.3 Integration of Digital and AI-Based Tools

Digital learning is no longer supplementary—it is central to the modern classroom. Future studies should investigate:

Adaptive learning platforms that personalize instruction to student misconceptions and expectation profiles.

Artificial Intelligence (AI) tutors capable of real-time feedback and expectation scaffolding.

Virtual and augmented reality to create immersive experiences linking physics concepts to real-world contexts.

The equity implications of digital innovations, ensuring reforms do not reinforce the digital divide.

8.4 Equity, Inclusion, and Identity

Addressing equity must be integral, not peripheral. Future research should examine:

How gender, race, and socioeconomic background intersect to shape expectations.

The impact of culturally relevant pedagogy in fostering expert-like beliefs among underrepresented groups.

Strategies for designing inclusive digital tools and active learning curricula.

A critical research agenda involves connecting expectations with identity formation—exploring how students come to see themselves (or fail to see themselves) as potential physicists.

8.5 Teacher Professional Development and Systemic Change

Future reforms must move beyond individual classrooms to systemic support. Needed initiatives include:

Sustained teacher training in constructivist and digital pedagogies.

Institutional policies that incentivize reform-oriented teaching.

Communities of practice that foster peer exchange among educators.

Large-scale educational reforms will require not only professional development but also addressing **structural** barriers such as rigid curricula and standardized testing pressures.

8.6 Interdisciplinary Approaches

Finally, physics education research should expand its disciplinary boundaries by integrating insights from:

Cognitive science and neuroscience to better understand how expectations influence learning processes.

Motivational psychology to connect expectations with self-efficacy and persistence.

Learning analytics to analyze digital trace data from online platforms, linking behavior patterns with shifts in expectations.

Such interdisciplinary approaches can yield richer, evidence-based models of how expectations develop and change.

9. CONCLUSION

Research over the past three decades has shown that student expectations in physics are neither fixed nor trivial; they are shaped by the interplay of pedagogy, teacher beliefs, cultural context, and systemic structures. Traditional instruction tends to reinforce fragmented, rote learning, while constructivist approaches foster conceptual reasoning, independence, and stronger connections to real-world applications. More recently, digital and hybrid methods have introduced new opportunities for engagement and personalization, though questions of access and implementation fidelity remain.

Despite substantial progress, critical challenges persist. Cross-cultural research reveals that expectations are shaped by broader educational systems, yet most instruments remain Western-centric. Equity concerns highlight that expectations are not uniform across gender, socioeconomic status, or cultural identity. Teacher professional development remains a linchpin for meaningful reform, but systemic barriers often limit its reach. Finally, existing surveys, while valuable, do not yet capture the full complexity of expectations, especially in digital learning environments or across long-term trajectories.

This review underscores that the future of physics education lies in a **global, inclusive, and interdisciplinary agenda**. By combining constructivist principles with digital innovations, adapting frameworks to diverse contexts, and embedding equity at the center of reforms, educators and researchers can better align student expectations with the practices of expert physicists. Such alignment is crucial not only for improving learning outcomes but also for sustaining student engagement and identity development in physics and STEM more broadly.

The task ahead is clear: physics education must continue to evolve from a transmission model toward one that empowers students as active, reflective, and globally connected learners.

ACKNOWLEDGEMENT

The author extends sincere gratitude to the academic and research communities whose foundational work in physics education has guided this review. Special thanks to the educators, scholars, and institutions whose research and pedagogical innovations have shaped our current understanding of student expectations in physics. Appreciation is also due to the students, whose diverse experiences and perspectives continue to inspire deeper inquiry into inclusive and effective teaching practices. Finally, the author acknowledges the support received from colleagues and mentors who provided valuable feedback throughout the development of this work.

REFERENCES

1. Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410–8415.
2. Perkins, K. K., Adams, W. K., Pollock, S. J., Finkelstein, N. D., & Wieman, C. E. (2006). PhET: Interactive simulations for teaching and learning physics. *The Physics Teacher, 44*(1), 18–23.
3. Deslauriers, L., Schelew, E., & Wieman, C. (2011). Improved learning in a large-enrollment physics class. *Science, 332*(6031), 862–864.
4. Lin, S. Y., Yen, C. F., Liang, J. C., & Chiu, M. H. (2016). Students' use of online learning platforms in physics. *Journal of Science Education and Technology, 25*(4), 636–648.
5. Battipede, A., et al. (2024). Physics Playground: Insights from a VR-based learning study. *arXiv preprint* arXiv:2412.12941.
6. Rizal, F., et al. (2022). Students' readiness in using virtual reality for physics learning. *Journal of Teaching and Learning, 16*(2), 89–103.
7. Bao, L., Cai, T., Koenig, K., Fang, K., Han, J., Wang, J., … & Wang, Y. (2009). Learning and scientific reasoning: Comparisons between Chinese and US students. *Science, 323*(5914), 586–587.
8. Singh, C., & Hake, R. R. (2007). Student expectations in introductory physics in India and the US. *Physics Education Research Conference Proceedings, 883*(1), 104–107.
9. Gire, E. T., Jones, B. D., & Price, E. (2015). Cross-cultural validation of the CLASS in Europe. *International Journal of Science Education, 37*(7), 1089–1112.
10. Akuma, F. V., & Callaghan, R. (2019). Cross-cultural adaptation of physics pedagogies in African contexts. *African Journal of Research in Mathematics, Science and Technology Education, 23*(1), 1–13.
11. Kost-Smith, L. E., Pollock, S. J., & Finkelstein, N. D. (2010). Gender disparities in second-semester college physics: The incremental effects of a "smog of bias." *Physical Review Special Topics–Physics Education Research, 6*(2), 020112.
12. Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M. C. (2010). Connecting high school physics experiences, identity, and physics career choice. *Journal of Research in Science Teaching, 47*(8), 978–1003.
13. Doucette, D., & Singh, C. (2024). Gender equity in physics labs: A review. *arXiv preprint* arXiv:2403.01522.

14. Douglass, K. A., & Brewe, E. (2018). Gender gaps in self-efficacy and physics identity. *Physical Review Physics Education Research, 14*(1), 010125.

15. Steidtmann, C. (2023). Declining interest in science in lower secondary school classes: The role of teaching quality. *Journal of Research in Science Teaching, 60*(4), 512–536.

16. Lo, C. K., & Hew, K. F. (2017). Using "flipped classroom" pedagogy to promote active learning in physics. *Interactive Learning Environments, 25*(8), 1017–1030.

17. Arons, A. B. (1990). *A guide to introductory physics teaching*. Wiley.

18. Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics, 50*(1), 66–71.

19. Goldberg, F., & Bendall, S. (1995). Making the invisible visible: A teaching/learning environment that builds on a new view of the physics learner. *American Journal of Physics, 63*(3), 978–991.

20. Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction, 12*(2), 151–183.

21. Hestenes, D. (1996). Modeling methodology for physics teachers. In *Proceedings of the International Conference on Undergraduate Physics Education*.

22. Laws, P. (1997). Promoting active learning based on physics education research. *American Journal of Physics, 65*(1), 14–21.

23. McDermott, L. C. (1993). How we teach and how students learn—A mismatch? *American Journal of Physics, 61*(4), 295–298.

24. Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227.

25. Redish, E. F., Saul, J. M., & Steinberg, R. N. (1998). Student expectations in introductory physics. *American Journal of Physics, 66*(3), 212–224.

26. Adams, W. K., Perkins, K. K., Podolefsky, N. S., Dubson, M., Finkelstein, N. D., & Wieman, C. E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey. *Physical Review Special Topics–Physics Education Research, 2*(1), 010101.

27. Zwickl, B. M., Hu, D., Finkelstein, N., & Lewandowski, H. J. (2014). E-CLASS: Development and validation of a new instrument for measuring students' beliefs about experimental physics. *International Journal of STEM Education, 1*(1), 1–18.

28. Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69*(9), 970–977.

29. Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey. *American Journal of Physics, 66*(1), 64–74.

S (Optional not mandatory)

The author, currently serving as Headmaster at Zilla Parishad High School in Kalavalapudi, Andhra Pradesh, India, holds Master's degrees in Biotechnology, Organic Chemistry, and Education. With 25 years of experience in teaching, the author is passionate about educational research and dedicated to improving teaching methods to enhance student understanding, retention, and application of knowledge. Focused on both cognitive and psychological aspects of learning, the author aims to empower students and contribute to the advancement of educational practices through ongoing research and innovation in pedagogy.