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New Approaches
Нови подходи

QUESTION-BASED LEARNING IN NANOTECHNOLOGY FOR MEDICINE AND ENGINEERING APPLICATIONS

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Abstract. This article presents a pedagogical framework using question-based learning (QBL) in nanoscience, nanotechnology, and their applications in medicine and engineering. This paper aims to create a multidisciplinary learning resource centered on question-based learning (QBL) that serves as a comprehensive and valuable reference for educators and students. QBL involves actively posing questions, gathering and analyzing information, building and applying knowledge, developing deep conceptual understanding, exploring creative possibilities, making informed decisions, and justifying conclusions through critical reasoning. To achieve these objectives, a qualitative literature survey was conducted utilizing platforms such as Google Scholar, Scopus, PubMed, and public repositories. This module presents examples of 66 structured questions covering interdisciplinary aspects of nanoscience/technology. This question-and-answer activity has attracted significant interest and excitement, as an active exercise in education, an increasingly important part of the student's transformational process in the higher education system.

Keywords: Question-based learning; Nanomaterials; inquiry-based teaching approach; nanomedicine; nanoengineering

Scope and Purpose of the Paper

This study develops and presents a Question-Based Learning (QBL) framework designed to facilitate interdisciplinary learning in nanotechnology, particularly across its applications in medicine and engineering. It encompasses conceptual, theoretical, and applied aspects of nanoscience and nanotechnology through a structured set of 66 representative questions designed to stimulate inquiry and critical engagement. The scope includes foundational principles of nanoscience, engineering applications, biomedical implications, and emerging technological possibilities, framed within an educational methodology that promotes active learning. The manuscript presents nanotechnology as a multidisciplinary field integrating physics, chemistry, biology, materials science, and engineering, while highlighting question-driven instruction as an effective pedagogical approach in higher education. It addresses both the design of the learning resource and its educational relevance in fostering analytical thinking, creativity, and decision-making skills among students.

The primary aim of this manuscript is to design and present a structured question-based learning resource that enhances comprehension of nanotechnology concepts as applied to medicine and engineering. Specifically, it aims to i) provide a curated set of thought-provoking questions that guide learners from fundamental principles to advanced applications in nanotechnology. ii) encourage active engagement through inquiry, information gathering, reasoning, and justification of conclusions. iii) support multidisciplinary integration by linking scientific theory with real-world biomedical and engineering applications, and iv) contribute to innovative teaching strategies in higher education by demonstrating how QBL can enhance transformational learning and student-centered education. The article aims to foster a deeper conceptual understanding, stimulate intellectual curiosity, and serve as a reference resource for educators and students in nanotechnology-related disciplines. The novelty lies primarily in the breadth and comprehensiveness of the question bank and the emphasis on QBL as a teaching tool in nanotechnology. This paper is categorised into the following sections: scope and purpose of the paper, theoretical foundations and aspects of QBL, novel and high-impact aspects of nanoscience, nano-perspectives on macro-ideas of questioning, methods and learning materials, results and discussion, conclusions and prospects, and a representative review questionnaire as Appendix I.

Theoretical Foundations and Aspects of QBL

QBL is a student-centric pedagogical approach, in which learners actively build knowledge by investigating questions and solving real-world problems. Key theories emphasize active inquiry, cognitive load management, and social collaboration to foster critical thinking. Core theoretical foundations include the following: i) constructivism, where learners actively construct knowledge by experiencing the world and reflecting on it (Bada, 2015). It emphasizes that learning is a social process in which individuals create meaning from experiences, often in collaboration with others, ii) experiential learning, when education should be based on real-world experiences, curiosity, and inquiry, moving away from rote memorization (Kolb et al., 2014), iii) cognitive load theory, where scaffolding is used to manage cognitive load, helping learners transition from studying examples to solving complex problems independently (Sweller, 2011), iv) discovery learning, where students learn through exploring, questioning, and investigating, with the teacher acting as a facilitator rather than an instructor (Kurniawati et al., 2021), and v) situated cognition theory, which considers that learning is most effective when it occurs within authentic, real-world contexts (Jenlink & Austin, 2013). Pure question-based learning, a highly efficient variant that decomposes learning material into small, question-driven modules and is often augmented by artificial intelligence, constitutes an important component of inquiry-based learning techniques (Bälter et al., 2024).

QBL promotes curiosity and a deeper connection to material through active engagement, encouraging critical thinking through analyzing, evaluating, and creating rather than just memorizing. This approach prioritizes collaborative problem-solving, strengthens communication skills, and encourages reflective practices that enhance metacognitive abilities for lifelong, independent inquiry. It represents a significant shift from conventional, passive, teacher-centered instruction toward an active, student-centered learning model, in which learning is driven by curiosity, self-directed questioning, and exploratory inquiry. Rooted in cognitive psychology and constructivist theory, this methodology reframes students as active problem-solvers and co-constructors of knowledge. QBL leverages the cognitive principle that recalling information from memory (retrieval) boosts long-term retention more effectively than re-reading. Empirical research indicates that students achieve greater and faster learning gains when they actively respond to questions with feedback, compared with passive study methods such as reading texts or watching instructional videos (Torres et al., 2022). Allowing learners to attempt to solve a problem before being taught the solution leads to better performance and deeper long-term learning compared to being told first. QBL ignites curiosity, allowing learners to delve beneath the surface to uncover underlying principles of why or how. Studies of public repositories for key qualitative data types on QBL-based learning, including classroom observations, interview transcripts, focus groups, and open-ended survey responses, indicate a significant enhancement in learning outcomes[1,2,3,4,5,6]. The Learning Feedback Model questionnaire presented at the end of the paper provides educators with a practical reference for understanding contemporary inquiry-based learning approaches and effectively applying question-based learning (QBL) techniques to enhance learning outcomes in intensive postgraduate education. The current research design incorporates thematic analysis and is grounded in the theories.

Novel and High-Impact Aspects of Nanoscience

Advanced nanomedicine for targeted drug delivery (TDD) and diagnostics, alongside transformative energy solutions such as high-efficiency solar cells and hydrogen fuel cells, represents some of the most promising and high-impact applications of nanoscience. Sustainable environmental technologies, including nanomaterial-based water purification and pollution control, further demonstrate the field's potential to address global challenges. Nanotechnology is also driving the development of advanced materials with exceptional strength and flexibility, high-density data-storage technologies, and smart, self-healing structures. In nanomedicine, engineered nanoparticles enable the targeted delivery of therapeutic agents to specific cell types, thereby improving treatment efficacy while minimizing off-target effects and associated adverse reactions (Chude-Okonkwo et al., 2019; Pereira et al., 2015; Chen et al., 2017; Debbage, 2009; Germain et al., 2020). Nanoscale devices enable earlier and more precise diagnosis of cancer and infectious diseases. The rational design of nanomaterials with tailored properties is driving significant advancements in tissue engineering, enabling the fabrication of next-generation biomedical implants with improved biocompatibility and functionality. Furthermore, advances in nanotechnology have facilitated the development of sophisticated wearable health sensors for the continuous monitoring of key physiological parameters, as well as nanosensor-based systems for the real-time detection of a wide range of environmental pollutants. These innovations support personalized healthcare, enable early detection of health and environmental risks, and enhance public safety (Wong et al., 2014; Abdin et al., 2013; Abdalla et al., 2020). Nanotechnology also plays a pivotal role in improving the energy-conversion efficiency of solar cells, thereby facilitating the broader adoption of renewable energy technologies and making clean energy more accessible to society (Wong et al., 2014; Abdin et al., 2013; Abdalla et al., 2020).

Functional nanomaterials offer significant potential for environmental remediation, including highly efficient water purification, greenhouse-gas capture, and oil-spill cleanup (Lee et al., 2017; Abdullah et al., 2022; Kharisov et al., 2014). In industrial processes, nano-engineered catalysts substantially increase reaction rates, lower raw material consumption, and reduce pollutant generation, with prominent applications in petroleum refining (Ampelli et al., 2014; Centi et al., 2014; Zhong et al., 2008). Within materials science and advanced manufacturing, the development of high-strength, lightweight, and durable nanocomposites is driving innovative applications in the construction and automotive sectors. In addition, self-healing nanomaterials have promising applications in microelectronics and aerospace systems, while smart nanomaterials with novel functionalities, including self-cleaning surfaces and flexible or foldable electronic components, are opening new avenues for advanced technological applications (Vafaeenezhad & Eslami-Farsani, 2024; Sharma et al., 2024; Kumar & Kumbhat, 2018). Nanotechnology offers the potential for ultra-dense memory devices for high-density data storage in smaller physical spaces (Yu & Meyyappan, 2006; Wang, 2018; Sebastian et al., 2020). Moreover, nanoscale components can create smaller, more efficient transistors and other electronic molecular switches, paving the way for more advanced computing (Fu et al., 2004; Xiang et al., 2016; Goldstein & Budiu, 2001; Tseng & Ellenbogen, 2001; Passian & Imam, 2019).

Nano-perspectives on Macro-ideas of Questioning

Cultivating the habit of asking probing questions in science classrooms is essential for stimulating learners' curiosity, fostering problem identification, and promoting a deeper understanding of the natural world. It functions as a foundation for research design, delineates knowledge gaps, cultivates critical thinking, offers a structured framework for experimentation, and facilitates problem-solving, thus underpinning discoveries, inventions, and innovations (Thimmappa, 2006, 2011, 2015, 2017). Formulating well-defined scientific questions for investigation requires careful consideration of prior knowledge, scientific variables, theoretical/experimental frameworks, data collection, hypothesis testing, potential outcomes, and limitations (Pedrosa de Jesus et al., 2005; Abrandt Dahlgren & Öberg, 2001; Chin & Chia, 2004). QBL is an active learning approach that uses thoughtfully designed questions to guide students to explore real-world problems. It encourages learners to raise questions on emerging and relevant topics, think critically, and seek answers throughout the course. Faculty members serve as facilitators by providing guidance, offering constructive feedback on students' responses, and addressing misconceptions to foster an understanding of the subject matter. This approach actively engages students in the learning process, strengthens their communication skills, fosters critical thinking, and develops problem-solving abilities while promoting greater learner autonomy. In pure QBL, questions and feedback are the core of the course, through a student-centric approach compared to the conventional education model, where a teacher presents facts/knowledge about the topic in classroom lessons (Sasson et al., 2018; Pedaste et al., 2015; Dochy et al., 2003; Herranen & Aksela, 2019).

This question-based learning (QBL) approach cultivates an orientation toward self-directed learning and problem-solving. As a student-centered pedagogy, it facilitates deeper learning satisfaction and contributes to the development of sustainable solutions. As a student-centered pedagogical approach, Question-Based Learning (QBL) promotes deeper learning, enhances student satisfaction, and contributes to the development of sustainable solutions. The process involves formulating meaningful questions, determining appropriate strategies, identifying and selecting relevant information from both online and offline sources, analyzing data, organizing pertinent findings, drawing evidence-based conclusions, and effectively communicating the results. The distinctive structure of QBL, coupled with the inherent ability of questions to capture the essence of a discipline and foster meaningful learning opportunities, can enhance student engagement across diverse learning preferences, particularly among self-directed and self-paced learners. Implementing QBL has shown significant positive impacts on educational outcomes in earlier studies: i) improved academic performance and long-term retention of knowledge and skills than traditional reading or video-based learning, ii) development of higher-order thinking skills, promoting critical thinking, synthesis, analysis, and evaluation rather than rote memorization, iii) increased student engagement and motivation: as learning is driven by questions and curiosity, students become more actively engaged and develop a greater sense of ownership over their learning process. iv) development of 21st-century skills as it fosters collaboration, communication, and problem-solving skills, v) personalization and adaptability as it accommodates diverse learning styles, allowing students to explore at their own pace and in their own way, and vi) real-world application as it connects academic content to authentic, real-world scenarios, making learning more relevant and impactful. However, challenges and considerations include the development of high-quality QBL content, which can be demanding and requires careful planning and scaffolding, making the process both resource- and time-intensive. Learners accustomed to passive learning may feel overwhelmed, stressed, or lost without direct instruction (initial frustration). If not properly scaffolded, open-ended inquiry can lead to high cognitive load, potentially hindering learning, and traditional, exam-based assessments may not adequately measure the skills acquired through QBL (assessment misalignment).

Nanomaterials have gained considerable significance in modern industries owing to their unique physicochemical properties and diverse technological applications. Recent advances in nanotechnology, a rapidly evolving interdisciplinary field, have attracted increasing interest from researchers worldwide, reflecting the continued growth of the field and its potential to shape future scientific and technological developments (Sanders, 2018; Guston, 2010; Schwarz et al., 2004; Patel et al., 2024; Cummings, 2013). Accordingly, this topic has been selected to formulate questions that explore the interdisciplinary dimensions of science, engineering, and technology, thereby promoting deeper and more meaningful learning. Furthermore, the outline of essential nanoscience concepts for graduate education published by Thimmappa (2024) provides a foundational framework for developing these questions. After the completion of the course, the students will be able to i) explain the basic concepts and the essential features of nanoscience and nanotechnology, ii) classify the nanoparticles into various categories based on different parameters, iii) describe the common synthetic techniques of nanoparticles, iv) discuss the data collection process and interpretation of instrumental data to extract useful information, v) make accurate qualitative statements about the properties of various types of nanoparticles, vi) speak about the recent advances and trends in specialized research in the area, and vii) present the prospects of nanoscience and applied research implications in solving practical issues. The scope of the present paper is limited to providing a perspective overview of nanotechnology through a question-based learning (QBL) methodology, with particular emphasis on its applications in medicine and engineering.

Nanotechnology has emerged as a transformative field in medicine, with diverse applications spanning advanced diagnostics, targeted drug delivery, and tissue engineering (Emerich & Thanos, 2003; Surendiran et al., 2009; Patil et al., 2008; Nikolova et al., 2020; Haleem et al., 2023). Delivering drugs to specific cells or tissues can increase treatment efficacy and reduce side effects. Nanotechnology can improve the accuracy and sensitivity of imaging and biosensing techniques. It can detect genetic disorders/irregularities in the human body, deliver delicate molecules like RNA to the cells, or create self-powered implantable medical devices. The manipulation of matter at the nanoscale allows designing new advanced materials, specific devices, and functional systems with enhanced properties or tailored characteristics, leading to applications in electronics, energy storage, and construction materials. Applications across disciplines like mechanical/electrical/civil/biomedical engineering allow the development of stronger and lighter materials, advanced electronic devices, high-performance concrete, and drug delivery systems. Nanotechnology is expected to play a pivotal role in the design and development of energy-efficient microchips, solar cells, medical devices, composite materials, and next-generation sensors (Varadaan et al., 2010; Kingsley et al., 2013; Mitin et al., 2008; Nalwa, 2004; Thimmappa, 2025, 2026). However, its widespread adoption is accompanied by several challenges, including safety concerns related to the potential toxicity of nanomaterials and their environmental impacts, the precise control and manipulation of nanoscale materials, and the high costs associated with manufacturing and large-scale production. Academic research in nanoscience and nanotechnology has led to many nanomaterials, nanodevices, nanoprocesses, and nanosystems for use in industries and daily life.

Methods and Learning Materials

The qualitative approach adopted in this study involves the formulation and development of representative review questions on nanoscience, nanoengineering, and nanotechnology. These questions encompass recent advancements, applications in medicine and engineering, and sophisticated analytical instruments used for the characterization of nanoparticles and nanomaterials.

1. Define and describe the following terms: Nanoscience and Nanotechnology.
2. Differentiate between nanoparticles and nanomaterials.
3. Discuss the three main classification schemes of nanoparticles with suitable examples.
4. Explain the working principle of the TEM. What useful information can be extracted from the image analysis?
5. Describe the major features of the CNT and list its applications in various fields.
6. Justify the statement "Nature is an abundant storehouse of the creation of nanoproducts."
7. Explain why the optical properties of nanoscale materials often differ from those of the same materials in the bulk state with suitable illustrative examples.
8. Discuss why nanoparticles have a lower melting temperature than the corresponding bulk material.
9. Write a technical essay on natural nanoparticles or functional nanomaterials.

10. Justify the statement "Developments in nanoengineering can bring constructive applications in many areas as well as destructive atmospheric pollution."

11. Discuss the problematic environmental consequences of the large-scale production of nanoparticles.

12. What are two broad approaches to synthesizing nanoparticles? Name and discuss four methods of preparation. Describe the advantages and disadvantages of wet methods.

13. What have been the trends in nanoscience research in recent years?

14. Explain the principle of AFM and its impact on our understanding of nanoparticles.

15. Briefly discuss the statement "Substances in their nanoparticle form interact differently from their bulk physical form".

16. Describe bonding concepts and perspectives in a nanoscience sense.

17. Give a critical explanation of the structural aspects of nanoparticles.

18. Comment on "Theoretical investigation of the structure of nanoparticles."

19. Explain the differences between particle stabilization and particle aggregation. Also, identify and list the factors that may disturb the solution stability.

20. Write a brief essay discussing the importance of electron microscopy techniques for characterizing nanoparticles.

21. What unique properties do nanomaterials possess? What properties allow nanoparticles to act as better catalysts?

22. Summarize some of the major synthetic techniques leading to the formation of nanoparticles.

23. Describe two examples in which the physical properties of nanoparticles differ from those of macromaterial counterparts.

24. Suggest design and planning principles of nanosystems that appreciate their usefulness. What methods are commonly used for the preparation of nanoparticles?

25. Describe the types of bonding in nanoparticles. Explain the factors influencing bonding.

26. Summarize the principal uses of nanoparticles in the industry.

27. Discuss the sources and impacts of solid nanoparticles. Describe the implications of attempts to produce nanoparticles on an industrial scale.

28. Elucidate ideas and ideals of nanoparticle production from a broad-based global perspective.

29. Write a two-page introductory essay answering each of the questions.

    i) What is the relationship between the nanosystem and nanoparticles?
    ii) How do temperature and solvent affect the state of aggregation?
    iii) What are the advantages of composite nanomaterials?

30. Give a detailed account of how the control steps help in the entire process of reduction of anthropogenic nanoparticulates.

31. What selective factors lead to unique behavior in nanomaterials?

32. Name the physical stabilization parameters of concern for nanoparticle design considerations.

33. Discuss the advantages and disadvantages of recent advancements in nanoscience.

34. What are zero-, one-, two-, and three-dimensional nanomaterials?

35. Write the working principles of SEM and XRD used in nanoparticle characterization.

36. Explain top-down and bottom-up approaches to producing nanomaterials.

37. Describe how oxide nanoparticles can be obtained by the sol-gel technique.

38. What is a nano-drug delivery system? What are the special structures/ features of the system?

39. What are some of the most interesting nanoparticles found in nature?

40. Discuss the societal and environmental impacts of nanotechnology.

41. What are the applications of nanoparticles in medical treatments or implantable medical devices? How can nanomaterials be harnessed for beneficial applications?

42. What are the potential risks and safety concerns associated with nanotechnology in medicine?

43. What are the latest advancements in nanotechnology for diagnostic imaging and targeted drug delivery, minimizing side effects?

44. How are nanoparticles designed to target specific cancerous cells or tissues in the body?

45. What are the synthetic techniques adopted in the design of nanomaterials with desired properties?

46. What are the ethical considerations in the design, development, and use of nanomedicine?

47. How can functional nanomaterials be engineered to improve the performance of present medical devices?

48. Explain the concept of 'nano-drug delivery systems.' How can they improve drug efficiency compared to conventional drugs?

49. How can nanoparticles be used to enhance image quality for early cancer detection?

50. Describe the nano-biosensors' potential for real-time monitoring of biomarkers in the human body.

51. Explain the concept of 'tissue engineering' using nanoparticles for cell growth and tissue regeneration.

52. How can nanomaterials be used in designing and developing implantable 'medical devices' and 'body parts' with improved functionality and biocompatibility?

53. What are the potential toxicities associated with nanoparticles, and how can they be minimized for advanced medical applications?

54. What are the design perspectives of nanomaterials to ensure their stability and biodegradability within the human body?
55. Frame ethical guidelines, regulations, and policies regarding the safe and efficient public use of nanoparticles.
56. Discuss the ethical implications of using nanomaterials for genetic manipulation.
57. What are the challenges involved in developing customized medicine approaches?
58. How can we precisely control the size, structure, and texture of nanomaterials?
59. How can we accurately characterize the structure and properties of nanomaterials using state-of-the-art techniques?
60. What are the most efficient techniques to synthesize large quantities of nanomaterials?
61. What are the working principles of the following spectroscopic and physical techniques used in the characterization of nanoparticles? UV-Vis spectroscopy, FTIR spectroscopy, Dynamic light scattering, Zeta potential, ICP-MS, and BET methods.
62. What are the toxicity aspects and environmental impacts of nanoparticles? How can we ensure the safe use of nanotechnology?
63. How can we manage and scale up nanotechnology production efficiently and affordably?
64. What regulatory frameworks are required to govern this powerful new technology?
65. How will nanomaterials interact with biological systems?
66. Provide a general overview of different microscopic, spectroscopic, and other physical techniques used for nanoparticle characterization.

Results and Discussion

The students actively participated in the true spirit of the learning process, as indicated by the chain of positive responses received in the classroom. Their sustained academic engagement in seeking answers through online resources and library materials enables them to gain greater exposure to and understanding of nanoscience. These information-search activities indicate heightened attentiveness and a strong interest in exploring diverse aspects of nanoparticles. Through collaborative investigation, learners address complex questions while acquiring the relevant scientific knowledge, including principles, ideas, concepts, methods, design approaches, and applications, needed to formulate evidence-based answers. Their learning is further assessed through their ability to reason, integrate information, and apply knowledge while actively engaging with the questions. In this learner-centered approach, the teacher assumes primarily a guiding and facilitative role, while QBL promotes greater learner confidence, motivation, engagement, and academic performance in postgraduate education. It significantly enhances critical thinking, creativity, conceptual understanding, logical reasoning, and innovative problem-solving skills. Asking typical cross-questions about the topic to elicit short oral answers led to a stimulating discussion about related scientific aspects from a broad perspective. This exercise provided students with an opportunity to develop and strengthen their scientific skills through open-ended interactions, as reflected in increased participation and improved learning performance. Students can explore various perspectives to investigate related interdisciplinary issues through questioning and develop strong analytical skills to find scientific solutions. Challenging questions make them think outside the box and seek answers with greater engagement. This inquiry-based teaching approach is effective in materials chemistry education. It can transform traditional educational practices by fostering learner curiosity, active engagement, and independent inquiry through a question-driven approach.

This qualitative study explores meanings, perspectives, and contextual dimensions through rich descriptive data drawn from textual materials, aiming to generate in-depth insights into question-based learning in nanotechnology for medicine and engineering. A systematic analysis of nanotechnology content is employed to formulate questions encompassing scientific ideas, concepts, principles, classifications, preparation methods, properties, applications, instrumentation, advantages and limitations, policies and practices, and the interrelationships among key technical parameters. QBL in nanotechnology for medicine and engineering focuses on engaging students through inquiry and exploration approaches. This educational mode encourages learners to formulate empirical, theoretical, analytical, experimental, and investigative questions and seek answers actively based on domain-specific knowledge. By integrating real-world nanotechnology applications, such as drug delivery systems, diagnostic tools, and materials engineering, students can better understand complex ideas, concepts, principles, methods, and the implications of nanoscale innovations in daily life and industry. Through problem-solving activities and collaborative projects, learners develop critical thinking and collaborative skills essential for careers in these rapidly advancing fields. This approach not only enhances conceptual understanding but also fosters a deeper appreciation of the transformative potential of nanotechnology in advancing healthcare and engineering solutions.

Conclusions and prospects

The article on qualitative educational research presents a pedagogical framework that integrates Question-Based Learning (QBL) into the study of nanoscience, nanotechnology, and their applications in medicine and engineering. The paper seeks to contribute to the field by developing a comprehensive and systematically structured set of questions addressing the interdisciplinary dimensions of nanotechnology. The integration of Question-Based Learning (QBL) into nanotechnology education offers a distinctive inquiry-driven approach that promotes interdisciplinary understanding, critical thinking, and deeper conceptual engagement among learners. Extensive QBL-based learning materials, combined with systematic observation of student engagement and learning responses during classroom implementation, provide valuable contributions to the science education literature. This paper introduces an innovative educational methodology that seamlessly integrates question-driven learning strategies within interdisciplinary nanotechnology curricula, highlighting their effectiveness in fostering deeper understanding and active participation among students. It explores how this method enhances critical thinking, problem-solving skills, and student engagement in both medical and engineering applications of nanotechnology. Thus, QBL is a powerful, research-backed methodology that moves beyond rote memorization to foster deep, lasting understanding. While it requires significant initial investment in curriculum design and a shift in student mindset, its ability to cultivate critical thinking, curiosity, and independent learning makes it highly effective for modern, student-centered education. A variant, 'Pure Question-Based Learning' (pQBL), represents a more intensive form of QBL in which the entire learning material is structured exclusively around questions designed to explore recent developments and future directions. Supported by detailed formative feedback on learners' responses and progress, pQBL offers a promising approach that integrates research-oriented learning with meaningful engagement in the research community.

APPENDIX I

Learning Feedback – Representative Review Questionnaire

Model Questions for QBL Topic: *Nanotechnology in Medicine and Engineering*

Unit 1 – *Understanding of Concepts*

How clearly did QBL help you understand the basics of nanotechnology?

Which nanotechnology concepts became easier to understand through guided questions?

Did QBL help you connect nanoscale properties to real-world applications?

How confident are you in explaining nanoparticle properties after this learning approach?

Which topic still feels unclear after QBL sessions?

Unit 2 – *Nanotechnology in Medicine*

How effectively did QBL help you understand nanoparticle-based drug delivery?

Were you able to analyse how nanotechnology improves disease diagnosis?

Which medical nanotechnology application interests you the most?

Did the questions help you understand risks and ethical issues in nanomedicine?
How confident are you in applying nanotechnology concepts to healthcare problems?

Unit 3 – *Nanotechnology in Engineering*
Did QBL help you understand nanomaterials used in engineering?
How well could you relate nanoscale properties to material strength and performance?
Were the engineering case-based questions clear and relevant?
Which engineering application did you find easiest to understand?
Did QBL improve your ability to solve real-world engineering problems?

Unit 4 – *Effectiveness of Question-Based Learning*
Did the questioning approach make the lessons more engaging than lectures?
How often did QBL encourage you to think critically?
Did QBL improve your problem-solving skills?
Were the questions appropriately challenging?
Did QBL encourage discussion and collaboration?

Unit 5 – *Student Engagement and Participation*
How comfortable did you feel answering questions during sessions?
Did QBL increase your interest in nanotechnology?
Were you motivated to research answers independently?
Did the questions promote teamwork?
How often did you actively participate in discussions?

Unit 6 – *Feedback on Teaching Method*
What did you like most about the QBL approach?
What challenges did you face while learning through questions?
How can the questions be improved?
Would you prefer more visual or real-life case-based questions?
Would you recommend continuing QBL for future courses?

Unit 7 – *Rating Scale Questions***: 1 (***strongly disagree***)** to **5 (***strongly agree***)**
QBL improved my understanding of nanotechnology concepts ---
QBL made learning more interactive ---
The questions encouraged critical thinking ---
The approach helped me apply knowledge practically ---
I would like QBL used in other subjects ---

Unit 8 – *Open-Ended Reflection Questions*
How did QBL change the way you learn?
Describe one question that helped you understand nanotechnology deeply.
What improvements would make QBL more effective?
How can QBL better connect medicine and engineering applications?
What additional topics should be included?

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Supporting Material: A sample questionnaire for assessing the effectiveness of QBL and the learning outcomes is available (*Appendix I*). Example student responses/classroom interaction transcripts are available on request from the author.

Declarations

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NOTES

1. https://datasetsearch.research.google.com/search/src&query=Open-ended-survey-responses-qualitative-answers-from-students-on-question-based-learning&docid
2. https://datasetsearch.research.google.com/search?src&query=Focus-groups-discussions-on-student-engagement-and-understanding-on-question-based-learning&docid
3. https://datasetsearch.research.google.com/search?src&query=Interview-transcripts-discussions-with-teachers-or-students-about-their-experiences-with-question-based-approaches&docid
4. https://datasetsearch.research.google.com/search?src-&query=question-based-learning-and-qualitative-data&docid= L2cvMTFrOXJyX3E4OA3D3D
5. https://datasetsearch.research.google.com/search?src=0&query=question-based-learning-and-qualitative-data&docid=L2cvMTFscDIxbXBoMQ3D3D
6. https://datasetsearch.research.google.com/search?src=0&query=question-based-learning-and-qualitative-data&docid =L2cvMTFtejlxeGM1eA3D3D

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