Enhancing Students’ Critical Thinking Skills through an Augmented Reality–Assisted STEM Approach: An Analysis of Physics Learning Outcomes

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Abstract. Learning outcomes in physics at Madrasah Aliyah (Islamic Senior High School) remain persistently challenging due to the abstract nature of the subject and students’ limited critical-thinking skills. This study aims to develop a physics learning model based on an Augmented Reality–Assisted STEM Approach to enhance meaningful learning experiences. This study employed a qualitative research design, incorporating Dick and Carey’s instructional analysis framework and Allison Rossett’s Training Needs Assessment. Data were collected through student questionnaires, classroom observations, and in-depth interviews with physics teachers. The comprehensive needs analysis informed the development of the Quantum Leap Model, which comprises conceptual, theoretical, and instructional components that integrate STEM, AR technology, and Islamic values within a love-based curriculum framework. Findings indicate a strong need for interactive, visual, and AR-assisted STEM approaches in physics instruction.

Keywords: STEM approach, Augmented Reality, Critical Thinking, Physics Learning, Quantum Leap Model, Love-Based Curriculum, Needs Analysis.

1 Introduction

Physics instruction in Madrasah Aliyah, particularly at Madrasah Aliyah Negeri (MAN) 2 Model Medan, faces substantial challenges. The abstract nature of physics concepts—such as those related to waves, optics, particle dynamics, and electricity—constitute a major source of learning difficulties, hindering students’ development of deep conceptual understanding. These challenges arise from limitations in instructional media and laboratory activities, the verbalistic nature of lecture-based teaching, and the lack of experience-oriented learning strategies.

Survey responses from Grade X students indicate that most learners: (a) struggle to comprehend abstract concepts without visual support; (b) are not yet accustomed to inquiry- and project-based activities aligned with the Science, Technology, Engineering, and Mathematics (STEM) approach; (c) have minimal exposure to digital learning media such as augmented reality (AR) or virtual reality (VR); and (d) require more systematic guidance in solving physics problems.

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These circumstances contribute to the suboptimal attainment of physics learning outcomes (*Capaian Pembelajaran*, CP) as mandated in the *Merdeka* Curriculum.

The STEM approach offers a learning pathway that connects theory to practice through the engineering design process, while AR technology holds substantial potential for presenting physics phenomena in a visual and immersive manner, thereby helping to reduce cognitive load [1]. These two approaches should be integrated within an instructional design framework capable of enhancing the effectiveness of physics learning.

As an institution grounded in Islamic values, MAN 2 Model Medan also expects instructional practices that internalize and strengthen students' character development. This study integrates Islamic values through the Love-Based Curriculum (*Kurikulum Berbasis Cinta*, KBC), which encompasses five dimensions of love: love for Allah SWT and His Messenger, love for knowledge, love for the environment, love for oneself and fellow human beings, and love for the homeland [2]. These values function as an ethical and spiritual framework for technology-enhanced modern instruction in the Madrasah context.

The needs analysis of physics learning outcomes—employing a STEM approach supported by AR technology—is instrumental in enhancing students' critical-thinking skills. This study aims to: (a) conduct a needs analysis of physics learning outcomes; (b) develop a physics learning model that applies a STEM approach assisted by AR while integrating Islamic values grounded in the Love-Based Curriculum; and (c) identify the needs of students and teachers through preliminary surveys and a Training Needs Assessment (TNA) method.

2 Review of related literature

2.1 The STEM approach in twenty-first-century learning

The Science, Technology, Engineering, and Mathematics (STEM) approach has become a pivotal component of twenty-first-century science education due to its capacity to integrate conceptual knowledge with real-world applications through authentic problem-solving. The Four Cs White Paper affirms that STEM learning directly contributes to the development of critical thinking, creativity, communication, and collaboration—four core 21st-century competencies [3]. STEM-based physics instruction enables students to engage deeply with the engineering design process, which requires them to analyze problems, design solutions, conduct experiments, and engage in reflection.

This integration is highly relevant for Madrasah Aliyah students, who require contextual learning experiences to meaningfully comprehend abstract physics concepts. Accordingly, STEM provides a robust foundation for fostering critical-thinking skills as essential learning outcomes in physics.

2.2 Augmented Reality as a medium for strengthening the understanding of abstract concepts

Augmented Reality (AR) technology enables three-dimensional digital representations to be superimposed onto real-world environments, thereby making abstract concepts more accessible to learners. AR has been shown to enhance spatial understanding, facilitate the exploration of physics phenomena that are not directly observable, and reduce cognitive load through visualizations that support information processing [4].

Based on Mayer's multimedia learning principles, media such as AR can enhance the learning process by utilizing dual channels (visual and auditory) and by designing presentations that minimize extraneous cognitive load [5]. This body of literature reinforces the argument that AR holds substantial potential for use in abstract physics topics such as waves, optics, electricity, and dynamics.

2.3 Instructional analysis using the Dick and Carey model

The Dick and Carey instructional systems design model is one of the most widely used frameworks in educational research because it emphasizes a systematic approach, needs analysis, formative evaluation, and measurable instructional planning [6]. In the context of developing physics instruction that applies a STEM approach supported by AR, this model is highly instrumental in: (a) identifying gaps in learning outcomes; (b) mapping the skills students must master; (c) formulating operational learning objectives; (d) designing appropriate instructional strategies; and (e) ensuring that evaluation aligns with the learning process.

The Dick and Carey model also provides a foundation for viewing instruction holistically, ensuring that each component supports one another in achieving the ultimate goal, namely the development of critical-thinking skills.

2.4 Training needs assessment by Allison Rossett

Training Needs Assessment (TNA) is employed to identify actual performance and compare it with optimal performance. Rossett explains that an effective needs analysis must involve five core elements: optimal performance, actual performance, feelings, causes, and solutions [7].

This method is highly relevant for MAN 2 Model Medan, which requires a learning model capable of addressing the gap between expected physics learning outcomes and students' actual conditions. Preliminary survey data, derived from questionnaire responses by 113 students and in-depth interviews with four physics teachers, indicate that most gaps arise due to: (a) limited visualization of concepts; (b) infrequent STEM-based practice; (c) insufficient availability of digital media such as AR; and (d) the predominance of lecture-based instruction. Accordingly, the needs analysis conducted through the instructional analysis and TNA frameworks provides an empirical foundation for developing a physics learning model at MAN 2 Model Medan.

2.5 Theoretical synthesis of the integration of the stem approach supported by augmented reality and the love-based curriculum

Physics learning in Madrasah Aliyah requires an instructional approach capable of bridging abstract concepts with concrete and meaningful learning experiences. Field observations indicate that most students encounter significant conceptual barriers when dealing with physics phenomena that cannot be directly observed. This condition contributes to the low levels of students' critical-thinking skills, particularly in identifying problems, analyzing cause–effect relationships, and evaluating scientific solutions. These gaps signal the need for an instructional model that is not only technologically innovative but also value-oriented in cultivating students' character.

Grounded in these needs, the integration of the STEM approach, AR technology, and the Love-Based Curriculum becomes a pedagogical imperative. The STEM approach provides an inquiry- and engineering design–based learning framework; AR enhances cognitive experiences through immersive visualization; and the Love-Based Curriculum reinforces the spiritual, emotional, and moral dimensions of the learning process. Together, these three components offer a robust theoretical foundation for the development of a physics learning model aimed at cultivating students' critical-thinking skills.

To provide a solid foundation for this synthesis, the theoretical framework is organized hierarchically, beginning with the grand theory, followed by the middle theory, and culminating in the application theory. This structure establishes a systematic conceptual progression that is scientifically sound and defensible.

Grand theory: philosophical and psychological foundations of learning

Constructivism as the primary theoretical pillar. Constructivist theory posits that knowledge is not transmitted directly but is constructed through active interaction with the environment and through the internalization of experiences [8-9]. Piaget and Vygotsky assert that learning occurs when students construct meaning from the phenomena they encounter [10-11]. In the context of physics learning, constructivism provides the foundation that students must experience, manipulate, and reflect upon physical phenomena in order to form stable cognitive structures. The STEM approach and AR align strongly with this perspective: STEM requires students to engage in the engineering design process, while AR offers immersive digital observation experiences that reinforce knowledge construction.

Value construction in the love-based curriculum as an ethical - spiritual framework. The Love-Based Curriculum, grounded in five dimensions of love—love for Allah and His Messenger, love for knowledge, love for the environment, love for others and oneself, and love for the homeland—strengthens the affective and spiritual dimensions of learning [2-3]. The Love-Based Curriculum does not function as a new pedagogical theory but rather as a value-laden framework that ensures the learning process remains aligned with moral and spiritual principles. The integration of the Love-Based Curriculum serves as the humanistic foundation of the Quantum Leap Model, positioning physics instruction not merely as the transmission of concepts but as the cultivation of an Islamic scientific character.

Middle theory: mechanistic explanation of the learning processes within the STEM–AR–the love-based curriculum framework. If the grand theory explains *why* learning occurs, then the middle theory clarifies *how* learning takes place within this framework.

Cognitive load theory and multimedia learning. Cognitive Load Theory (Sweller) and Multimedia Learning Theory (Mayer) posit that appropriate visualization can: (a) reduce extraneous cognitive load; (b) optimize working memory; and (c) enhance knowledge transfer [12-13]. AR functions as an instructional medium that aligns with these theories: students can directly observe particle motion, waves, or force vectors through three-dimensional digital objects, thereby reducing the gap between abstract representations and real-world perception.

STEM pedagogy and the engineering design process. Within the STEM approach, the engineering design process (EDP) provides a scientific inquiry sequence that includes: (a) defining the problem; (b) developing a plan; (c) generating solutions; (d) testing and evaluating the solutions; (e) making improvements; and (f) presenting the results [1,11]. The EDP provides a clear mechanistic structure for stimulating critical-thinking activities. When AR is employed during the stages of unveiling concepts and testing solutions, the engineering design process becomes more concrete and measurable.

Internalization of values through the love-based curriculum. The Love-Based Curriculum functions as the middle theory in the affective domain by explaining how values shape students' motivation, work ethic, and scientific behavior. For instance, love for knowledge encourages students to engage in rigorous investigation; love for the environment necessitates solving physics problems within ecological contexts; and love for self and others is reflected in networked collaboration. Accordingly, the Love-Based Curriculum influences the motivational climate and learning disposition—two essential factors in the effectiveness of STEM-based learning supported by AR.

Application theory: the implementation of theory within the quantum leap model. At the application theory level, the aforementioned theories are materialized into a practical model that can be implemented by teachers. The Quantum Leap Model represents a comprehensive synthesis of the integration of STEM, AR, and the Love-Based Curriculum.

Structure of the quantum leap model. The physics learning model, whose syntaxes are derived from the synthesis of the aforementioned theories, consists of eleven instructional syntaxes: (a) Questioning—timulating curiosity (STEM-EDP + Love-Based Curriculum: love for knowledge); (b) Unveiling Concepts (AR)—visualizing abstract phenomena; (c) Applying STEM—implementing physics concepts within the engineering design process (EDP); (d) Networked Collaboration—collaboration grounded in Islamic ethical values; (e) Testing Solutions (AR simulations)—evaluation through digital experimentation; (f) Uplifting Knowledge—constructing knowledge through dialogic interaction; (g) Mastery Demonstration—presenting outcomes (critical communication); (h) Linking to Future—transferring concepts to novel problems; (i) Empowering with Feedback—providing formative and reflective feedback; (j) Assessing Holistically—covering cognitive, affective, and process skills; and (k) Projecting Forward—reflection guided by Love-Based Curriculum values.

Mechanism for developing critical thinking. This model establishes learning conditions that target four components of critical thinking: (a) clarification—achieved through questioning; (b) analysis—facilitated through applying STEM and testing solutions; (c) evaluation—developed through mastery demonstration and feedback; and (d) inference—supported through projecting forward and linking to future contexts. The integration of AR further strengthens the analysis and clarification components [3], [14]. STEM strengthens the evaluation and inference components, while the Love-Based Curriculum reinforces learners' mental dispositions and scientific ethics throughout each of these stages.

Through an inductive approach, it can be concluded that the integration of STEM, AR, and the Love-Based Curriculum provides a robust theoretical foundation for the development of a comprehensive physics learning model. The grand theory (constructivism and Love-Based Curriculum values) offers a philosophical orientation that views learning as a process of meaning construction. The middle theory (cognitive load theory, multimedia learning, and STEM pedagogy) explains the psychological mechanisms through which students build knowledge via AR-based visualization and engineering design activities. The application theory

(Quantum Leap Model) serves as a practical bridge that unifies these theoretical levels into a systematic, effective, and contextually relevant instructional syntax for the *Madrasah* setting.

Thus, this theoretical synthesis not only strengthens the conceptual foundation of the study but also provides direction for developing a physics learning model capable of enhancing students' critical-thinking skills while simultaneously embedding the values of love emphasized in the Love-Based Curriculum.

3 Method

This study employs a qualitative approach with a focus on needs assessment to establish the foundation for developing a physics learning model. Two frameworks serve as the primary basis: (a) the instructional analysis framework of Dick and Carey, which is used to identify learning objectives, prerequisite skills, task analysis procedures, and instructional evaluation [15]; and (b) Rossett's Training Needs Assessment (TNA) method, which analyzes optimal performance, actual performance, feelings, causes, and solutions to obtain a clear understanding of the actual needs present in the physics classroom [7,16]. The data sources and participants in this study consisted of four teachers and 114 tenth-grade students at MAN 2 Model Medan.

Data collection techniques included: (a) student questionnaire surveys addressing learning experiences, media needs, and perceptions of physics instruction; (b) classroom observations to examine instructional patterns and barriers to conceptual understanding; and (c) in-depth interviews with teachers regarding the implementation of STEM and the use of AR. Complementary data were obtained from a review of physics learning outcomes, teaching modules (lesson plans), and learning assessments.

Data analysis involved data reduction, thematic categorization, cross-verification, and synthesis of the instructional needs analysis based on the physics learning outcomes. The output of the analysis is a needs map that serves as the foundation for constructing the conceptual model, theoretical model, and instructional model.

4 Results and Discussion

4.1 Results

Needs analysis of physics learning outcomes. The TNA results reveal three main findings: (a) the learning outcomes are highly abstract and require substantial visualization, particularly in topics such as waves, optics, electricity, and particle dynamics; (b) students' critical-thinking skills are low, especially in the indicators of problem clarification, analysis of cause–effect relationships, and evaluation of solutions; and (c) teachers require a systematic instructional model capable of integrating STEM practices with AR technology support.

Quantum Leap Model. The development results, derived from the theoretical foundation and survey data, produced three descriptive models. First, the Conceptual Model integrates three key components: (a) physics learning outcomes aligned with the *Merdeka* Curriculum; (b) the STEM approach supported by AR, emphasizing engineering design and problem-solving; and

(c) Islamic values grounded in the Love-Based Curriculum, serving as an ethical and spiritual framework for cultivating humble and morally grounded scientific character.

Second, the Theoretical Model synthesizes constructivist theory, cognitive load theory, AR design theory as a cognitive tool, STEM pedagogical approaches, and Islamic values embedded in the Love-Based Curriculum, which encompasses five dimensions of love: love for Allah SWT and His Messenger, love for knowledge, love for the environment, love for oneself and fellow human beings, and love for the homeland. This model asserts that critical-thinking skills develop through the interaction of concrete experiences, AR-based visualization, collaboration, and value-oriented reflection. These values function as an ethical and spiritual framework for technology-enhanced modern learning within the Madrasah context.

Third, the Quantum Leap Instructional Model—an acronym representing the stages of physics learning that implement the STEM approach supported by AR—consists of eleven syntaxes corresponding to the eleven letters in the phrase "Quantum Leap." These learning stages are: Questioning—stimulating curiosity; Unveiling Concepts—revealing concepts through AR-based visualization; Applying STEM—designing solutions grounded in STEM integration; Networked Collaboration—collaborating synchronously or asynchronously; Testing Solutions—conducting experiments and simulations; Uplifting Knowledge—constructing new understanding; Mastery Demonstration—presenting and defending arguments; Linking to Future—connecting concepts to future challenges; Empowering with Feedback—receiving formative feedback from teachers and peers; Assessing Holistically—assessing cognitive, affective, and process skills; and Projecting Forward—reflecting and formulating subsequent action plans.

Teacher and student responses. The TNA survey results indicate that 86% of students reported that AR helps them understand abstract concepts; 79% felt more confident in solving problems; and 90% of teachers stated that the model provides a clear and easily adaptable instructional structure. The primary challenges identified relate to the availability of devices and AR training.

Based on the completed questionnaires, a total of 114 students participated, although several items contained missing responses. Overall, students' perceptions of various aspects of the physics instruction they experienced over one semester in Grade 10 tended to cluster around a neutral position. Nevertheless, as illustrated by the bar charts, students' reported levels of interest in, or discomfort with, learning physics provide meaningful insight into their learning potential and their capacity to develop a deeper understanding of physics concepts. These patterns suggest that affective factors—such as engagement and perceived difficulty—play an important role in shaping students' learning experiences. A detailed description of these responses is presented in Figures 1 through 9, which collectively depict students' attitudes and perceptions across the surveyed dimensions.

As illustrated in Figure 1, the questionnaire responses from 114 students show that interest in learning physics is largely dominated by the neutral category. A total of 54 students (47.40%) selected scale point 3. Positive responses, corresponding to scale points 4 and 5, were reported by 43 students (37.70%), whereas negative responses on scale points 1 and 2 were reported by 17 students (14.90%). Overall, these results indicate that students' attitudes toward physics learning tend to range from neutral to moderately positive.

I am interested in learning physics. (1 = strongly disagree, …, 5 = strongly agree).

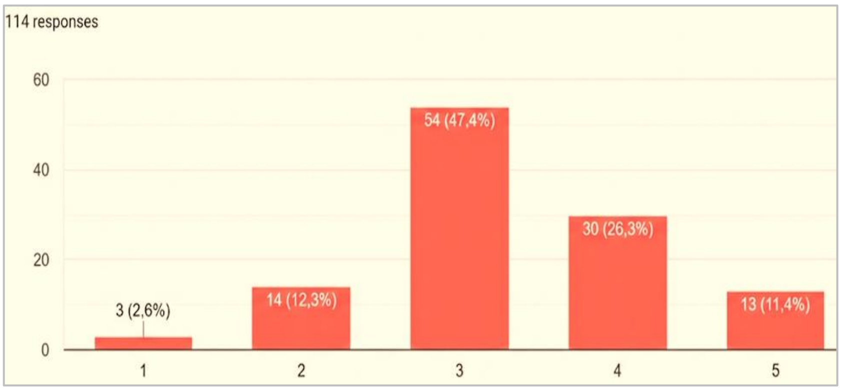

Fig. 1. Students' interest in learning physics

As shown in Figure 2, responses from 114 students indicate that perceptions of physics instruction as boring are largely concentrated in the neutral category. A total of 51 students (44.70%) selected scale point 3. In contrast, 43 students (37.70%) disagreed or strongly disagreed with the statement (scale points 1 and 2), while only 20 students (17.50%) agreed or strongly agreed (scale points 4 and 5). These findings suggest that students do not strongly perceive physics learning or physics classes as boring.

I feel that the current physics instruction is boring. (1 = strongly disagree, …, 5 = strongly agree).

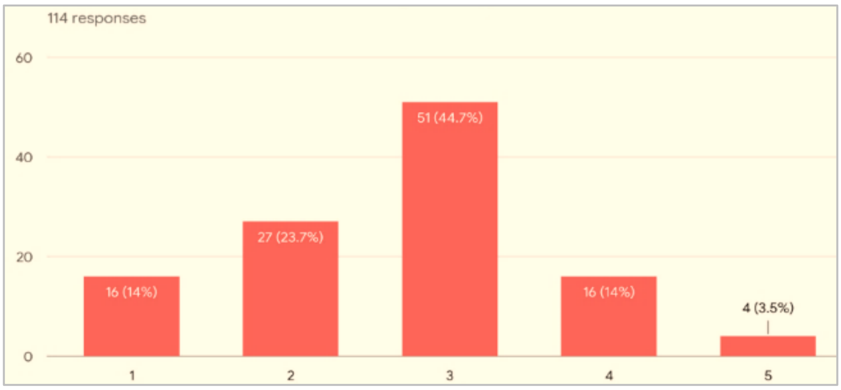

Fig. 2. Perceptions of physics learning as boring

As shown in Figure 3, responses from 114 students indicate that interest in trying new technologies for learning is primarily centered on the neutral category. A total of 47 students (41.20%) selected scale point 3. Positive responses on scale points 4 and 5 were reported by 49 students (43.00%), while negative responses on scale points 1 and 2 were reported by 18 students (15.80%). Overall, these findings suggest that students' attitudes toward the use of new technologies in learning tend to range from neutral to positive.

I enjoy trying new technologies (such as Augmented Reality, AR) for learning. (1 = strongly disagree, …, 5 = strongly agree).

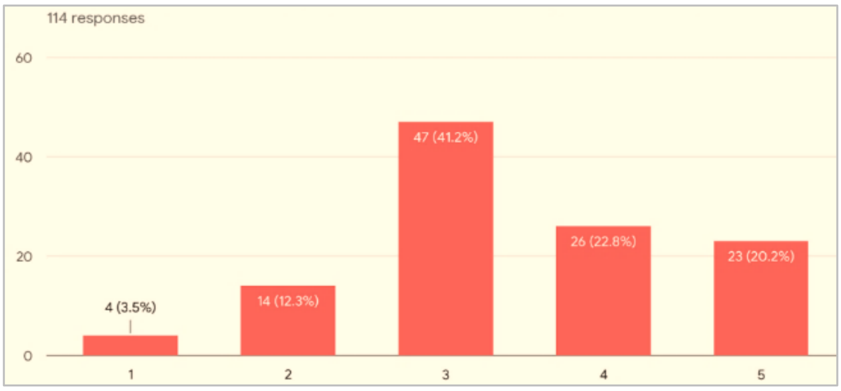

Fig. 3. Interest in new technologies

As shown in Figure 4, responses from 114 students indicate that beliefs about the role of AR in supporting physics understanding are largely centered on the neutral category. A total of 46 students (40.40%) selected scale point 3. Positive responses on scale points 4 and 5 were reported by 55 students (48.20%), whereas negative responses on scale points 1 and 2 were reported by 13 students (11.40%). Overall, these results suggest that students' attitudes toward the use of AR in physics learning tend to range from neutral to positive.

I believe that Augmented Reality (AR) can help me understand physics concepts. (1 = strongly disagree, …, 5 = strongly agree).

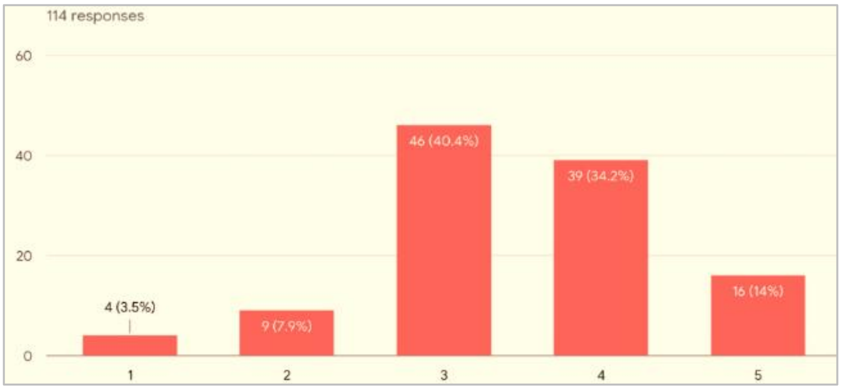

Fig. 4. Beliefs about the role of Augmented Reality (AR) in facilitating learning

As shown in Figure 5, responses from 111 students (with several items left unanswered) indicate that students' comfort in using digital devices for learning in the classroom tends to fall within the positive category. The largest proportion of responses was at scale point 4, selected by 41 students (36.90%), followed by scale points 5 and 3, each chosen by 27 students (24.30%). Negative responses on scale points 1 and 2 were relatively low, reported by only 16 students

(14.40%). Overall, these results suggest that the majority of students feel comfortable using digital devices as part of the learning process.

I feel comfortable using digital devices (smartphones or tablets) for learning in the classroom. (1 = strongly disagree, …, 5 = strongly agree).

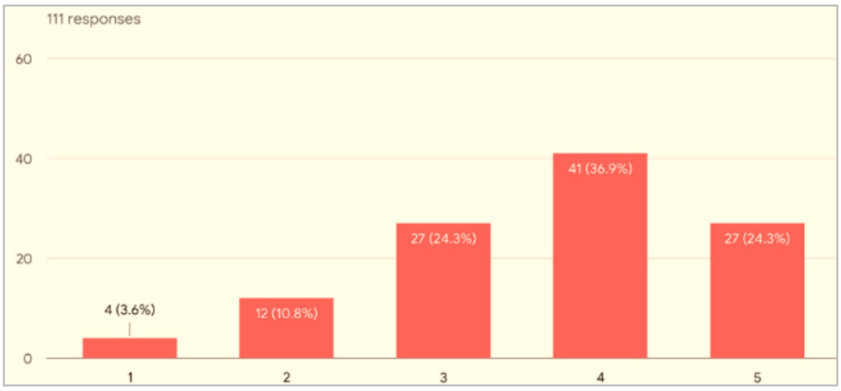

Fig. 5. Comfort in using digital devices for learning

As shown in Figure 6, responses from 113 students indicate that perceptions of the importance of linking Islamic values with science education tend to be strongly positive. The largest proportions of responses were distributed across scale points 3, 4, and 5, accounting for 31.90%, 31.00%, and 31.00%, respectively, resulting in a total of 106 students (93.90%) expressing neutral to positive agreement. In contrast, negative responses on scale points 1 and 2 were minimal, reported by only 7 students (6.20%). These findings suggest a broad consensus among students regarding the importance of integrating Islamic values into science learning.

I believe that Islamic values are important to be integrated into science lessons. (1 = strongly disagree, …, 5 = strongly agree).

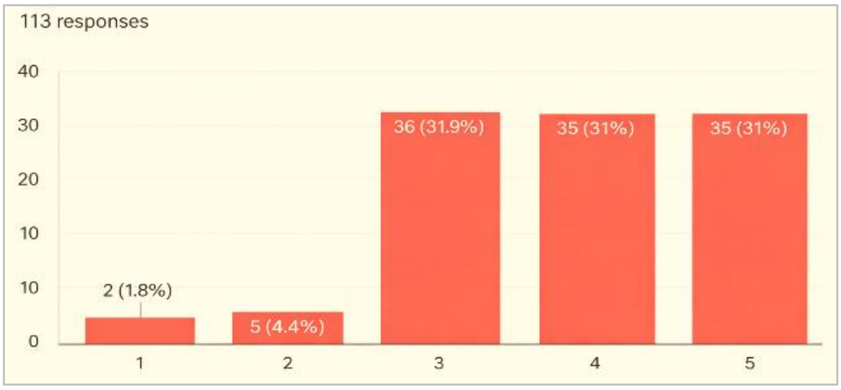

Fig. 6. The importance of integrating Islamic values into science education

Overall, as summarized in Table 1, students' responses to physics learning based on the questionnaire results indicate a generally neutral-to-positive tendency. Most aspects—including interest in learning physics, the use of new technologies, the role of Augmented Reality (AR), comfort in using digital devices, and efforts to integrate Islamic values with science—showed high percentages in the neutral-to-positive category, ranging from 84.20% to 93.90%. In contrast, perceptions of physics learning as boring tended to fall within the neutral-to-negative range. These findings underscore that students' attitudes are not polarized; rather, they reflect a generally favorable acceptance of physics learning and the supporting innovations.

Table 1. Students' responses to physics learning

Type of Response	Tendency	Percentage
Interest in learning physics	Neutral–positive	85.10%
Physics content is boring	Neutral–negative	82.40%
Learning physics using new technologies	Neutral–positive	84.20%
AR technology clarifies physics concepts	Neutral–positive	88.60%
Comfort in learning with digital devices	Neutral–positive	84.60%
The importance of integrating Islamic values with science	Neutral–positive	93.90%

The questionnaire also asked students to identify the factors that most strongly influenced their responses among the options they selected. The results of this analysis are presented in Figures 7 through 9.

As shown in Figure 7, questionnaire responses from 111 students indicate that the primary factor driving students' interest in learning physics is the ability to see connections between physics and everyday life or religious values, reported by 44 students (39.60%). Other contributing factors include engaging experimental demonstrations, selected by 31 students (27.90%); the use of physics visuals or animations, noted by 17 students (15.30%); and clear and easy-to-understand explanations from teachers, reported by 14 students (12.60%). Responses classified under the "other" category were minimal, with only 5 students (4.60%).

What makes you interested in learning physics? (Select one or more options)

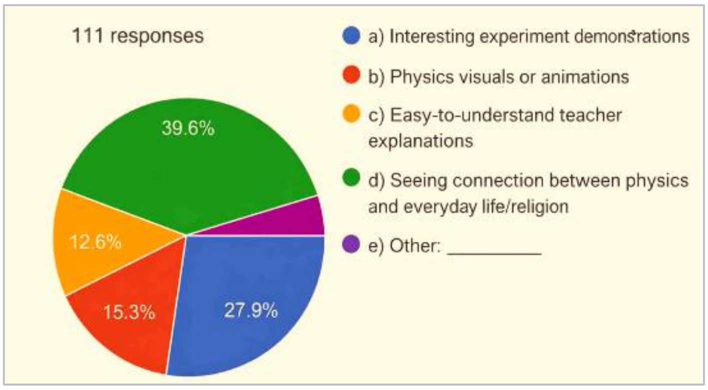

Fig. 7. Factors influencing students' interest in physics

As shown in Figure 8, questionnaire responses from 113 students indicate that the frequency of smartphone or tablet use for learning outside of school is predominantly in the "almost every day" category. A total of 74 students (65.50%) reported using these devices nearly every day, while 34 students (30.10%) stated that they use them occasionally. In contrast, only a very small proportion of students reported using smartphones or tablets two to three times per week or not using them at all. These findings suggest that the majority of students are already accustomed to using digital devices as a means of learning beyond the school environment.

How often do you use a smartphone or tablet for learning outside of school or madrasah?

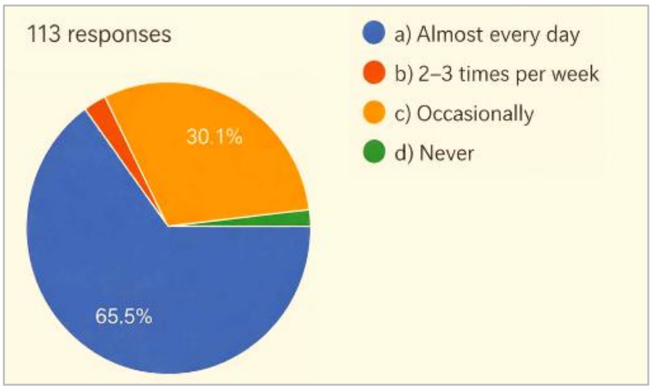

Fig. 8. Use of smartphones for learning

As shown in Figure 9, questionnaire responses from 112 students indicate that the primary suggestion for improving physics learning in the classroom is the addition of more experimental or practical activities, reported by 51 students (45.50%). Other suggestions include providing more relevant example problems, noted by 32 students (28.60%); using interactive learning media such as videos or Augmented Reality, selected by 16 students (14.30%); and linking instructional content to religious values. Responses in the "other" category were relatively limited, indicating a consistent student preference for learning approaches that are practical and contextually meaningful.

Please mention one thing that you believe could improve physics learning in the classroom?

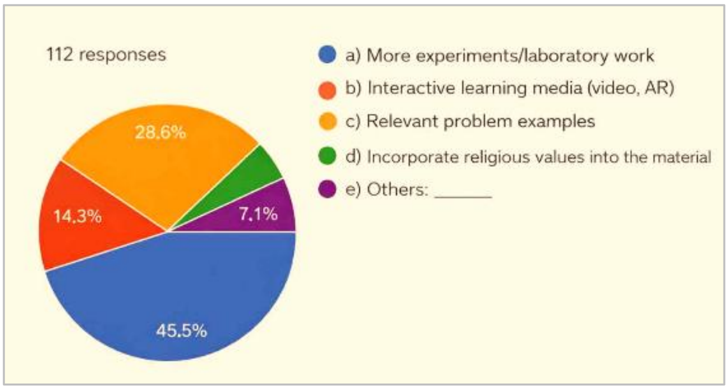

Fig. 9. Factors that could improve physics learning

Based on the descriptive analysis of the data presented in Figures 7 through 9, student responses from MAN 2 Model Medan reveal a consistent pattern linking interest, learning habits, and expectations for physics learning. Students' interest in physics is primarily influenced by the extent to which physics content is connected to everyday life or religious values (39.60%). At the same time, the majority of students are already accustomed to using digital devices for learning outside the classroom, with usage occurring almost daily (65.50%). This condition aligns with students' suggestions for improving physics instruction, where the most frequently expressed expectation is the inclusion of more experimental or practical activities (45.50%). Overall, Table 2 underscores that contextualized physics learning, supported by the use of digital devices and reinforced through experimental activities, constitutes a dominant factor shaping positive student responses.

Table 2. Factors influencing students' responses

Factors	Positive factors	Percentage
Interest in learning physics	Connections between physics and everyday life	39.60%
Use of digital devices for learning outside the classroom	Daily access to digital devices	65.50%
Improvement of physics learning	More experiments or practical activities	45.50%

4.2 Discussion

The findings of this study demonstrate that the Quantum Leap Model effectively addresses the learning needs in physics education, which demand concrete, integrative, and meaningful experiences. By integrating STEM and AR within an Islamic values framework, this model not only achieves technical robustness but also fosters a holistic orientation. Augmented reality technology serves as a cognitive tool that enhances understanding by overcoming abstraction barriers through three-dimensional visualization, direct interaction, simulation of physics phenomena, and reduction of cognitive load [17]. This capability allows students to transform abstract concepts into concrete representations, thereby creating an enjoyable learning environment that increases motivation and fosters positive attitudes during the learning process [3,18].

Augmented reality technology as a cognitive tool for enhancing understanding. In the Unveiling Concepts phase, AR overcomes abstraction barriers via three-dimensional visualization, direct interaction, simulation of physics phenomena, and reduction of cognitive load. Moreover, this approach aligns with the literature on cognitive load theory, which highlights the role of visual media in facilitating comprehension. Specifically, the visual and interactive nature of augmented reality helps students visualize complex physics phenomena, making abstract concepts more tangible and accessible [19]. Research indicates that such immersive visualization significantly improves student engagement and conceptual understanding by enabling experiential learning opportunities that traditional methods often lack [20-21].

Quantum leap syntax as a critical-thinking pedagogy. The Quantum Leap syntax promotes critical thinking through a structured sequence of learning processes: inquiry that stimulates questioning and hypothesis formation; experimentation that facilitates empirical testing and observation; collaboration that encourages peer discourse and diverse perspectives; scientific argumentation that demands evidence-based reasoning and rebuttal; and constructive reflection that fosters metacognitive evaluation and synthesis of knowledge [22-24]. This integration actively embeds critical thinking throughout the pedagogy, aligning with student preferences for practical activities as evidenced in the needs analysis [25-26].

Integration of islamic values as an ethical foundation. The Islamic values integrated into this model bolster students' character development by cultivating scientific ethics, intrinsic motivation for learning, spiritual awareness of knowledge as a divine trust, and a scientific persona rooted in Indonesian identity [27-29].

A physics learning model integrating STEM and AR to enhance critical-thinking skills has implications for physics curriculum development in madrasahs and secondary schools, immersive technology-based instructional design, teacher training and professional development, and AR effectiveness research in STEM education [11,14,30]. However, as a theoretical model, it requires empirical validation to confirm its effectiveness. Current limitations include the need for adequate AR devices, reliance on data from a single madrasah, and lack of quantitative experimental evidence on physics learning outcomes. Future research should prioritize classroom experiments to assess its impact on critical thinking and character development [31-32], including evaluations of AR active learning benefits and effective AR activity integration into curricula [33].

5 Conclusion

This study affirms that physics instruction requires an integrated approach capable of bridging the abstraction of concepts with the need to strengthen critical-thinking skills. The Quantum Leap Model, developed through a needs-analysis process, proves to be relevant, systematic, and adaptable to the demands of twenty-first-century education. The integration of STEM, AR technology, and Islamic values produces an instructional design that is not only pedagogically robust but also rich in meaning. Both teachers and students demonstrated readiness and positive responses toward this model. Moreover, it is recommended as an alternative framework for secondary-level physics instruction, particularly in *Madrasah Aliyah*.

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