

Integrating Neuro-Pedagogy into Indonesian Islamic Religious Education: A Brain-Based Learning Framework for the Digital Era

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ARTICLE INFO	ABSTRACT
Keywords: neuro-pedagogy; islamic religious education; brain-based learning; digital learning; educational neuroscience; instructional design	Islamic Religious Education (IRE) in the digital era continues to face significant challenges, particularly monotonous, teacher-centered instruction misaligned with how the brain naturally learns, weakening value internalization and meaningful learning. This study aims to develop a comprehensive conceptual framework for integrating neuro-pedagogy into IRE by proposing an operational model teachers can directly implement in the classroom. Using a library research design with a qualitative- conceptual approach, this study analyzed literature on educational neuroscience, neuro-pedagogy, IRE challenges, and brain-based learning theories, applying content analysis and theoretical synthesis to identify principles of attention, emotion, multisensory experience, and memory consolidation. The findings show these principles are highly relevant to IRE's goals, integrating cognitive, affective, and psychomotor dimensions, and translate into concrete strategies across Aqidah-Akhlaq, Al-Qur'an- Hadith, and Fiqh. The study proposes the 4C Neuro-Pedagogy IRE Model (Connect, Create Meaning, Construct Multisensory Learning, and Consolidate) as a classroom-ready framework for meaningful, student- centered learning that does not require advanced technology. This study concludes that neuro-pedagogy offers a scientific and practical foundation for strengthening character formation, spiritual awareness, and learning engagement in Islamic education, and recommends further empirical testing across diverse contexts.
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INTRODUCTION

Islamic Religious Education (IRE) occupies a strategic position within the Indonesian national education system. It is not merely responsible for transmitting religious knowledge at the cognitive level but also for fostering moral character, cultivating spiritual awareness, and preparing students to become complete human beings endowed with faith, knowledge ¹, and noble character. Within an ideal pedagogical framework, IRE should be designed as a holistic learning experience that stimulates cognitive, affective, and psychomotor domains in a balanced and integrated manner through creative, contextual, and relevant approaches that respond to contemporary educational dynamics ². Furthermore, amid the rapid transformation brought about by the digital era, IRE is expected to bridge transcendent Islamic values with the complex realities and challenges faced by the digital generation.

However, the realities of classroom practice reveal conditions that remain far from these ideals. Numerous studies consistently indicate that lecture-based instruction continues to dominate IRE teaching practices in Indonesian schools, despite the availability of more innovative and empirically supported pedagogical alternatives ³. This condition is further aggravated by the limited utilization of educational technology, insufficient variation in instructional media, and the lack of pedagogical innovation grounded in contemporary understandings of how students learn ⁴. Consequently, many students perceive IRE as monotonous, uninteresting, and disconnected from their everyday experiences ⁵. The implications of these conditions extend beyond students' perceptions. Poor learning experiences directly contribute to weaker comprehension of religious materials, declining intrinsic motivation to study religion, and, most importantly, the failure to internalize Islamic values into students' daily behavior ⁶. In other words, a systemic failure has emerged in fulfilling the fundamental mission of IRE, namely, character formation and value

¹ Arnida Yanti, "Fun PAI Learning Strategies," *Pedagogics: Journal of Education and Research* 2, no. 3 (2024): 349–57; Zuhri Zuhri Dwi Apriansah et al., "PAI Learning Strategy in the Independent Learning Curriculum at Aisiyah Creative Junior High School Rejang Lebong" (PhD thesis, CURUP STATE ISLAMIC RELIGIOUS INSTITUTE, 2024).

² Rita Patriasih et al., *Building Quality Education: From Pedagogy to Technology* (PT. Lost Gama Education, 2025); Maratul Qiftiyah et al., *Learning and Learning* (U ME Publishing, 2025).

³ Abdul Mun'im Amaly et al., "The Necessity and Reality of Islamic Religious Education in Schools," *Futura Islamic Scientific Journal*, ahead of print, June 20, 2023, <https://doi.org/10.22373/jiif.v23i1.13190>; Ashila Arasy et al., "Why is Students' Interest in Learning in PAI Low? Analysis and Improvement Strategies," *IHSANIK A : Journal of Islamic Religious Education*, ahead of print, April 29, 2025, <https://doi.org/10.59841/ihsanika.v3i2.2606>.

⁴ Juniari Agung Wicaksono and Galih Candra, "The Problem of the Application of Reading the Qur'an to Students at SMK Psm 2 Kawedanan, Magetan Regency," *Al-Fatih: Journal of Islamic Studies* 11, no. 01 (2023).

⁵ Desi Susanti and Siti Jubaidah, "The Application of Active Learning Methods to Improve Understanding of Islamic Religious Values in Grade V Students at SD Negeri 003 Pangkalan Kerinci," *JOURNAL of Educational Action Studies (JSTE)* 1, no. 1 (2025): 207–11.

⁶ Farraz Aulia Ihsan et al., "Weaknesses in the Implementation of Islamic Religious Education Learning in Indonesian Schools: Causes and Solutions," *Mesada: Journal of Innovative Research* 2, no. 1 (2025): 262–74; Yeti Nurizzati and Binga Juanti, "Internalization of Islamic Religious Values in Environment-Based Social Studies Learning," *Entita: Journal of Social Sciences and Social Sciences Education*, 2025, 367–84; Lisa Seprina Br Sembiring et al., "The Influence of Less Than Optimal Islamic Religious Education on the Formation of Student Character in Indonesia," *Mesada: Journal of Innovative Research* 1, no. 2 (2024): 219–30.

internalization rather than the mere transmission of information.

These challenges become increasingly urgent when viewed from the perspective of the digital era. Contemporary learners, commonly referred to as digital natives, have grown up within highly stimulating, interactive, and technology-rich environments that demand immediate relevance and engagement⁷. Their brains have become accustomed to processing information through multiple sensory channels simultaneously, receiving rapid feedback, and maintaining attention only when exposed to meaningful and contextual stimuli. At the same time, the digital era presents significant threats to character formation, ranging from the widespread exposure to morally problematic content to the weakening of digital ethics among adolescents⁸. Meanwhile, the persistence of traditional instructional approaches in IRE has created a widening mismatch between the ways teachers teach and the ways students' brains optimally learn. If left unaddressed, this gap may reduce the relevance and transformative potential of IRE in responding to the educational demands of the twenty-first century⁹.

Recent developments in educational neuroscience offer a promising perspective for addressing these challenges. A growing body of research consistently demonstrates that the effectiveness and durability of learning outcomes are determined not merely by the amount of information delivered but by the ways in which the brain is stimulated during the learning process¹⁰. The human brain learns most effectively when certain neurological conditions are fulfilled, including focused attention stimulated by novelty and relevance¹¹, emotional engagement that activates the limbic system and amygdala as gateways to memory formation¹², and multisensory experiences that strengthen synaptic connections and support long-term memory consolidation¹³. These principles constitute the foundation of neuro-pedagogy, an educational approach that intentionally aligns pedagogical strategies with the biological

⁷ R. Akbar and Nur Saidah, "Transformasi Kompetensi Guru Pai Di Abad 21: Perubahan Paradigma Pembelajaran Di Era Digital," *Oasis : Jurnal Ilmiah Kajian Islam*, ahead of print, February 3, 2025, <https://doi.org/10.24235/oasis.v9i2.19315>.

⁸ Emi Rohmiati, "The Use of Digital Media in Learning Islamic Religious Education: Opportunities and Challenges," *Urwatul Wutsqo: Jurnal Studi Kependidikan Dan Keislaman*, ahead of print, March 1, 2025, <https://doi.org/10.54437/urwatulwutsqo.v14i1.1952>.

⁹ Cahyo Hasanudin, *Revolusi Media Pembelajaran Di Era Society 5.0 Untuk Mendorong Pembelajaran Berbasis Teknologi* (Seval Literindo Kreasi, 2025); Wahyu Warastuti et al., "Penerapan Literasi Digital Dalam Membangun Kemampuan Berpikir Kritis Siswa Di Sekolah Dasar," *Cetta: Jurnal Ilmu Pendidikan* 8, no. 2 (2025): 350–65.

¹⁰ Shofura Mufidah et al., "Analisis Pemahaman Mahasiswa PIAUD Terhadap Konsep Stimulasi Otak Anak Usia Dini Berdasarkan Perspektif Neurosains," *Pendas: Jurnal Ilmiah Pendidikan Dasar* 10, no. 02 (2025): 262–71; Rahmi Rivalina, "Pendekatan Neurosains Meningkatkan Keterampilan Berpikir Tingkat Tinggi Guru Pendidikan Dasar," *Kwangsan* 8, no. 1 (2020): 332456.

¹¹ Azmi Maulana et al., "Hakikat Psikologi Belajar," *Kognisi: Jurnal Manajemen Pendidikan Dan Konseling* 1, no. 02 (2025).

¹² Sunarsih Sunarsih et al., *Psikologi Pendidikan: Teori Dan Penerapan Pada Praktik Pengajaran* (PT. Green Pustaka Indonesia, 2025); Eka Wartani et al., "Membangun Struktur Otak Untuk Mendukung Perkembangan Emosi Anak Usia Dini: Perkembangan Emosi Anak Usia Dini," *JIIP-Jurnal Ilmiah Ilmu Pendidikan* 6, no. 11 (2023): 8785–93.

¹³ Yusron Abda'u Ansyar et al., *Pendekatan Neurosains Kognitif Untuk Meningkatkan Kemampuan Literasi Siswa Sekolah Dasar* (CV Jejak (Jejak Publisher), 2025); Rizatul Hasanah et al., "Keberagaman Aspek Psikologis Peserta Didik Dan Implikasinya Dalam Proses Pembelajaran," *JURNAL TIPS JURNAL RISET, PENDIDIKAN DAN ILMU SOSIAL* 2, no. 2 (2024): 88–100.

mechanisms underlying how the human brain learns ¹⁴. Unlike purely technical or instrumental educational innovations, neuro-pedagogy operates at a more fundamental level by addressing how the brain receives, processes, stores, and utilizes information in the formation of knowledge, values, and character.

Despite its growing prominence, studies that specifically and systematically integrate neuro-pedagogical principles into the context of Islamic Religious Education remain limited. Existing educational innovations have proposed various solutions, including the integration of digital technologies, project-based learning, and adaptive personalized instruction. However, most of these approaches are not grounded in an understanding of the neurological mechanisms that underlie their effectiveness ¹⁵. Furthermore, educational neuroscience research has generally focused on science, mathematics, and general education, with limited attention to the unique characteristics of religious education, which encompasses spiritual development, moral character formation, and the transmission of cultural and religious values. These dimensions cannot simply be equated with the teaching of academic content ¹⁶. More specifically, no comprehensive framework has yet been developed to operationalize neuro-pedagogical principles across the major domains of IRE, including Aqidah-Akhlaq, Al-Qur'an-Hadith, and Fiqh, within the context of Indonesian Islamic education. This gap in the literature represents a significant and urgent area for scholarly inquiry, considering the substantial potential of neuro-pedagogy to revitalize IRE practices.

Based on this identified research gap, this article addresses three research questions: (1) What fundamental problems in IRE learning in the digital era require solutions grounded in scientific understandings of brain functioning? (2) How can neuro-pedagogical principles be systematically integrated into IRE instructional design to address these challenges? (3) What conceptual model can be proposed as an operational framework for IRE teachers to implement brain-based learning approaches in classroom practice? These questions are explored through an extensive literature review and an interdisciplinary theoretical synthesis that integrates educational neuroscience, contemporary pedagogical theories, and Islamic educational scholarship.

Unlike previous studies that mainly discuss educational neuroscience or pedagogical innovation separately, this study proposes an integrated conceptual framework that operationalizes neuro-pedagogical principles specifically for Islamic Religious Education. The proposed 4C Neuro-Pedagogy Model offers a practical instructional framework that translates neuroscientific principles into classroom strategies across Aqidah-Akhlaq, Al-

¹⁴ Neneng Maryam Jamaliah Nurul Janah and Asep Supena, "Trend Riset Neuropedagogi Dan Implementasinya Dalam Pendidikan," *EduHumaniora | Jurnal Pendidikan Dasar Kampus Cibiru* 13, no. 1 (2021): 16–25.

¹⁵ Sari Salsabila et al., "Development of Snakes and Ladders Learning Media Based on Joyful Learning in Islamic Religious Education Subjects," *AL-WIJDÂN Journal of Islamic Education Studies*, ahead of print, April 28, 2025, <https://doi.org/10.58788/alwijdn.v10i2.6854>; Syaifuddin Syaifuddin and Junaedi Junaedi, "Conceptual Analysis of It Media Integration In The Digital Islamic Education Curriculum As An Effort To Strengthen The Character Of Junior High School Students: A Library Perspective," *Jurnal Edusci*, ahead of print, July 3, 2025, <https://doi.org/10.62885/edusci.v2i6.805>.

¹⁶ Mary Helen Immordino-Yang and Antonio Damasio, "We Feel, Therefore We Learn: The Relevance of Affective and Social Neuroscience to Education," *Mind, Brain, and Education* 1, no. 1 (2007): 3–10, <https://doi.org/10.1111/j.1751-228X.2007.00004.x>.

Qur'an-Hadith, and Fiqh. This interdisciplinary integration represents the primary novelty of the present study.

Existing brain-based learning frameworks generally focus on general education without considering the unique objectives of Islamic Religious Education, such as value internalization, spiritual awareness, and character formation. In contrast, the proposed 4C Neuro-Pedagogy Model contextualizes neuroscientific principles within the epistemological and pedagogical foundations of Islamic education, making it directly applicable to IRE classroom practice.

This article aims to develop a comprehensive conceptual framework for integrating neuro-pedagogy into Islamic Religious Education by proposing the 4C Neuro-Pedagogy Model for IRE as an operational framework that can be directly implemented by teachers in classroom settings. The significance of this study is twofold. Theoretically, it contributes to the literature by establishing an interdisciplinary bridge between educational neuroscience and Islamic education in Indonesia, an area that has not previously been systematically conceptualized. Practically, it provides evidence-based and adaptive guidance for IRE teachers in designing instructional practices that not only fulfill the normative goals of Islamic education but also align with the ways in which the brains of digital-generation learners learn most effectively.

RESEARCH METHOD

This study employed a library research design using a qualitative-conceptual approach ¹⁷, as the purpose of the study was primarily theoretical, namely to formulate a conceptual framework for integrating neuro-pedagogy into Islamic Religious Education (IRE). Consequently, the study did not require empirical data collected from the field. In this context, library research is not merely a process of compiling references but rather a critical analysis and interdisciplinary synthesis of ideas drawn from educational neuroscience, contemporary pedagogical theories, and Islamic educational studies in order to generate new conceptual perspectives that have not been explicitly formulated in previous literature ¹⁸.

The object of analysis consisted of scholarly literature within three major domains: (1) educational neuroscience and the principles of neuro-pedagogy, (2) challenges and innovations in Islamic Religious Education in the digital era, and (3) brain-based learning theories relevant to educational practice, including brain-based learning, embodied cognition, and multimedia learning. The sources were obtained through systematic searches of reputable academic databases, including Google Scholar, Scopus-indexed journals, and SINTA, using keywords such as “*neuro-pedagogy*,” “*educational neuroscience*,” “*brain-based learning*,” “*Islamic Religious Education*,” “*Islamic education*,” “*digital learning*,” “*embodied cognition*,” “*multimedia learning*,” “*working memory*,” and “*value internalization in Islamic education*.” The search included national and international journal articles, scholarly books, and research reports published between 2005 and 2026, with priority given to publications from the last five years, while

¹⁷ Bahrum Subagiya, “Penelitian Kepustakaan (Library Research) Dalam Penelitian PAI,” *Jurnal Pendidikan Islam* 12 (2023): 43.

¹⁸ Richard J. Torraco, “Writing Integrative Literature Reviews: Guidelines and Examples,” *Human Resource Development Review* 4, no. 3 (2005): 356–67, <https://doi.org/10.1177/1534484305278283>.

seminal studies published before this period were retained because of their theoretical significance. Source selection was guided by the principles of relevance, recency, and credibility, resulting in 62 references as the primary corpus of analysis.

Data collection and analysis were conducted in three stages. First, the selected literature was classified according to the three research domains. Second, content analysis was employed to identify key concepts, major themes, and patterns related to attention, memory consolidation, limbic-system functions, challenges in IRE practices, and effective neuroscience-based instructional strategies. Third, a comparative-integrative synthesis was undertaken to connect the findings and formulate the 4C Neuro-Pedagogical Model for Islamic Religious Education as the main conceptual contribution of this study. The model provides a brain-based operational framework for designing more active, meaningful, and relevant IRE learning experiences for digital-generation learners.

RESULT AND DISCUSSION

Challenges of Islamic Religious Education Learning in the Digital Era

Islamic Religious Education (IRE) in the digital era continues to face several fundamental challenges that affect the effectiveness of the learning process. Numerous studies indicate that IRE instruction in many Indonesian schools remains dominated by teacher-centered approaches characterized by one-way lecturing, limited variation in instructional media, and minimal opportunities for active student participation ¹⁹. This instructional pattern is further reinforced by assessment practices that primarily emphasize memorization and the reproduction of information, leaving limited space for higher-order thinking processes such as analysis, reflection, and moral reasoning. Consequently, learning activities often become monotonous, insufficiently contextualized, and unable to create meaningful learning experiences for digital-generation students ²⁰. When learners are positioned merely as passive recipients of information, their opportunities to question, relate, and interpret religious teachings within real-life contexts become increasingly restricted ²¹. As a result, IRE risks losing its relevance among students who grow up within highly dynamic information ecosystems.

The predominance of pedagogical approaches centered on verbal memorization has also caused IRE to emphasize cognitive achievement while neglecting affective and psychomotor dimensions. Such an imbalance enables students to memorize religious texts, recite doctrinal principles, and perform well on examinations, yet often fails to facilitate the translation of religious knowledge into everyday attitudes and behaviors ²². Consequently, many learners understand Islamic teachings primarily at the level of theoretical knowledge without

¹⁹ Amaly et al., "The Necessity and Reality of Islamic Religious Education in Schools"; Arasy et al., "Mengapa Minat Belajar Siswa Dalam PAI Rendah? Analisis Dan Strategi Peningkatan."

²⁰ Oksana K. Korobkova et al., "A Scoping Review of Contemporary Frameworks, Challenges, and Future Directions on Educational Technology for Digital Generations," *Contemporary Educational Technology* 17, no. 4 (2025): ep611.

²¹ Handan Yalvaç Arıcı, "The Future of Religious Education: The Role and Contributions of Youth Theology," *Religions* 16, no. 4 (2025): 454.

²² Abdullah Al Fraidan and Hind Alotaibi, "Evaluating the Efficacy of Islamic Religious Test-Taking Paradigms in Modulating Test Anxiety During Reading Comprehension Assessments Among Saudi EFL Students," *World Journal of English Language* 15, no. 5 (2025).

experiencing meaningful value internalization ²³. This phenomenon reflects a gap between knowing and being, between cognitively understanding Islamic teachings and genuinely embodying them as part of one's identity and character. In this context, religious education has not fully succeeded in connecting Islamic teachings with students' lived experiences, causing religious values to remain as memorized information rather than deeply internalized beliefs.

These challenges become increasingly complex with the emergence of the digital generation, whose learning characteristics differ substantially from those of previous generations. Contemporary learners tend to respond more positively to visual, audiovisual, interactive, and technology-supported learning environments as a consequence of their daily exposure to rapid, multimodal, and highly stimulating information ecosystems. They also demonstrate relatively shorter attention spans when confronted with repetitive and monotonous instructional stimuli ²⁴, due to their continuous engagement with rapidly changing digital content across various platforms. Such cognitive characteristics require learning environments that are dynamic, rich in stimuli, and supportive of active exploration. Nevertheless, IRE practices in many schools continue to rely on verbalistic instructional approaches that are poorly aligned with the learning preferences and cognitive characteristics of contemporary students. Consequently, a significant gap has emerged between instructional designs employed by teachers and the ways in which students' brains process information most effectively.

In addition to pedagogical factors, limited digital literacy among teachers and the insufficient integration of educational technology represent significant challenges. Many IRE teachers continue to rely on conventional teaching approaches and have not yet optimally incorporated digital media into classroom instruction ²⁵, either because of limited technological competence or because of deeply rooted teaching traditions that have been maintained across generations. The generational gap between teachers as digital immigrants and students as digital natives further widens pedagogical communication within the classroom ²⁶. Moreover, technological infrastructure limitations in several regions, particularly in areas with restricted internet access and limited availability of digital devices, exacerbate the disparity between students' learning needs and classroom realities. These conditions illustrate a substantial mismatch between how teachers teach and how digital-generation students learn, a discrepancy that may continue to widen the gap between the potential of educational technology and its actual implementation in educational practice.

²³ Amiruddin Siahaan et al., "Internalization of Islamic Values in Students in Learning Islamic Religious Education," *Al-Isblab: Jurnal Pendidikan* 14, no. 4 (2022): 5769–80.

²⁴ Akbar and Saidah, "Transformasi Kompetensi Guru Pai Di Abad 21: Perubahan Paradigma Pembelajaran Di Era Digital."

²⁵ Abdul Qayyum Thabranie et al., "Application of Technology-Based IRE Learning Methods to Increase Student Learning Motivation," *Fikroh: Jurnal Pemikiran Dan Pendidikan Islam* 18, no. 3 (2025): 571–88.

²⁶ Nanang Abdillah et al., "Digital Transformation in Islamic Religious Education Learning: A Study of Theory and Implementation in Schools," *International Journal of Educational and Psychological Sciences*, ahead of print, July 7, 2025, <https://doi.org/10.59890/ijeps.v3i4.76>; Faisol Hakim and Puspita W., "Rekonstruksi Kurikulum PAI Di Ruang Digital: Strategi Pembelajaran Berbasis Teknologi Untuk Generasi Digital," *An-Nadwah: Journal Research on Islamic Education*, ahead of print, March 10, 2025, <https://doi.org/10.62097/annadwah.v1i01.2062>.

The consequences of monotonous learning practices are reflected not only in low levels of student engagement but also in the weakness of memory formation and value internalization processes. From a neuroscience perspective, learning environments characterized by limited variation in stimuli and minimal emotional engagement tend to fail in optimally activating working memory, thereby reducing the likelihood that information will be consolidated into long-term memory ²⁷. This finding aligns with the fundamental principles of brain-based learning, which suggest that the brain learns most effectively when information is processed through multisensory pathways and accompanied by personally meaningful emotional experiences ²⁸. Without adequate emotional involvement, religious content tends to remain as superficial information that is easily forgotten rather than becoming meaningful knowledge embedded within long-term cognitive structures ²⁹. Furthermore, the absence of meaningful emotional and spiritual experiences limits the internalization of religious values, resulting in shallow processes of faith and character development that are vulnerable when students encounter real-life challenges.

Moreover, less interactive learning environments make students increasingly susceptible to distractions from digital content that provides more attractive sensory stimulation, especially considering that digital-generation learners are accustomed to immediate and intensive stimuli that far exceed those offered by conventional lecture-based instruction. In the long term, these conditions may weaken students' critical thinking abilities, moral awareness, and digital ethics, all of which should be strengthened through religious education ³⁰. Indeed, IRE should function as one of the primary spaces for cultivating students' moral compass amid the overwhelming flow of digital information. The accumulation of pedagogical, generational, infrastructural, and neurocognitive challenges demonstrates that mere methodological modification is insufficient. Therefore, educational innovation is required that not only incorporates technology but also scientifically understands how students' brains function during learning processes. This necessity provides the foundation for the development of a brain-based learning framework in Islamic Religious Education, which is discussed in the subsequent section.

Principles of Neuro-Pedagogy and Their Relevance to Islamic Religious Education

²⁷ Mahmud Hafiz et al., "Reconstruction of Islamic Religious Education Curriculum in Building Moderate Student Character in the Digital Era," *Edusoshum: Journal of Islamic Education and Social Humanities*, ahead of print, March 15, 2025, <https://doi.org/10.52366/edusoshum.v5i2.142>; Muhamad Yamastio Sektingtyas and Hafidz Hafidz, "The Role of Islamic Religious Education Teachers in Preventing Brain Rot Through Character Education at SMP Negeri 1 Manyaran," *Electronic Journal of Education, Social Economics and Technology*, ahead of print, April 30, 2025, <https://doi.org/10.33122/ejeset.v6i1.617>.

²⁸ Alok Kumar Padhan and Sangeeta Yaduvanshi, "Brain-Based Learning in the Digital Era: Strategies for Effective Online Education," *Asian Journal of Education and Social Studies* 51, no. 9 (2025): 731–41; Dante Jorge Dorantes-González, "Foundations of Neuroscience-Based Learning," in *Digital Teaching and Learning in Higher Education*, ed. Leonid Chechurin (Springer International Publishing, 2022), https://doi.org/10.1007/978-3-031-00801-6_1.

²⁹ Samsiroh Samsiroh et al., "Neuroscience in Islamic Education: A Systematic Review of Implications for Memorization, Devotion, and Faith," *Journal of Social Science Studies* 4, no. 2 (2024): 195–206; Iris Delikoura et al., "From Superficial Outputs to Superficial Learning: Risks of Large Language Models in Education," arXiv:2509.21972, preprint, arXiv, November 3, 2025, <https://doi.org/10.48550/arXiv.2509.21972>.

³⁰ Rohmiati, "The Use of Digital Media in Learning Islamic Religious Education: Opportunities and Challenges."

Neuro-pedagogy represents an interdisciplinary approach that integrates neuroscience, cognitive psychology, and pedagogy to understand how the brain receives, processes, stores, and utilizes information during learning processes³¹. This approach emerged from the recognition that many educational practices have long relied on intuitive or traditional pedagogical assumptions that are not always supported by empirical understandings of how the brain actually functions during learning. Neuro-pedagogy seeks to bridge this gap by employing findings from neuroscience as a scientific foundation for instructional design. It emphasizes that effective learning should be aligned with the biological mechanisms of the human brain, suggesting that instructional design is not merely a matter of teaching methods or pedagogical styles, but also a matter of synchronizing learning stimuli with the functioning of students' neural and cognitive systems.

From a neuroscientific perspective, learning begins when information enters the sensory register, the initial stage at which environmental stimuli, whether visual, auditory, or kinesthetic are first received by the sensory system before undergoing further cognitive processing. Information can only proceed to subsequent stages if it successfully attracts sufficient attention, as the human brain naturally selects which stimuli deserve deeper cognitive processing and which are ignored. Subsequently, working memory processes information through meaningful repetition, conceptual association, and contextual interpretation before the information is consolidated into long-term memory³². This consolidation process is neither automatic nor instantaneous; rather, it requires active learner engagement in connecting new information with existing knowledge structures. Given the limited capacity of working memory, learning experiences that lack meaning or relevance to students' prior experiences are unlikely to be retained in long-term memory. Consequently, information delivered monotonously and without meaningful context tends to persist only temporarily before gradually disappearing from learners' memory.

Neuroscientific findings further demonstrate that emotions play a central role in learning processes. Rather than functioning merely as complementary elements, emotions determine whether information is sufficiently important to warrant deeper cognitive processing. The limbic system, particularly the amygdala, serves as a gatekeeper that determines whether information possesses sufficient emotional significance to be processed further³³. This mechanism explains why learning experiences accompanied by emotional engagement tend to produce stronger and more durable memory traces than information delivered in emotionally neutral ways. Information associated with curiosity, empathy, awe, or meaningful emotional experiences is generally remembered more effectively than emotionally neutral content. In addition, the dopaminergic reward system contributes to strengthening learning motivation through experiences of success and positive feedback³⁴. Consequently,

³¹ Janah and Supena, "Trend Riset Neuropedagogi Dan Implementasinya Dalam Pendidikan."

³² K. Anders Ericsson and Walter Kintsch, "Long-Term Working Memory.," *Psychological Review* 102, no. 2 (1995): 211; Yovan P. Putra and Bayu Issetyadi, *Lejatkan Memori 1000%* (Elex Media Komputindo, 2010).

³³ Wartani et al., "Membangun Struktur Otak Untuk Mendukung Perkembangan Emosi Anak Usia Dini"; Moh Hafis Xafier et al., "Neuroscience & Kepemimpinan: Pemanfaatan Ilmu Otak Dalam Pengambilan Keputusan Kepemimpinan," *PERFORMANCE: Jurnal Bisnis & Akuntansi* 15, no. 1 (2025): 144–56.

³⁴ Raja Ritonga et al., "The Role of Neuroscience in Enhancing Learning Motivation," *Edu Global: Jurnal Pendidikan Islam* 6, no. 1 (2025): 1–5.

instructional designs that allow students to experience achievement, even on a small scale, may reinforce their motivation to remain actively engaged in learning.

The principle of embodied cognition emphasizes that learning is not solely a mental activity but also involves bodily movement, physical interaction, and social engagement with the environment. Consequently, separating cognitive activity from physical activity in educational settings represents an overly narrow understanding of how the brain functions. Multisensory learning that combines visual, auditory, kinesthetic, and experiential elements has been shown to strengthen long-term memory formation ³⁵. The greater the number of sensory pathways involved in processing information, the stronger the neural connections that are established and the easier it becomes to retrieve information in the future. Brain-based learning likewise emphasizes the importance of emotionally safe, active, and sensory-rich learning environments that facilitate optimal synaptic development. Conversely, environments characterized by pressure, anxiety, or excessive stress may inhibit higher-order cognitive functions because the brain under stressful conditions tends to allocate its resources toward survival responses rather than deep information processing.

Within the context of Islamic Religious Education, the principles of neuro-pedagogy demonstrate substantial relevance and may even be considered conceptually complementary. Islamic education fundamentally aims not only to transmit religious knowledge but also to cultivate moral character, spiritual awareness, and behavioral transformation. These objectives closely correspond to neuro-pedagogical principles that position emotional engagement and meaningful experience as central components of effective learning. Therefore, IRE requires instructional approaches capable of integrating cognitive, affective, and psychomotor dimensions holistically, consistent with the broader objectives of Islamic education, which seek to develop *insan kamil* (the complete human being) rather than individuals who merely possess textual religious knowledge.

The theory of cognitive engagement suggests that students' attention and involvement can be sustained through rich variations of stimuli, including visual materials, audio elements, physical activities, and emotional experiences ³⁶. The theory of cognitive engagement suggests that students' attention and involvement can be sustained through rich variations of stimuli, including visual materials, audio elements, physical activities, and emotional experiences ³⁷. Together, these theoretical perspectives reinforce the argument that IRE practices dominated by one-way lectures may fail to optimize both the cognitive and emotional capacities of learners in processing Islamic values.

These findings suggest that the internalization of Islamic values is more likely to occur when IRE is designed in contextual, multisensory, and emotionally meaningful ways. Under

³⁵ Beatrice Aruanno et al., "Virtual Reality Laboratory for Engineering and Material Science Immersive Learning," *Computer Applications in Engineering Education* 33, no. 3 (2025): e70041, <https://doi.org/10.1002/cae.70041>.

³⁶ Chi-Cheng Chang and Tseng-Chuan Chen, "Effects of Digitization/Mobilization and Emotional Design of Textbooks on Emotion, Various Cognitive Load and Cognitive Performance," *Education and Information Technologies* 28, no. 11 (2023): 14827–55, <https://doi.org/10.1007/s10639-023-11779-5>.

³⁷ Richard E. Mayer, "The Past, Present, and Future of the Cognitive Theory of Multimedia Learning," *Educational Psychology Review* 36, no. 1 (2024): 8, <https://doi.org/10.1007/s10648-023-09842-1>; Michael Noetel et al., "Multimedia Design for Learning: An Overview of Reviews With Meta-Meta-Analysis," *Review of Educational Research* 92, no. 3 (2022): 413–54, <https://doi.org/10.3102/00346543211052329>.

such conditions, religious values no longer remain merely as cognitive knowledge but become embedded within long-term memory structures and manifested in students' everyday behavior. Consequently, neuro-pedagogy offers more than a technical innovation in teaching; it provides a scientific foundation for developing Islamic Religious Education that is more humanistic, active, and responsive to the characteristics of digital-generation learners. Understanding these principles therefore constitutes an essential foundation for formulating more concrete brain-based learning frameworks for IRE, as discussed in the following section.

Integrating Neuro-Pedagogy into Islamic Religious Education

The integration of neuro-pedagogy into Islamic Religious Education (IRE) is founded on the understanding that religious learning involves the simultaneous processing of cognitive, emotional, spiritual, and motor dimensions rather than merely the one-way transmission of information from teachers to students. These dimensions cannot be clearly separated in practice because cognitive understanding of religious teachings becomes significantly more meaningful when accompanied by emotional engagement, concrete experiences, bodily involvement, and social interaction ³⁸. Religious instruction that emphasizes verbal memorization without meaningful experiences often fails to establish strong emotional connections and value internalization ³⁹. Consequently, Islamic teachings risk remaining as information memorized for assessment purposes rather than becoming values that genuinely shape students' perspectives and everyday behavior.

From a neuroscientific perspective, the human brain learns more effectively when exposed to relevant, emotionally meaningful, and multisensory stimuli because these elements simultaneously activate broader neural networks than verbal stimuli alone. The activation of attention through novelty, the engagement of the limbic system through emotional experiences, the strengthening of synaptic connections through multisensory experiences, and the utilization of reward systems through positive feedback constitute essential principles that can be incorporated into IRE instruction ⁴⁰. These principles do not operate independently but rather reinforce one another within a continuous learning cycle. Attention captured through novel stimuli facilitates emotional engagement, which is subsequently strengthened through multisensory experiences and ultimately reinforced through positive feedback that enhances students' motivation to remain engaged in learning. The following sections illustrate how these principles may be translated into various domains

³⁸ Kübra Yıldız, "Exploring the Theoretical Connections Between Psychology of Religion and Religious Pedagogy: An In-Depth Analysis," *Türk Din Psikolojisi Dergisi*, no. 11 (2025): 145–78; İsmail Demir, "Reason, Understanding and Cognition in Religious Education in The Context of The Educational Value of Cognitive Processes," *YAZIT Kültür Bilimleri Dergisi* 5, no. 2 (2025): 552–75.

³⁹ Nur Yahya and Imam Anas Hadi, "Critical Analysis of the Relationship Between Qur'an Memorization and Learning Outcomes in Islamic Religious Education at the Elementary School Level," *Jurnal Ilmu Pendidikan Dan Sains Islam Interdisipliner*, 2026, 13–26.

⁴⁰ Gayle Gregory and Martha Kaufeldt, *The Motivated Brain: Improving Student Attention, Engagement, and Perseverance* (ASCD, 2015); Edmund T. Rolls, "Limbic Systems for Emotion and for Memory, but No Single Limbic System," *Cortex* 62 (2015): 119–57; Lu Li et al., "The Role of Positive Emotions in Education: A Neuroscience Perspective," *Mind, Brain, and Education* 14, no. 3 (2020): 220–34, <https://doi.org/10.1111/mbe.12244>.

of Islamic Religious Education.

In the teaching of *Aqidah* and *Akhlak*, emotional engagement and attentional activation may be facilitated through Islamic storytelling, moral case studies, reflective discussions, and triggering questions closely related to adolescents' lived experiences. Such narrative strategies are consistent with neuroscientific findings indicating that the limbic system responds more strongly to information presented through stories and concrete moral dilemmas than to abstract and normative explanations of ethical concepts⁴¹. This approach enables students not only to understand moral concepts theoretically but also to reflect upon Islamic values in relation to their own experiences. As a result, learning shifts from merely identifying what is right and wrong toward developing empathy, moral judgment, and self-awareness.

To strengthen memory consolidation, teachers may incorporate multisensory experiences through infographics, educational videos, concept maps, animations, and role-playing activities that simulate moral situations. The use of varied media serves not merely to attract students' attention but also to activate multiple neural pathways simultaneously. Each sensory modality is processed through distinct neural circuits, and the involvement of multiple pathways contributes to stronger memory traces. Such activities support both information encoding and retrieval processes, thereby increasing the likelihood that moral values learned in the classroom will be remembered and applied when students encounter authentic moral situations outside school.

In the teaching of the Qur'an and Hadith, neuro-linguistic approaches may be implemented through rhythmic recitation, meaningful repetition, chunking techniques, and semantic encoding that connect the meanings of verses to students' everyday experiences⁴². Rhythmic recitation and repetition function not only as pronunciation exercises but also as cognitive strategies that assist the brain in organizing lengthy textual units into meaningful segments that are easier to store and retrieve from memory. The combination of visual, auditory, and contextual meaning enables the auditory and visual cortices to work synergistically in strengthening memory retention. Consequently, students are not only able to recite verses accurately but also develop deeper comprehension and longer-lasting retention of their meanings, resulting in learning outcomes that extend beyond mechanical memorization.

Meanwhile, the teaching of *Fiqh* may be developed through experiential learning approaches such as worship simulations, case-based learning, and problem-solving activities based on contemporary religious issues. These experiential approaches align closely with the principle of embodied cognition, whereby physical and motor involvement in practicing acts of worship contributes to stronger procedural memory formation than theoretical explanation alone. Such strategies not only enhance students' conceptual understanding but also cultivate critical thinking and decision-making skills grounded in Islamic legal principles. Students therefore become capable not only of understanding legal rulings textually but also

⁴¹ Umar Wyne, "The Narrative Mind: Biological, Cognitive, and Philosophical Foundations of Storytelling," *Journal of Religion and Society* 4, no. 02 (2025): 1104–16.

⁴² Nai Ding, "Sequence Chunking Through Neural Encoding of Ordinal Positions," *Trends in Cognitive Sciences* 29, no. 7 (2025): 641–54; Aneri Soni and Michael J. Frank, "Adaptive Chunking Improves Effective Working Memory Capacity in a Prefrontal Cortex and Basal Ganglia Circuit," *Elife* 13 (2025): RP97894.

of analyzing and applying them contextually when confronted with complex religious issues in everyday life.

Within this framework, digital technology functions as a learning amplifier rather than an independent instructional objective. Interactive videos, gamification, educational applications, virtual simulations, and digital quizzes that provide immediate feedback can be utilized to increase attention, motivation, and student engagement while simultaneously responding to the characteristics of digital-generation learners discussed previously. These learners generally demonstrate greater responsiveness to visual, interactive, and technology-supported forms of instruction. Nevertheless, technology itself should not be regarded as the primary goal of instruction but rather as a tool that supports learning processes aligned with the mechanisms of brain functioning.

This distinction is particularly important to prevent the integration of technology in IRE from becoming superficial or merely trend-driven. Instead, educational technology should be deliberately designed according to scientific principles concerning how students' brains attend to, process, and retain religious information in meaningful and sustainable ways. Therefore, the integration of neuro-pedagogical principles into IRE not only offers practical instructional innovations but also provides a theoretical and scientific foundation for developing religious education that is more meaningful, contextual, and responsive to the learning characteristics of digital-generation students.

The 4C Neuro-Pedagogical Model for Islamic Religious Education

Based on the synthesis of findings from educational neuroscience and the characteristics of Islamic Religious Education (IRE) discussed in the preceding sections, this study proposes the **4C Neuro-Pedagogical Model for Islamic Religious Education** as an operational framework for brain-based learning. The model is developed to address the persistent gap between theoretical findings in neuroscience and the practical need of IRE teachers for instructional guidance that can be directly implemented in classroom settings. In other words, the 4C Model translates scientific principles related to attention, emotion, memory, and consolidation into a systematic, sequential, and adaptable instructional framework that can be utilized by teachers without requiring extensive expertise in neuroscience. The model is specifically designed to facilitate the holistic integration of cognitive, affective, and psychomotor dimensions within religious education, thereby addressing the cognitive imbalance that has long characterized IRE practices, as identified in the previous discussion of educational challenges.

The 4C Model consists of four interconnected stages: **Connect, Create Meaning, Construct Multisensory Learning, and Consolidate**. These stages should not be understood as isolated instructional steps but rather as a continuous learning cycle that reflects the natural sequence of information processing within the human brain—from the initial capture of attention, to meaning construction, neural reinforcement through multisensory experiences, and ultimately the consolidation of knowledge and values into long-term memory.

The first stage, **Connect**, focuses on activating students' attention and emotional engagement through Islamic storytelling, reflective questioning, and contextual phenomena

that create a *brain-ready state*. This stage occupies a critical position because, as discussed in relation to the sensory register and limbic system, information that fails to capture learners' attention and emotional involvement is unlikely to undergo deeper cognitive processing regardless of its substantive importance. By initiating instruction through stories, triggering questions, or phenomena relevant to students' everyday experiences, teachers create neurological conditions that are more receptive to new information before moving toward deeper meaning construction.

The second stage, **Create Meaning**, emphasizes the construction of meaning by connecting Islamic teachings with students' personal experiences and social realities. This stage serves as a bridge between the attentional engagement established during the Connect phase and the deeper processing that occurs within working memory. Neuroscientific research suggests that information lacking contextual relevance is less likely to be retained in long-term memory. Consequently, teachers are encouraged not merely to deliver religious concepts or scriptural evidence but to guide students in discovering the relevance of these teachings to their own questions, experiences, and contemporary challenges. Through this process, Islamic values are no longer perceived as abstract knowledge to be memorized but rather as meaningful responses to real-life situations.

The third stage, **Construct Multisensory Learning**, provides students with multisensory learning experiences through visual materials, audio resources, discussions, simulations, and active practices that strengthen encoding and memory retention processes. This stage operationalizes the principles of embodied cognition and multisensory learning discussed previously. The involvement of multiple sensory and motor pathways contributes to stronger neural connections and more durable memory formation. Its implementation may vary according to the specific domain of IRE. For example, *Aqidah* and *Akhlak* instruction may employ infographics and educational videos, Qur'anic and Hadith studies may utilize rhythmic recitation and chunking techniques, while *Fiqh* instruction may involve worship simulations and experiential activities. Despite these variations, all instructional activities share a common objective: enriching information-processing pathways so that learning does not rely solely on verbal instruction.

The final stage, **Consolidate**, aims to strengthen value internalization through retrieval practice, structured reflection, repeated reinforcement, and contextual assignments. This stage determines whether learning experiences developed during the previous phases become enduring knowledge and internalized values or gradually disappear over time, as often occurs in instruction that ends with information delivery alone. Through active recall, reflective activities, and tasks requiring the application of Islamic values in real-life contexts, the Consolidate phase ensures that learning extends beyond classroom boundaries and develops into sustained patterns of thinking and behavior.

The proposed model demonstrates that IRE can be designed in ways that are more interactive, meaningful, and aligned with the biological mechanisms of the human brain without compromising its spiritual orientation and Islamic values. On the contrary, grounding instructional design in principles of brain functioning increases the likelihood that spiritual and religious values will be genuinely internalized rather than merely transmitted verbally. Consequently, neuro-pedagogy functions not only as a theoretical perspective but

also as a practical framework that teachers can apply in everyday instructional settings. The 4C Model therefore offers a concrete response to the pedagogical challenges facing Islamic Religious Education in the digital era while simultaneously providing an evidence-based framework for designing more effective and meaningful religious learning experiences.

To provide a clearer operational representation of the proposed framework, Figure 1 illustrates the interrelationship among the four stages of the 4C Neuro-Pedagogical Model. The figure demonstrates how the processes of attention activation, meaning construction, multisensory engagement, and value consolidation operate as a continuous learning cycle that aligns brain-based learning principles with the objectives of Islamic Religious Education.

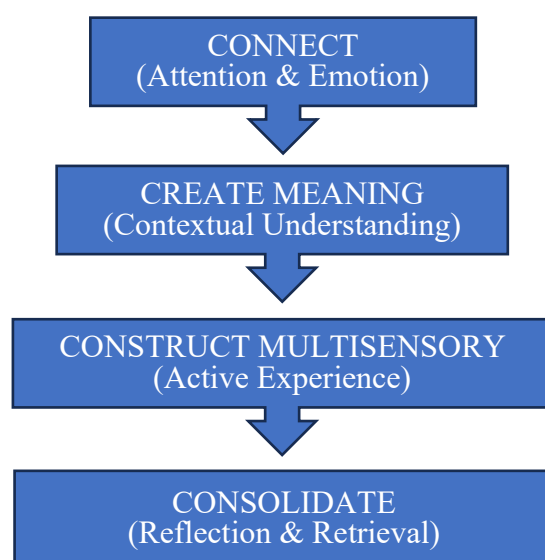


Figure 1. The 4C Neuro-Pedagogical Model for Islamic Religious Education

Implications and Challenges of Implementing Neuro-Pedagogy in Islamic Religious Education

The implementation of neuro-pedagogy in Islamic Religious Education (IRE) requires a fundamental shift in teachers' roles, from information transmitters to learning experience designers capable of developing instructional experiences that align with the ways students' brains learn⁴³. This transformation represents more than a mere change in terminology; it reflects a substantial shift in how teachers conceptualize their professional responsibilities. Rather than focusing primarily on content delivery, teachers are expected to design learning experiences that effectively activate students' attention, emotions, and memory processes. Consequently, the pedagogical competence of IRE teachers can no longer be assessed solely on the basis of religious content mastery, but also on their ability to recognize students' cognitive and emotional conditions and translate such understanding into adaptive instructional strategies. Teachers therefore need to understand how attention is generated, how emotions influence memory retention, and how multisensory experiences enhance

⁴³ Quang Nhat Nguyen and Dung Thi Hue Doan, "Beyond Comprehensible Input: A Neuro-Ecological Critique of Krashen's Hypothesis in Language Education," *Frontiers in Psychology* 16 (2025): 1636777.

learning effectiveness. These emerging competencies represent new professional demands that have not traditionally been incorporated into conventional teacher education programs for Islamic Religious Education.

In practical terms, IRE teachers need to develop learning experiences that stimulate students' attention and emotional engagement through storytelling, visual media, reflective discussions, and contextual phenomena, in accordance with the Connect and Create Meaning stages of the 4C Model described earlier. In addition, teachers should develop basic neurological literacy regarding concepts such as working memory, encoding, retrieval, and consolidation in order to make more informed instructional decisions ⁴⁴. Such literacy does not require teachers to become neuroscience specialists; rather, it provides a conceptual framework that helps them understand why certain instructional strategies successfully attract students' attention while others fail. Consequently, pedagogical decisions become less dependent on intuition or habitual practices and increasingly grounded in scientific understandings of how students' brains process information.

The integration of digital technologies, including interactive videos, gamification, virtual simulations, and digital quizzes, may further support multisensory learning experiences and enhance student engagement. However, the use of educational technology should remain firmly grounded in neuro-pedagogical principles rather than being driven solely by technological trends. Likewise, assessment practices should be reoriented toward more holistic approaches that evaluate not only verbal memorization but also contextual understanding, spiritual reflection, and the application of Islamic values in everyday behavior. Assessment systems that focus exclusively on memorization risk reproducing the same instructional patterns that have been identified as underlying problems in contemporary IRE.

Despite its considerable potential, the implementation of neuro-pedagogy continues to face several challenges, including limited digital literacy and neurological literacy among IRE teachers, insufficient professional development opportunities, and inadequate technological infrastructure in many schools ⁴⁵. These challenges are closely interconnected. Limited neurological literacy hinders the pedagogical transformation required for brain-based instruction, while the scarcity of relevant professional training restricts teachers' access to neuro-pedagogical knowledge. At the same time, disparities in technological infrastructure further constrain the implementation of digitally supported multisensory learning, particularly in schools with limited resources. Therefore, the adoption of neuro-pedagogical approaches should be conducted gradually and adaptively according to the context of each educational institution. Initial implementation may begin with simple instructional strategies that do not depend heavily on advanced technologies and can subsequently be expanded as teachers' competencies and institutional capacities develop.

⁴⁴ Maryamsadat Tabatabaiean and Shahin Nematizadeh, "Exploring Memory Systems: Types, Processes, and Implications for Learning and Teaching," *Journal of Cognition, Emotion & Education* 2, no. 2 (2024): 25–38; Zuomin Yang et al., "A Review of Short-Term, Long-Term, and Memory Consolidation Mechanisms in the Hippocampus and Cerebral Cortex," *IEEE Access*, 2025, <https://ieeexplore.ieee.org/abstract/document/10942600/>.

⁴⁵ Fikri Amrullah et al., "Strategi Pembelajaran Pendidikan Agama Islam Berbasis Neuroeducation Dalam Meningkatkan Pemahaman Dan Kecerdasan Spiritual Siswa," *Reslaj: Religion Education Social Laa Roiba Journal* 7, no. 7 (2025), <https://doi.org/10.47467/reslaj.v7i7.7662>.

It is important to emphasize that neuro-pedagogy does not necessarily depend on sophisticated technology. Simple instructional strategies such as storytelling, role-playing, worship simulations, reflective discussions, and experiential learning can effectively optimize students' brain engagement when they are intentionally designed according to neuroscientific principles. These strategies become meaningful when they are structured to capture attention, stimulate emotional involvement, and create opportunities for meaningful repetition rather than functioning merely as routine classroom activities. This perspective is particularly important for schools operating under limited technological conditions, as it demonstrates that the fundamental principles of neuro-pedagogy remain accessible regardless of resource constraints.

Therefore, the essence of neuro-pedagogy lies not in the use of digital technology itself but in understanding how the brain learns. Technology should be viewed as one possible facilitator rather than a prerequisite for brain-compatible Islamic Religious Education. By emphasizing scientific understandings of learning processes rather than technological sophistication alone, neuro-pedagogy offers an inclusive and adaptable framework that can be implemented across diverse educational contexts. Consequently, the successful implementation of neuro-pedagogy in IRE depends not merely on technological availability but on teachers' capacity to design meaningful learning experiences that align with the cognitive, emotional, and spiritual characteristics of contemporary learners.

CONCLUSION

This study developed a conceptual framework for integrating neuro-pedagogy into Islamic Religious Education (IRE) and demonstrates that brain-based learning offers a relevant response to the persistent challenges of teacher-centered instruction in the digital era. The proposed 4C Neuro-Pedagogy Model (Connect, Create Meaning, Construct Multisensory Learning, and Consolidate), translates neuroscientific principles into practical instructional strategies across Aqidah-Akhlaq, Al-Qur'an-Hadith, and Fiqh. By emphasizing attention, emotional engagement, multisensory learning, and memory consolidation, the model supports more meaningful, student-centered learning while preserving the spiritual and moral objectives of Islamic education. Because its emphasis lies in instructional design rather than technological sophistication, the model is also adaptable to resource-limited educational settings.

Theoretically, this study contributes by bridging educational neuroscience and Islamic education through a practical brain-based instructional framework. However, as a conceptual library study, its findings require empirical validation in authentic classroom settings. Future research should examine the effectiveness of the 4C Model using experimental or mixed-methods designs across diverse educational contexts, while teacher education and professional development programs are encouraged to incorporate neuro-pedagogical competencies to support evidence-informed IRE practices.

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