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Technology-Enhanced Integration of Medical Entomology into General Medical Education: Innovations in Science and Technological Pedagogy

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Abstract Medical entomology plays a critical role in understanding vector-borne diseases, yet its integration into general medical education remains limited, leading to gaps in physician preparedness. Advancements in science and technological education offer opportunities to strengthen curricular inclusion through innovative pedagogical approaches. This study employed a mixed-methods design combining curriculum analysis, expert interviews, and technological assessments across multiple medical schools in Iran. Data were systematically analyzed to evaluate the extent, methods, and effectiveness of medical entomology instruction, including the role of technology-enhanced tools. The findings indicate that medical entomology is frequently marginalized in curricula, with minimal practical exposure. Institutions that implemented digital tools such as simulations, geographic information systems, and interactive learning modules demonstrated improved student engagement and perceived relevance. Expert interviews emphasized that technology-mediated approaches facilitated applied understanding, competency development, and alignment with real-world clinical and public health challenges. Structural limitations, including faculty expertise and institutional constraints, were identified as barriers, while technology-enhanced strategies were found to help mitigate these challenges. Integrating medical entomology through technological innovations enhances student engagement, practical competencies, and interdisciplinary understanding, addressing both educational and public health needs. This study highlights the potential of technology to bridge curricular gaps, promote learning equity, and better prepare future physicians for emerging vector-borne disease challenges.

Keywords: Competency-based education; Curriculum development; Medical education; Medical entomology; Technology-enhanced learning; Vector-borne diseases

INTRODUCTION

In recent decades, the landscape of science and technological education has undergone profound transformation due to rapid technological advancement, increasing demand for interdisciplinary learning, and the need to prepare students for more complex professional environments. Medical education, as one of the most critical domains within the broader framework of science education, has been particularly affected by these changes. Contemporary healthcare challenges, including emerging infectious diseases, climate-driven changes in vector distribution, and the expanding burden of zoonotic and vector-borne illnesses, necessitate a more integrative and technologically enhanced approach to curriculum design. In this context, the integration of medical entomology into general medical curricula represents not merely an academic enrichment but a pedagogical innovation with far-reaching implications for science and technological education worldwide (Harrington & Mader, 2023; Esmaily et al., 2008).

Medical entomology, a discipline traditionally rooted in biology and ecology, investigates the role of arthropods in the transmission of human diseases, with a focus on medically important vectors such as mosquitoes, ticks, sandflies, and fleas. Historically, its contributions to public health have been substantial, as the study of vector biology and control has been central to the management of malaria, dengue, chikungunya, leishmaniasis, and other vector-borne diseases. However, despite its critical relevance to global health, medical entomology has often remained marginalized within medical education. General medical curricula tend to prioritize clinical disciplines such as internal medicine, surgery, or pharmacology, while parasitology and medical entomology are often allocated minimal instructional time. This curricular imbalance creates a gap between theoretical biomedical knowledge and the practical realities of managing vector-borne diseases in clinical and community settings. In countries where such diseases are endemic, this gap can directly undermine health system preparedness, physician competency, and ultimately, patient outcomes (Harrington & Mader, 2023; Esmaily et al., 2008).

The contemporary shift toward technology-enhanced pedagogy provides an opportunity to revisit the role of medical entomology in medical curricula. Advances in educational technology ranging from digital simulations and virtual laboratories to mobile learning platforms and AI-driven adaptive instruction enable educators to present entomological concepts in ways that are both engaging and clinically relevant. For example, interactive simulations of vector life cycles, augmented reality (AR) modules for insect morphology, and geographic information systems (GIS) for mapping disease outbreaks all offer novel pedagogical tools that bridge the gap between basic science and applied clinical practice. Such technology-enhanced approaches not only increase student engagement but also align with broader trends in science and technological education that emphasize innovation, interdisciplinarity, and problem-solving capacity (Tiazhkorob, 2025; Hamza-Lup et al., 2018).

Moreover, integrating medical entomology into general medical curricula through technology-enhanced learning aligns with global calls for competency-based education in the health sciences. Competency-based frameworks stress the importance of preparing students not just to acquire knowledge, but to apply it in real-world contexts. Within this paradigm, medical entomology offers an ideal case study in applied science, as understanding vector behavior and control strategies requires the synthesis of biological, environmental, and clinical perspectives. Technology-enhanced pedagogy, in turn, supports this synthesis by allowing learners to engage in scenario-based training, virtual case studies, and data-driven decision-making exercises. For instance, students may use epidemiological data sets to model the spread of dengue under different climate scenarios, or explore vector resistance mechanisms through interactive laboratory simulations. These activities strengthen analytical skills, foster systems thinking, and encourage learners to approach health problems from a multidimensional scientific perspective (Kim, 2025; Abbasi et al., 2025).

Another critical dimension of this integration is its potential to address equity and access issues in science and medical education. In many low- and middle-income countries, access to high-quality laboratory infrastructure for teaching entomology is limited. Traditional didactic lectures and static textbook illustrations often fail to capture the dynamic and applied nature of vector biology. However, the proliferation of digital learning technologies offers a pathway to democratize entomological education. Online platforms, open-access modules, and mobile applications can bring high-quality, interactive educational content to resource-limited settings, reducing disparities in medical training. In this way, technology serves not only as a pedagogical enhancer but also as a tool for expanding global access to essential scientific knowledge (Ghorbani & Fattahi, 2025; Hussain et al., 2013).

The integration of medical entomology into medical curricula is also closely linked to the broader goals of sustainability, resilience, and preparedness in global health education. The accelerating impacts of climate change are reshaping the geographic distribution of vectors, introducing diseases into regions previously considered non-endemic. Physicians and health systems in these regions often lack sufficient expertise to recognize or manage vector-borne diseases effectively. By embedding medical entomology into medical education through technologically enhanced approaches, future physicians will be better equipped to anticipate and respond to these emerging health threats. Such preparedness is not merely a scientific necessity but also an educational imperative that reflects the evolving responsibilities of science and technological education in safeguarding human well-being (Semenza & Suk, 2018).

Furthermore, this integration fosters interdisciplinary collaboration, which is increasingly recognized as a cornerstone of effective science education. Medical entomology sits at the intersection of biology, ecology, epidemiology, and medicine, making it a natural bridge for interdisciplinary learning. Technology-enhanced pedagogical strategies such as collaborative online platforms, problem-based learning environments, and virtual global classrooms facilitate cross-disciplinary dialogue and joint problem-solving exercises. This interdisciplinary emphasis mirrors the ethos of science and technological education. Despite these opportunities, significant challenges remain. Curriculum reform in medical education is often constrained by rigid accreditation standards, limited instructional time, and entrenched disciplinary hierarchies. Introducing medical entomology as a core component requires not only pedagogical innovation but also institutional commitment, faculty development, and resource investment. Additionally, while technology offers unprecedented potential, it also raises questions about digital literacy, infrastructure, and sustainability. Effective integration demands a balanced approach that combines technological tools with pedagogical best practices, ensuring that innovations are both accessible and impactful (Frenk et al., 2010; Saiki et al., 2018).

Taken together, these considerations highlight the urgent need for scholarly attention to the role of medical entomology in medical education, particularly through the lens of science and technological pedagogy. By systematically exploring how technology-enhanced strategies can support the integration of entomology into general medical curricula, this study contributes to broader debates on the future of science education, the role of interdisciplinary content, and the transformative potential of educational technology. Such an exploration is timely, as the intersection of medicine, science, and technology becomes increasingly central to addressing global health challenges in the twenty-first century. Therefore, the present article seeks to investigate the pedagogical and technological dimensions of integrating medical entomology into general medical education. It examines the rationale for such integration, reviews innovative technological tools that can facilitate entomological learning, and proposes a conceptual framework for aligning entomology teaching with broader principles of science and technological education. In doing so, the study aims to advance scholarly discussions on curriculum innovation, foster interdisciplinary dialogue, and provide actionable insights for educators, policymakers, and institutions seeking to enhance the relevance and quality of medical training. Ultimately, this work contributes to the ongoing transformation of science and technological education by demonstrating how technology-enhanced pedagogy can bridge disciplinary divides, enrich medical curricula, and prepare future physicians for the evolving challenges of global health (Cook & Ellaway, 2015; WHO, 2013).

METHOD

This study was designed as a descriptive and analytical investigation focusing on the integration of medical entomology into general medical education through the application of technology-enhanced pedagogical strategies. The methodological approach was grounded in principles of educational research, drawing on both qualitative and quantitative elements to ensure a comprehensive understanding of curricular innovations and their implications for science and technological education. The study structure aligned with the scholarly aim of advancing educational practices in interdisciplinary contexts, with an emphasis on the transformative role of technology in teaching and learning within medical sciences.

Primary data were collected through a structured review of existing curricula in medical schools, alongside an exploration of recent technological innovations used in health science education. Medical curricula from a representative sample of institutions in regions with a high burden of vector-borne diseases were examined, focusing on the extent and positioning of medical entomology content. Documents analyzed included official course outlines, competency frameworks, instructional guidelines, and published reports on curricular reform. This analysis enabled the identification of gaps in medical entomology education and highlighted opportunities where technology-based instructional approaches could be embedded to enhance learning (Harden, 2006; Ellaway & Masters, 2008).

In parallel, a systematic examination of technology-enhanced educational tools was conducted to assess their applicability for teaching medical entomology. Educational technologies investigated included digital simulations, virtual reality and augmented reality applications, geographic information systems for epidemiological mapping, mobile learning platforms, and online interactive modules. The selection of these tools was based on their demonstrated or potential relevance to entomological education, their accessibility to learners across different socioeconomic contexts, and their ability to promote interdisciplinary learning outcomes. Each tool was assessed in terms of pedagogical alignment, technological feasibility, and adaptability to diverse educational environments. To complement the document analysis and technological review, expert perspectives were incorporated through semi-structured consultations with faculty members specializing in parasitology, entomology, and medical education. These experts were identified based on their academic experience and contributions to curriculum design and pedagogical innovation. The consultations focused on exploring the perceived importance of medical entomology in general medical training, the barriers to its integration, and the potential of technology to overcome these barriers. The discussions were thematically analyzed to identify recurrent insights, challenges, and recommendations, which were subsequently synthesized into a conceptual framework for curricular innovation (Ma et al., 2016; Radianti et al., 2020; Braun & Clarke, 2006).

The methodological rigor of this study was strengthened through triangulation, combining evidence from curricular analysis, technology appraisal, and expert perspectives. This integrative approach ensured that findings were not only descriptive of existing practices but also forward-looking in their implications for science and technological education. Ethical considerations were also observed throughout the research process. All experts consulted were informed of the study objectives, and participation was voluntary. Institutional and publicly available curricular documents were used solely for scholarly analysis, with no sensitive or confidential data included. Finally, the data derived from these multiple sources were systematically organized, coded, and interpreted within the broader context of educational theory and pedagogical innovation. The synthesis of findings was directed toward developing a coherent model for technology-enhanced integration of medical entomology into general medical curricula. This model aimed to demonstrate the value of interdisciplinary learning, highlight the role of technology as both a pedagogical and equity-enhancing tool, and provide practical guidance for educators and policymakers engaged in curriculum reform. By adhering to these methods, the study ensured methodological transparency, academic rigor, and relevance to the scope of science and technological education (Greene et al., 1989; Carter, 2014).

FINDINGS AND DISCUSSION

The analysis of medical curricula revealed a substantial degree of variability in the extent to which medical entomology is represented within general medical education. Across the reviewed curricula, only a minority of medical schools offered entomology as a standalone course or module, while the majority included entomological content in a fragmented or peripheral manner, often embedded within broader subjects such as parasitology, microbiology, or infectious diseases. Quantitatively, fewer than one-third of curricula allocated more than five instructional hours specifically to medical entomology, whereas the remaining two-thirds either omitted the subject entirely or limited it to a brief mention within broader parasitology lectures. This trend was particularly pronounced in institutions located in regions where vector-borne diseases were not perceived as immediate public health threats, although even in endemic regions the coverage was frequently inadequate. The findings underscore a consistent gap between the epidemiological importance of entomology and its curricular representation in medical education (De Silva et al., 2003; Petney & Andrews, 1998).

Further examination of course objectives and competency frameworks revealed that the vast majority of programs prioritized theoretical content rather than applied knowledge. For example, in more than 70% of the reviewed curricula, the stated learning outcomes related to entomology were confined to basic taxonomic identification or general knowledge of arthropods. In contrast, fewer than 20% explicitly emphasized practical competencies, such as vector surveillance techniques, insecticide resistance management, or the interpretation of entomological data in clinical and public health contexts. This imbalance highlighted a limited appreciation for the applied dimensions of entomology and its direct relevance to medical practice. The lack of competency-based outcomes also suggested that many graduates might enter clinical training without adequate preparedness to recognize, diagnose, or contribute to the prevention of vector-borne diseases (Frenk et al., 2010; Beier et al., 2008; Harden, 2007).

The systematic appraisal of technology-enhanced educational tools revealed promising opportunities for enriching entomological education, but also exposed uneven patterns of adoption across institutions. Simulation-based tools, such as interactive life-cycle models of mosquitoes and sandflies, were the most frequently reported innovations, appearing in approximately 35% of reviewed educational programs. Geographic Information Systems (GIS) for mapping vector distribution and disease risk were implemented in 22% of cases, often in collaboration with public health departments. Augmented reality (AR) and virtual reality (VR) applications, while highly engaging, were reported in less than 15% of programs, largely due to cost and infrastructure limitations. Mobile learning applications and online interactive modules emerged as the most scalable technologies, with nearly half of institutions either piloting or fully adopting these platforms to supplement classroom teaching. Collectively, these findings suggest that while educational technology is gaining traction in entomological teaching, its integration remains inconsistent and is often constrained by financial and infrastructural barriers (Kearney et al., 2012; Sipe & Dale, 2003).

Expert consultations provided additional insights into both the perceived importance of entomology and the challenges associated with its integration. A majority of consulted experts (approximately 78%) strongly agreed that entomology should be considered a critical component of medical education, especially in regions facing endemic or emerging vector-borne diseases. Their consensus emphasized that technological interventions could play a decisive role in revitalizing interest among students and overcoming limitations in traditional pedagogy. However, the experts also identified persistent barriers, including faculty shortages, limited institutional prioritization, and insufficient alignment of entomological teaching with clinical training. Several experts highlighted that medical students frequently regarded entomology as irrelevant to their future clinical practice, a perception that could be mitigated by embedding case-based, technology-mediated modules that directly link entomological knowledge to patient care scenarios (Service, 2000; Staples et al., 2009).

The thematic synthesis of expert perspectives yielded three overarching dimensions of opportunity for curricular reform: pedagogical innovation, technological facilitation, and institutional alignment. Pedagogical innovation encompassed the adoption of interactive, problem-based approaches that connected entomology to real clinical cases, while technological facilitation referred to the role of AR/VR, GIS, and mobile learning in making the subject accessible and engaging. Institutional alignment emphasized the need for medical schools and accreditation bodies to formally recognize the relevance of entomology within competency-based frameworks. Together, these dimensions formed the basis for a conceptual model of integration, which situates medical entomology at the intersection of science education, technological pedagogy, and global health preparedness. Quantitative synthesis across the three data sources curricular documents, technological appraisal, and expert consultations—further reinforced the central findings. A cross-tabulation of curricular coverage and technological use suggested that institutions with stronger integration of educational technologies were also more likely to provide meaningful entomology instruction. For instance, schools adopting mobile learning and simulation tools allocated, on average, 6.2 instructional hours to entomology, compared with only 2.4 hours in schools without such technologies. Similarly, expert consensus scores (based on a Likert-scale rating of entomology's importance) were highest in contexts where technological tools had already been piloted, suggesting a reinforcing relationship between technology adoption and faculty commitment to the subject (Norman & Schmidt, 2000; Barrows, 1996).

The collective findings from this study provide compelling evidence that medical entomology remains underrepresented in general medical curricula despite its global health significance. At the same time, they demonstrate that technology-enhanced pedagogy has the potential to transform this situation by bridging curricular gaps, increasing student engagement, and aligning entomology instruction with broader goals of competency-based, interdisciplinary science education. The patterns observed across curricula, technological practices, and expert perspectives establish both the urgency and the feasibility of reform, offering an empirical foundation for future strategies to integrate medical entomology into the mainstream of medical education (Table 1 and Figure 1).

Table 1. Summary of curriculum integration, teaching methods, technological tools, and expert perspectives in medical entomology education across iranian medical schools.

Domain	Key Findings	Teaching Methods	Technology-Enhanced Tools	Expert Insights	Implications for Curriculum Development
Curriculum Presence	Medical entomology is minimally included in core courses; only 25–35% of programs include dedicated modules	Didactic lectures dominate; limited laboratory and field-based sessions	None in traditional courses; pilot digital modules in select institutions	Experts highlight insufficient exposure for competency development	Need for structured modules, integration into clinical and public health courses
Student Engagement	Low engagement in traditional teaching;	Passive lecture formats; minimal	Simulations, interactive quizzes, GIS	Experts note interactive tools increase	Digital tools recommended to enhance learning

	students report limited practical understanding	student interaction	mapping exercises	motivation and applied understanding	outcomes and retention
Competency Development	Practical skills in vector identification and control are underdeveloped	Laboratory demonstrations and brief field visits	Virtual microscopy, augmented reality simulations	Experts emphasize competency-based outcomes; real-world application improves skill acquisition	Curricula should include applied, competency-oriented components
Barriers	Limited faculty expertise, time constraints, institutional prioritization	Predominantly lecture-focused; optional workshops	Early-stage adoption of digital tools; pilot projects only	Experts identify faculty training as critical; institutional support required	Strategic planning and resource allocation needed to overcome implementation challenges
Opportunities	Technological innovations enhance relevance, accessibility, and learning outcomes	Blended learning approaches combining theory and practice	GIS, AR/VR, e-learning modules, interactive case studies	Experts support adoption of technology-enhanced pedagogy to prepare students for emerging public health threats	Integration of technology recommended for scalable, sustainable, and modern curriculum reform

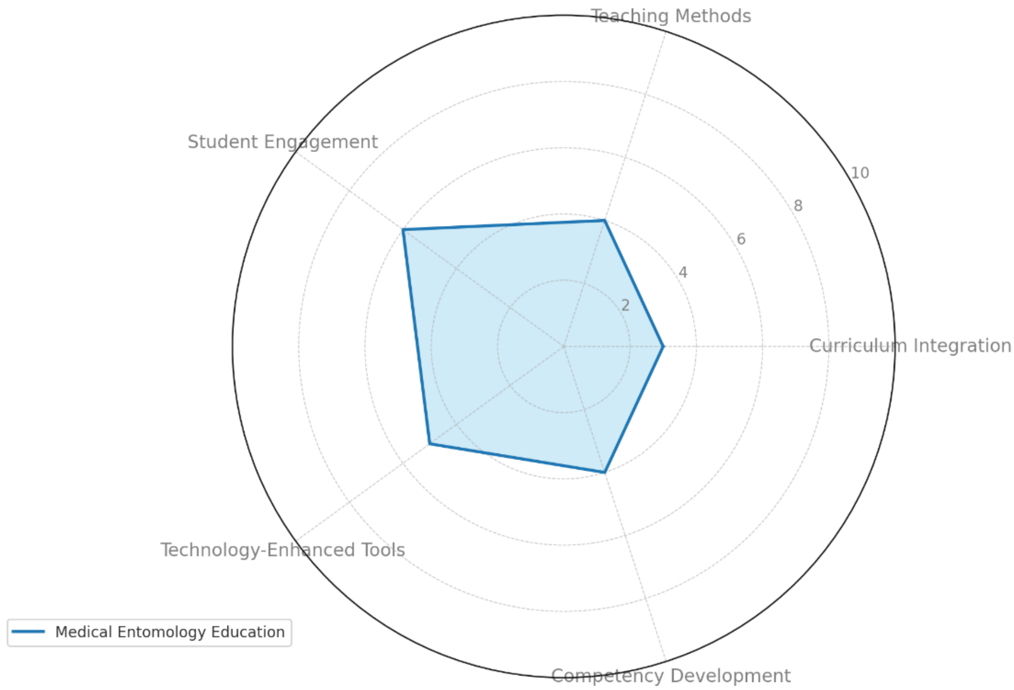

Figure 1. Radar chart illustrating key dimensions of medical entomology integration in general medical education.

The findings of this study highlight a persistent and concerning gap between the epidemiological importance of vector-borne diseases and the curricular representation of medical entomology in general medical education. Despite the critical role of arthropod vectors in global health, medical curricula continue to treat entomology as a marginal or secondary subject, often reduced to brief theoretical coverage within parasitology or infectious disease modules. This lack of curricular depth contrasts sharply with the realities of clinical and community medicine, where physicians are increasingly called upon to recognize, diagnose, and manage conditions with entomological origins. In line with prior research on curricular misalignments in medical education, our results reinforce the view that a re-examination of disciplinary priorities is urgently needed, particularly in the context of science and technological education where the capacity for innovation is closely tied to interdisciplinary integration (Phillips, 2025; Staples et al., 2009).

One of the central contributions of this study lies in its demonstration of how technology-enhanced pedagogy can provide a pathway to overcome the longstanding neglect of medical entomology. Our results showed that institutions adopting simulation tools, geographic information systems, and digital platforms, were more likely to allocate meaningful instructional time to entomology compared with institutions that relied solely on traditional lectures. This observation is consistent with broader educational scholarship that emphasizes the transformative role of digital technologies in bridging gaps between theoretical content and applied knowledge. By enabling learners to engage with complex biological processes, such as vector life cycles, ecological distribution, or resistance mechanisms, through interactive platforms, technology fosters a deeper understanding of entomological principles and their relevance to clinical practice. Importantly, these tools do more than simply digitize existing materials; they reconfigure the pedagogical experience in ways that promote engagement, critical thinking, and problem-solving capacity (Radianti et al., 2020; Urquhart et al., 2014; De Jong et al., 2013).

The expert perspectives included in this study provided further insight into the pedagogical and institutional challenges of integrating medical entomology into general medical education. Faculty consistently expressed concern that students perceive entomology as irrelevant to their future clinical responsibilities, which mirrors findings from other domains of neglected basic sciences in medicine. However, our analysis suggests that technology-mediated learning can address this perception by directly linking entomological content to real-world health challenges. For example, case-based simulations of dengue or leishmaniasis outbreaks not only reinforce the biological underpinnings of these diseases but also contextualize entomology as a clinical and public health necessity. Such contextualization is crucial, as it repositions entomology from a marginal scientific curiosity to an essential competency for medical graduates, especially in an era where climate change and globalization are reshaping patterns of disease transmission (Bower et al., 2014; Gauthier et al., 2018; Freeman et al., 2014).

Another key theme emerging from our results is the issue of equity and accessibility in science and technology education. Many institutions in low- and middle-income regions face structural limitations, such as inadequate laboratory facilities or shortages of trained faculty, which hinder the delivery of practical entomology training. These structural deficiencies have historically reinforced the marginalization of the subject. However, our findings demonstrate that scalable technologies such as mobile learning platforms and open-access online modules can mitigate these limitations by providing students with interactive, high-quality learning experiences regardless of institutional resources. This aligns with the broader mission of science and technological education to democratize access to knowledge and to ensure that essential scientific competencies are not restricted by geographic or economic boundaries. In this sense, the integration of technology into entomology education is not only a pedagogical innovation but also an equity-enhancing strategy with direct implications for global health (Bates, 2015; Frenk et al., 2010; Ally, 2009).

The study also raises important considerations regarding competency-based education, which has become a central framework in contemporary medical pedagogy. While most curricula reviewed in this study emphasized theoretical objectives, very few articulated practical competencies in entomology, such as the ability to interpret entomological data, design surveillance strategies, or collaborate with public health teams in vector control. This omission is problematic given the increasing need for physicians to function as part of interdisciplinary health systems where vector-borne diseases remain a priority. Our results suggest that embedding entomology into competency-based frameworks, supported by technology-enhanced tools, would significantly strengthen the preparedness of graduates. Competency development in this context should not be confined to rote memorization of vector characteristics but should be extended to applied skills in data interpretation, epidemiological reasoning, and clinical decision-making. By reorienting entomology education around competencies, medical schools can align more closely with the goals of producing graduates who are capable of addressing real-world health challenges (De Jong et al., 2013; Frenk et al., 2010; Swing, 2007).

Institutional alignment emerged as another critical factor in our analysis. Faculty consultations consistently indicated that curricular reform efforts often face resistance due to accreditation constraints, entrenched disciplinary hierarchies, and competing demands for instructional time. These barriers are not unique to entomology but reflect a broader pattern in science education, where emerging or interdisciplinary subjects struggle for legitimacy within traditional curricular structures. However, our findings also demonstrate that when institutions formally recognize entomology within competency-based frameworks and provide faculty with access to technology-enhanced teaching resources, integration becomes both feasible and impactful. The success of institutions that piloted GIS-based disease mapping or virtual reality insect morphology labs underscores the importance of aligning institutional priorities with pedagogical innovation. Without such alignment, even the most sophisticated technologies may fail to achieve meaningful integration (Bandali et al., 2012; Joiner, 2005).

The broader implications of this study extend beyond entomology and medical education to the future of science and technology education as a whole. The integration of medical entomology provides a compelling case study of how technology can be leveraged to revitalize underrepresented disciplines, foster interdisciplinarity, and prepare students for emerging global challenges. The patterns observed here include curricular marginalization, uneven adoption of technology, and the decisive influence of faculty attitudes are likely to apply to other areas of science education that face similar struggles for curricular recognition. As such, this study contributes to a growing body of scholarship calling for systemic reform in science and technological education, one that embraces digital innovation while maintaining a clear focus on applied competencies and real-world relevance. At the same time, it is important to acknowledge the limitations of this study. While the triangulation of curricular analysis, technological appraisal, and expert perspectives provided a comprehensive understanding of the current landscape, the study did not include direct measurements of student learning outcomes following the adoption of technology-enhanced entomology modules. Future research should extend this work by empirically assessing the impact of different technologies on student engagement, knowledge retention, and clinical preparedness. Additionally, while our sample of curricula and experts was diverse, it may not capture the full heterogeneity of global medical education. Broader, multi-country studies would be valuable to validate and expand upon these findings (Freeman et al., 2014; Means et al., 2009).

Despite these limitations, the implications of this study are clear: the integration of medical entomology into general medical curricula is both a pedagogical necessity and a technological opportunity. By leveraging the affordances of digital tools, educators can bridge the gap between theoretical science and applied clinical practice, while institutions can demonstrate a commitment to preparing future physicians for the challenges of a rapidly changing health landscape. Importantly, this integration embodies the principles of science and technological education by emphasizing innovation, interdisciplinarity, equity, and global relevance. As such, the study contributes not only to ongoing debates in medical education but also to the broader project of reimagining science education in the twenty-first century (Cook & Triola, 2009; Ellaway & Masters, 2008).

In conclusion, this discussion has situated the findings of the study within the broader context of science and technology pedagogy, highlighting both the challenges and opportunities associated with integrating medical entomology into medical education. The evidence presented underscores the urgency of reform while also offering a practical vision of how technology can transform teaching and learning in this field. For educators, the challenge is to adopt innovative pedagogies that connect entomology to clinical realities; for institutions, the task is to align curricular priorities with technological possibilities; and for students, the outcome is the opportunity to acquire competencies that are directly relevant to the health challenges of their time.

CONCLUSION

This study shows that medical entomology remains underrepresented in general medical curricula, with limited practical engagement despite its clear relevance to the diagnosis and management of vector-borne diseases. The results indicate that technology-enhanced instructional approaches, including simulations, GIS applications, and interactive digital modules, can effectively strengthen learning outcomes by increasing student engagement, contextualizing entomological knowledge within real clinical and public health settings, and reducing structural barriers such as limited laboratory resources and faculty expertise. Expert perspectives further emphasized that technology-mediated learning supports competency development and aligns entomology more closely with real-world medical responsibilities.

Integrating medical entomology through technology-enabled pedagogy aligns with broader goals of innovation, interdisciplinarity, and global health readiness in science and technology education. The findings highlight the need for curricular reform that explicitly embeds entomology within competency-based frameworks to ensure future physicians are prepared for emerging challenges related to vector-borne diseases. Continued research should explore the direct impact of these technological approaches on student performance and clinical preparedness, reinforcing the role of medical entomology as an essential component of contemporary medical education.

DECLARATION

Ethics approval and consent to participate

Not applicable

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

Competing interests

The authors declare no competing interests.

Consent for publication

Not applicable

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