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Adapting Medical Museums: Technology, education, and research

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Abstract
In Malaysia, medical museums are transforming, extending their reach beyond conventional medical student training to encompass public education and health awareness. This modernisation incorporates cutting-edge technologies such as 3D printing, QR codes, augmented reality, diversified exhibitions, and hands-on learning experiences. The overarching goal is to captivate a broader audience while advancing medical research and public health education. To achieve this, strategies like interactive exhibits and multi-sector collaborations are employed. This study explores the role of medical museums and the impact of technological innovations on visitor experience and engagement.

Keywords: Medical museum; technology; medical education

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1.0 Introduction

Since the 17th century, medical museums have been instrumental in preserving medical history, offering educational resources, and advancing the field (J. L. Turk, 1994). While initially aimed at medical students, they also served the general public (Wakefield, 2007). However, public display of anatomical specimens faced societal and legal challenges, leading to the closure of many museums (Bates, 2008). In Victorian England, dissected body displays drew thousands of daily visitors but were curtailed by legislation like the Obscene Publication Act, refocusing the museums primarily toward medical students (Bates, 2008; Alberti, 2011). Unlike general museums that preserve culture, medical museums primarily educate health sciences students. The modernised Royal College of Surgeons Museum in the UK illustrates this dual role, attracting thousands of annual visitors while maintaining a focus on education (Alberti, 2011). To adapt to societal norms, museums might use technology to screen sensitive material, thus solving historical controversies. Through interactive displays, technology also enhances visitor participation and learning (Ahmad et al., 2018). There is a shift toward public engagement in Malaysia, where medical museums were once exclusively for medical students, highlighting their evolving societal role. The museums now aim to educate, promote public health, and advance research. Adapting to these changing needs necessitates technological innovation and strategic planning to maximise community impact.

2.0 Literature Review

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2.1 Research question

This review is intended to be objective and comprehensive and apply a sophisticated understanding of technological innovations' impact on medical museums' adaptation for educational and research purposes. First, we defined the research question as "What is the role of medical museums in educating the public and medical students?". Secondly, "How can technology be used to enhance medical museums for education and research?"

2.2 Decline and Revival

This section explores the evolving role of medical museums in medical education and disease understanding. Traditionally significant for teaching and housing formalin-preserved specimens, their relevance has waned due to the rise of multimedia education and space constraints (Marreez et al., 2010; Sappol, 2004). Despite this decline, some medical schools are devising strategies for their preservation (S. J. M. M. Alberti, 2011). The article questions the factors behind this decline and discusses the future relevance of these museums in the face of advancing educational technologies.

2.3 Medical Museums in Malaysia

This article highlights the diversity of museums in Malaysia, noting a range from broad-focused establishments like the National Museum in Kuala Lumpur to specialised ones, such as the Army Museum in Seremban and the Paddy Museum in Alor Star (Salleh, 2020; Malaysian, 2018). Of Malaysia's 236 museums, 22 are managed by the Museum Department (JMM), but not all fall under the Ministry of Tourism, Arts and Culture (MOTAC) (Abdul Malek, 2021b). Medical museums are unique because they are usually governed by university medical faculties, with notable exceptions like the Biotechnological Museum and Lau King Howe Hospital Memorial Museum ("Lau King Howe Hospital Memorial Museum", 2023). These differ significantly from other museums' objectives, administration, and museological practices.

2.4 Function

Medical museums offer educational benefits that multimedia tools can't match, including enhanced classroom capabilities, self-directed learning, and fostering small-group collaboration (Marreez et al., 2010). These museums help prevent social isolation and improve observational skills crucial for medical practice. They provide tangible anatomical and pathological specimens, allowing a deeper understanding than multimedia can offer. Medical museums also serve as valuable research resources, preserving specimens that can be re-examined for new disease insights.

3.0 Methodology

This is a qualitative study using a systematic literature review that employs a standard and rigorous approach to comprehensively examine the impact of technological innovations on the adaptation of medical museums, with a specific focus on advancements in education and research. The methodological framework is designed to ensure the selection, analysis, and synthesis of relevant scholarly literature systematically and unbiasedly (Royal Literary Fund, 2014; Purdue Writing Lab, 2020)

3.1 Research Design

The research design employs a qualitative and exploratory approach to gather insights from diverse scholarly sources. This approach facilitates an in-depth understanding of the topic while accommodating the multidimensional nature of technological advancements in medical museums.

3.2 Literature Search Strategy

A comprehensive search strategy was formulated to identify relevant literature from various academic databases, including PubMed, Web of Science, Scopus, Semantic Scholar and Google Scholar. The search utilised a combination of keywords such as "medical museums," "technology," "virtual reality," "augmented reality" "digital archives," "QR code" "education," and "research.", "3-D printing" Boolean operators were employed to refine the search and ensure the inclusivity of relevant literature. The search range was from 2018-2023.

3.3 Inclusion and Exclusion Criteria

Articles were included if published in peer-reviewed journals, conference proceedings, or books and focused on integrating technology in medical museums. Only English-language publications from the last six years (2018-2023) were considered to ensure relevance and currency. Exclusion criteria included articles not directly related to the technological aspects of medical museums and those needing more empirical or theoretical contributions.

3.4 Screening and Selection

An initial screening of titles and abstracts was conducted to identify articles that met the inclusion criteria. Subsequently, selected papers underwent a full-text assessment to ensure alignment with the research objectives. Two researchers carried out the process independently to minimise bias and enhance reliability.

3.5 Data Extraction and Synthesis

A data extraction framework was developed to extract relevant information from the selected articles systematically. This framework encompassed vital aspects such as technological innovations, educational impacts, research contributions, and ethical considerations. The extracted data were then synthesised using thematic analysis to identify recurring patterns, concepts, and insights.

3.6 Quality Assessment

The quality and rigour of selected articles were evaluated using established criteria adapted from relevant quality assessment tools for qualitative research. This assessment encompassed factors such as the clarity of research objectives, methodological rigour, contextual relevance, and citation quality.

3.7 Ethical Considerations

Ethical considerations were considered throughout the review, particularly about using sensitive medical information and patient privacy concerns discussed in the literature. The synthesis and presentation of data were conducted in a manner that respects ethical guidelines and safeguards patient confidentiality.

3.8 Limitations and Bias

The literature review acknowledges potential limitations, including the possibility of publication bias and the exclusion of non-English literature. While efforts were made to minimise bias through systematic search and selection processes, it is essential to recognise the inherent limitations of any review.

3.9 Researcher Reflexivity

The researchers' perspectives and potential biases were acknowledged throughout the review process. Reflexivity was maintained by documenting and reflecting upon personal biases and assumptions that might influence data selection, analysis, and interpretation.

3.10 Synthesis and reporting

The findings were synthesised into a coherent narrative highlighting the evolving landscape of technological adaptations in medical museums, emphasising educational and research dimensions. The literature was organised thematically, and connections between different studies were drawn to present a holistic perspective.

4.0 Findings

4.1 Audio Recording

The Anatomical Museum at Leiden University Medical Center in the Netherlands has been redesigned, organising exhibits based on age and disease categories. Students must visit the museum and can access audio recordings to assist them during their tours. Evaluation of Leiden medical students showed that the museum enhancements were beneficial and improved their visits. The Medical Museum at Kawasaki Medical School in Japan combines traditional specimens with information technology to promote independent learning. Australian medical museums have expanded their activities by creating satellite museums and offering online access to their collections. These efforts have increased public awareness and generate financial resources for support (Marreez et al., 2010)

4.2 Three-Dimensional printing (3-D printing)

This section explores the versatile application of 3D-printed haptic models in medical education and training, particularly focusing on medical students, trainees, and patient education. Three-dimensional models can enhance Medical Education. The potential of 3D-printed haptic models in medical education is discussed, emphasising two key domains: learning anatomy with pathology and structure-function correlations and simulation-based training. Medical students and residents stand to benefit significantly from both generalised anatomical models and patient-specific models for comprehensive and targeted learning experiences (Bartellas, 2016). 3D printing significantly improves undergraduate anatomy learning outcomes (O'Reilly et al., 2016)

This section delves into the utilisation of 3D-printed models for teaching medical anatomy. A review of relevant studies highlights these models' numerous advantages over traditional teaching methods like cadaver dissection and plastinated specimens. These benefits encompass ease of storage, reproducibility, cost-effectiveness, scalability, presentation of rare cases, and avoidance of ethical and legal complexities (Zhang et al., 2016; Yang et al., 2023). Recent technological advancements, such as multicolour printing and polymaterials, further elevate the effectiveness of anatomy instruction. Notably, a pilot study underscores the complementary role of 3D models within cadaver-based curricula. In a randomised controlled trial, medical students utilising 3D-printed models demonstrated superior comprehension of intricate spinal anatomy compared to peers using CT images or conventional 3D printers (Lim et al., 2016). Additional research corroborates the superiority of 3D-printed models over traditional resources like textbooks and digital learning tools. By promoting a better understanding of organ functions, pathological conditions, and disease mechanisms, these findings underscore the practicality of 3D-printed models in enriching anatomical education. (Bartellas, 2016).

3-D printing can enhance patient-centric education. The application of 3D-printed models extends to surgical training, offering trainees an immersive platform to practice specialised skills in a stimulating environment. Such models have proven invaluable in enhancing trainees' grasp of surgical procedures, thus augmenting their preparedness for real-life surgical scenarios (Bartellas, 2016). This section examines the significant role of patient education in medical settings, particularly through integrating pre- and post-surgical

3D models. Patients and their families found the anatomical models engaging and immensely beneficial, showcasing the potential of these models to facilitate effective patient education (Bartellas, 2016). Anatomical collections vital for training future doctors and specialists can be preserved from desiccation by digitising specimens through high-resolution micro-CT/MRI scans. These scans then create segmented virtual 3D models and keep a comprehensive database (Kiraly et al., 2019). In conclusion, integrating 3D-printed haptic models into medical education has revolutionised the teaching and learning of anatomy, bolstered surgical training, and enriched patient education. The multifaceted benefits of these models underscore their indispensable role in advancing medical education and enhancing patient outcomes.

4.3 Augmented reality

Augmented reality-based systems are valuable tools for exhibiting explanations and can boost student motivation. The potential global impact of applying AR technology to anatomical museums was shown to be invaluable, suggesting that AR-based systems could revolutionise anatomical exhibitions worldwide. (Sugiura et al., 2018). Mobile applications can be used to enhance the effect of augmented reality(AR). Not only will the mobile phone allow a different “augmented” view, but it can also be used for navigation and location-based services, especially with the use of Wi-Fi access points, Bluetooth beacons, and Google API location data. AR-geotags can label places of interest, making them easily discoverable for visitors. By using their smartphones, visitors can access additional information through AR-markers, such as geolayers or multimedia content. We can also apply the Internet of Things (IoT) in museums and exhibits, enabling interaction with physical objects through mobile devices (Barkova et al., 2018).

Augmented reality can superimpose the original architecture on top of a current ruin (Liu & Wang, 2009). Technology like the unified XR experiences in virtual museums blends physical and virtual worlds for innovative, social interactions. It introduces "true mediated reality," which allows visitors to engage with interactive, virtual characters that replace traditional museum artefacts (Margetis et al., 2020). Augmented reality has been used in museums in various ways, including enhancing anatomy education, improving visitor engagement and interaction, providing virtual tours and simulations, and preserving and displaying rare or delicate specimens (Wang & Zhu, 2022). Possible roles of augmented reality in improving the medical museum include enhancing anatomy education, improving visitor engagement and interaction, providing virtual tours and simulations, and preserving and displaying rare or delicate specimens. Augmented reality can display virtual objects in videos captured from the real world, significantly enhancing the learning experience (Sugiura et al., 2018). Augmented reality can also create immersive educational information about the artefacts, exhibits, and artwork displayed in the museum (Wynn et al., 2021). Overall, augmented reality can improve the accuracy and effectiveness of medical exhibits and education in museums.

4.4 Quick response code (QR code)

QR codes have become ubiquitous across various sectors, including retail and everyday transactions, making them easily recognisable by most mobile phone cameras. These digital barcodes can directly link to bank accounts or specific web addresses, thereby obviating the need for manual input of lengthy URLs. Within the context of museum management, this technology offers a streamlined method for disseminating extensive information to visitors. By embedding URLs into QR codes, administrators can direct patrons to relevant educational content accessible through their mobile devices. Students were very positive about using QR codes that help their learning, attributed to the materials' easy access, time, and location independence. (Mogali et al., 2019). Integrating low-cost 3D-PSB models with QR code systems holds transformative potential for anatomical education, particularly in studying cranial structures (Yang et al., 2023).

4.5 Virtual Museum

Virtual medical museums can significantly enhance education for medical students and the general public. Virtual museums can provide a more intimate and personal voyage through exhibitions, and visitors can touch, choose, observe, and control the exhibits in virtual museums (Zouboula et al., 2008). Studies have shown that virtual museum tours can improve social inclusion, physical and mental health, and quality of life in community-dwelling older adults (Beauchet et al., 2022). Virtual museums can also promote higher-order thinking skills like creativity (Zhou et al., 2022). Furthermore, virtual museums can offer educational programs to various audiences, such as teacher's guides, lesson plans, or even colouring books]. Medical museums can supplement undergraduate medical teaching-learning activities and enable teachers to help increase medical students' empathy and tolerance for ambiguity, key domains (Marreez et al., 2010). Finally, virtual museums can be considered learning agents for upward learning curves, as such solutions can help broaden the spectrum of collaboration (Daniela, 2020).

4.6 Virtual reality

Virtual reality (VR) can help improve medical museums to educate and display exhibits safely. VR technology can significantly enhance the learning experience by allowing visitors to interact with virtual objects in videos captured from the real world (Sugiura et al., 2018). Virtual Reality (VR) is another technology that museums can employ. VR provides visitors an immersive experience in an artificial world, where they can interact with virtual components using VR equipment, e.g. a headset and a sight visor. AR and VR applications can enhance visitor experiences (Barkova et al., 2018). Virtual museums can allow students to learn and study in a context where they can touch, choose, observe, and control the exhibits (Zouboula et al., 2008). In the current climate of COVID-19 and stay-at-home orders, virtual environments have become an invaluable means of entertainment and education. The National Museum of Health and Medicine has provided virtual educational resources for visitors during COVID-19 (Jacqueline, 2020). VR technology enables the recreation of diverse spaces, including inaccessible or nonexistent locations. People with mobility issues can easily explore museum collections with a VR headset. These virtual tours are further enhanced when digital content is available across multiple online platforms (Kholin & Slesar, 2021). The text highlights the importance of public engagement and visitor satisfaction in promoting effective learning and exploration within a museum. This, in turn, fosters a culture of learning and contributes to the museum's role in shaping a sustainable future. The text also cites a study by Ahmad et al. (2018) that supports these findings. The article suggests that medical-related celebratory events can increase health awareness and generate revenue. Medical museums can support research and education, and curators and research officers can ensure collection accuracy for up-to-date information. Museum collections can drive medical research advancement.

4.7 Artificial Intelligence (AI)

The Museum of Tomorrow in Rio de Janeiro and the Smithsonian Institution have implemented AI-powered chatbots and humanoid robots to enhance the visitor experience and improve operational efficiency (Styx, 2020). The chatbot IRIS+ engages with visitors while the Pepper series robots address inquiries and share educational stories. (Levere, 2018). Beyond augmenting visitor engagement, AI also serves as an instrumental asset in streamlining museum operations. It can analyse and forecast visitor behaviour patterns, bolster security protocols, and optimise staff workflows, thereby contributing to operational efficiency (Styx, 2020). AI can be used to create art and medical devices displayed in museums. This can be used to showcase the latest technological advancements (Manuel, 2021). Museums can also use AI exhibits to educate the public about the role of AI in various fields, including healthcare (Lyu, 2020). Overall, AI has the potential to revolutionise the way museums operate and engage with visitors, making them more interactive, informative, and enjoyable for all.

5.0 Discussion

Adapting medical museums to current technological trends is a leap forward in educational paradigms and a bridge between tradition and innovation. Several key technologies stand out as particularly transformative. Including audio recordings in anatomical museums, exemplified by Leiden University Medical Center, marks a notable advancement in visitor experience and educational effectiveness. Similarly, the fusion of traditional and digital elements at the Medical Museum at Kawasaki Medical School signifies a broader trend of enhancing medical museums to promote independent learning. Both cases show the imperative for medical museums to evolve in line with technological possibilities to better serve educational objectives and public engagement.

Three-dimensional printing has emerged as an influential tool, especially for anatomy education. Research confirms that 3D-printed models assist in educating medical students, patient-centric education, and surgical training. These models have various advantages over traditional methods, including cost-effectiveness and ethical feasibility. They demonstrate a holistic improvement in the quality and effectiveness of medical education, echoing the findings of Bartellas (2016) and O'Reilly et al. (2016). Augmented Reality (AR) and Virtual Reality (VR) technologies offer unprecedented interactivity and engagement, providing medical students and the general public with a more immersive learning experience. Studies like those of Sugiura et al. (2018) and Barkova et al. (2018) point out that these technologies have transformative potential for anatomical exhibitions and educational curricula. As Beauchet et al. (2022) observed, they can also contribute to social inclusion.

Quick Response codes (QR codes) have simplified the transfer of information. They serve as low-cost yet effective tools for instant data sharing, corroborated by the findings of Mogali et al. (2019). The seamlessness QR codes introduce into educational dissemination is noteworthy, especially when combined with other technologies like 3D-PSB models. Virtual museums represent technological integration, providing an expansive, easily accessible educational platform transcending physical boundaries. In light of the COVID-19 pandemic, the importance of such virtual platforms has been significantly underscored. Lastly, Artificial Intelligence (AI) promises to overhaul operational aspects of museum management. From interactive chatbots to data analytics for visitor behaviour, AI makes museums more efficient, interactive, and tailored to individual needs, as stated by Styx (2020) and Levere (2018).

6.0 Conclusion and Recommendations

In conclusion, the fusion of technological innovation with traditional museum offerings is reshaping the scope and significance of medical museums. This synergy enhances educational experiences, bolsters operational efficacy, and cultivates public engagement, reaffirming the museum's role as a cornerstone for lifelong learning and research. The amalgamation of these elements indicates an auspicious future for medical museums. However, more comprehensive research is needed to evaluate the cumulative effects of these technologies on students' academic performance and retention of anatomical and pathological information. Equally compelling would be to gauge whether these advancements succeed in capturing public interest and fostering a deeper inclination to learn. Additionally, a closer scrutiny of the quality and interactivity of digital content specifically tailored for medical museums warrants further investigation.

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Paper Contribution to Related Field of Study

This paper originated as a humble funding proposal to elevate our medical museum. Yet, it quickly became apparent that our ideas would resonate more deeply when framed within an international context, benchmarked against global achievements in medical museum management and development. Consequently, this underscores that our proposals are not simply desirable upgrades but crucial pathways for advancing medical education for medical students, allied health students, and the general public.

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