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Artificial Intelligence: Opportunities and Challenges in Health Professions Education

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Artificial intelligence (AI) refers to intelligent computer systems capable of performing tasks that require human intelligence through the applications of algorithms, data analysis and computations. In simple words, AI can perform cognitive tasks that generally require human intelligence.[1] Another significant aspect of AI is Machine Learning (ML), which can learn by experience, adapt to new inputs, and make autonomic decisions. Machine learning models use large datasets to identify patterns and accurately predict outcomes. This includes the recognition of objects and faces through cameras and sensors.[2] By mimicking human intelligence, AI can solve complex problems across various fields, learn from each application and provide a variety of solutions to mimic intelligent human behaviour. On November 30, 2022, OpenAI released ChatGPT (Chat Generative Pre-Trained Transformer), an advanced chatbot created using OpenAI's GPT-3 model of large language models (LLM) and has been meticulously fine-tuned through supervised and reinforcement learning techniques.[3] GPT-3 has advanced text-generation capabilities for tasks like answering questions, drafting emails, writing articles, creating poetry, generating code, and translating languages. Despite the ability of GPT-3 (and improved GPT-4) to comprehend context, make decisions and handle lengthy dialogue, faculty reactions were mixed with expectations for a more engaging and comprehensible AI tool.[4] Naysayers were concerned about missing references, inaccurate data, and scientific responses which lacked depth and needed further analysis. Others started embracing this tool, using it for their own academic roles, emphasising the importance of AI while exercising caution. In the field of health professions education, this newfound interest and debate on AI have, in a short period of time, led to numerous publications either in the form of commentaries, reviews or research papers.[5-7] While there are several published articles related to medical education discussing the advantages and challenges of the use of AI in student learning and assessment, there is a noticeable absence of analysis on the role of AI in faculty development and Health Professions Education (HPE) research.[8-10] This editorial commentary, while adding to a number of publications, aims to provide a different perspective by highlighting the opportunities and challenges that AI brings to five areas of health professions education: student learning experience, assessment, healthcare, faculty development and HPE research.

Student Learning Experience

Opportunities

AI has the potential to improve the student learning experience by improving the quality of personalised learning, offering an intelligent tutoring system, and providing immediate responses in checking grammar, getting the answers to questions, generating a set of games, analysing a paragraph, or translating languages. Intelligent Tutoring System (ITS) provides personalised step-by-step tutorials on structured subjects like math and physics. The system determines the most effective learning pathway by utilising expert knowledge and responding to student progress. A survey on the ITS between 2000 and 2018 showed that the ITS system consists of four types of models: knowledge, student, pedagogy, and user interface. The user interface part of ITS consists of interaction among the users and the domain knowledge, and it

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presents text and graphics in response to the user's input. Depending on the student's behaviour pattern, the pedagogical model adjusts speed, picks the right tutoring strategy, and gives appropriate feedback to students.[11] ChatGPT can provide personalised tutoring and feedback to students based on their individual learning needs. Chen *et al.* (2020) demonstrated that ChatGPT could provide personalised mathematics tutoring and explanations tailored to student's misconceptions.[12]

Challenges

While guided by the ITS and following adaptive tests generated by the AI tools, students' responsibility and efforts toward learning the basic principles of foundational subjects are often minimised. Tailoring explanations or feedback to meet a student's individual needs can be challenging in an AI-based adaptive system due to the machine's lack of understanding of context. It is essential to guide the students by the teachers to interpret the feedback they receive in AI-based learning systems. While going through a study related to MathBot, it was found that the study did not follow the standard protocol of identifying samples from the students who only went through the MathBot. Convenience sampling did not exclude the students who went through the MOOC, videos, and online quizzes apart from the AI tool.[13] It has been argued that although ITS has benefited students through personalised tutoring, inquiry-based knowledge-gaining approaches practised in learning science, like guided discovery and collaborative learning, are being ignored. Mizumoto and Eguchi (2023) utilised the GPT-3 text-DaVinci-003 to automatically score 12,100 essays of non-native written English (TOEFL11) and compared the scores with the benchmark level. The study concluded that although automated scoring using GPT can provide a certain level of accuracy, it still cannot achieve perfect agreement with human raters. To avoid the delay in scoring observed in human scoring, and observation of an acceptable level of reliability and validity in automated scoring, it was proposed that AI-based automated scoring should be used in conjunction with human evaluation.[14]

Many educators have raised concerns that students would most likely lose their ability to think critically when confronted with real-life complex problems with the continuous use of AI. When utilising ChatGPT for academic writing purposes, it is capable of producing content that incorporates evidence obtained from online search engines. Nonetheless, it lacks the capacity to analyse and delve into literary works comprehensively.[15] Interaction and emotional connection created by the teacher require examples from real life in the learning process to allow the students to apply the knowledge effectively. The assignments or projects require the generation of new ideas from the students, followed by feedback from the teachers. Learning style varies among the students, which requires the teachers to employ different types of teaching strategies to aim for optimal engagement of the students in the session.[16] The field of health professions education is gradually recognising that the emergence of AI may require teachers to adapt their roles. In order to enhance the education of students, it is important for teachers to collaborate and integrate AI systems into their teaching practices.

Assessment

Opportunities

Automated scoring using AI tools can improve the opportunities for improvement in feedback to the students. AI has been used to automate formative assessment and provide feedback and thus, aims to improve patient outcomes. Incorporating innovative formative assessment methods, AI can aid in continuing professional education by identifying knowledge and skills gaps and providing support for learning over time. Using ML algorithms can enhance the effectiveness of evaluating surgical skills. An algorithm was trained using surgeons' experience levels to differentiate between various levels of operative skills and identify the gaps in student's skills.[17]

Educators navigating the growing use of AI in assessment face a complex dilemma. AI tools could offer more efficient methods to tailor questions to match a student's skill level, monitor students, provide feedback, and perform grading. Meticulous use of big data analytics with AI could also profile students' backgrounds, monitor student progress, and predict the probability of dropping out.[18] These technological advancements can save educators valuable time and offer a highly personalised approach to student academic journeys.

Challenges

Educators worry that relying on AI might compromise development such as problem-solving, critical thinking and creativity.[19] Role of AI in formative assessment is widely acknowledged, but there remains a query about whether AI might diminish students' capacity for understanding their own weaknesses and compromise the learning that arises from uncertain and varied thinking. The concerns about plagiarism with AI tools have also challenged the principles of academic integrity. To mitigate the concerns, some universities have provided policies or statements on the use of AI in assessment, and these policies largely focused on use (permit to use or not to use), acknowledgement of use, referencing and academic misconduct penalties.[20,21]

Healthcare

Opportunities

The ability of AI to analyse vast data and recognise patterns has varied applications in healthcare. This is useful in medical imaging and diagnostics whereby AI can help in detecting and diagnosing diseases from medical images such as X-rays, MRI scans and CT scans. The applications of AI were previously limited to basic data analysis. Now, AI occupies a significant role in the field of diagnostics,[22] personalised medicine, and patient care. Notably, systems like IBM Watson have emerged as transformative solutions in the realm of cancer therapy. Machine learning and natural language processing have demonstrated significant transformative potential, contributing to advancements in several domains, such as radiology and genetic analysis.[23] We foresee significant advancements in patient monitoring, predictive analytics, and treatment alternatives as AI systems evolve. Despite the existence of ongoing challenges to data privacy and ethical concerns, there is a distinct trend showing a significant integration of AI within the healthcare industry.

Challenges

The integration of AI into healthcare holds promise, but there is a need to overcome significant challenges. These include protecting patient data, addressing data bias, ensuring system interoperability, navigating complex regulations, addressing ethical and legal concerns, gaining clinical credibility, and allocating resources. The key concerns also include standardisation, the need for continuous learning, patient trust, and eliminating health inequities. Collaboration, creating ongoing education, and transparency with a focus on patient outcomes are crucial for a successful implementation. Food and Drug Administration (FDA) has already approved 40 AI-based medical devices. A few examples of the applications include medical imaging platform, retinal image-based diagnosis of diabetic retinopathy, cancer detection using the characterisation of cancer genomics, prediction of acute kidney disease and tools to assist emergency medical care. The pressing question that has not received enough attention is about the lack of informed consent in the capture of the data which has been used to build the AI tools. Are there enough precautions being taken to prevent the possibility of biases in the data being used by the AI tools while predicting the diagnosis? The term "black-box" is widely used to describe the non-interpretable machine learning algorithms behind precision medicine, which are beyond the understanding of clinicians.[24] A report recently discussed the use of "synthetic" cancer cases instead of real cancer cases, being used to train the IBM Watson oncology detection tool.[25]

Faculty Development

Opportunities

The capability of AI to personalise the learning process can assist in meeting the specific needs of the digital learners. The adaptive instructional content delivered by AI would be suitable to facilitate deeper comprehension of complex concepts. Compared to discussing difficult concepts with peers, the faculty would prefer less intimidating interaction with AI-based tools to understand complex concepts. AI can be used to analyse faculty members' past development activities, learning needs, preferences, and performance data to predict their future needs and preferences and create personalised development plans.[26] AI-based digital tools can help capture the diverse activities of an educator and facilitate building a portfolio aligned with the needs of the reflection of teaching scholarship. To integrate AI technology into curriculum development and instructional delivery, HPE educators need to be trained to adopt the skills of data analysis.

Challenges

Despite the potential of utilising AI for faculty development activities, it can also present several challenges that need to be addressed. Key challenges include data privacy and security, bias and fairness, trust and acceptance, limited customisation and personalisation, and need for continuous evaluation and improvement.[26] As AI relies on large amounts of data to make informed decisions and recommendations, ensuring the privacy and security of faculty members' personal and sensitive data can be a significant challenge. The algorithm of machine learning often fails to identify the context and biopsychosocial aspects of the data. Hence, numerical data dependency may reduce the quality of instructional content and may create confusion among the educators. Lack of availability of adequate and diverse data on the parameters of faculty development is a serious impediment to the development of trustworthy AI tools. Therefore, it is important to strike a balance between automation and customisation to ensure that faculty members' specific requirements are adequately addressed. AI systems need to be continuously evaluated and improved to ensure their effectiveness and relevance. This requires ongoing monitoring, feedback collection, and analysis of the AI algorithms and their impact on faculty development outcomes. Faculty developers need to have mechanisms in place to assess the performance and efficacy of AI systems and make necessary adjustments.

HPE Research

Opportunities

AI can be utilised in the research process in various ways, offering numerous benefits and opportunities. Besides its significant role in managing and analysing large datasets in research, AI can also help write research projects and articles for publication. Multiple AI tools have been shown to help with the review of literature, data collection, analysis and even interpretation.[27] Medical education literature has been dominated by authors from English-speaking countries and language has been perceived as a barrier. LLMs can be used to translate and correct manuscripts, facilitating authors from non-native English-speaking countries in their publications. LLMs can replace the role of librarians in facilitating systemic reviews.[28]

Challenges

While AI presents exciting opportunities for research, it also raises important ethical considerations. Many publishers have banned LLMs from authorship and have implemented regulations forcing the researchers using LLMs to document such usage in the methods section. Publishers are working on developing LLM detection tools to identify non-human authorship. The controversial use of AI tools has led to their ban in some educational institutions.[29,30] Many educational institutions have come up with guidelines to ethically use AI in research. Although AI has the capacity to increase efficiency and create novel insights for university research, it is essential to remember that these AI-generated outputs are based on algorithms trained on large datasets, for which bias is unavoidable. While AI-generated content can be beneficial, it also introduces unique challenges in the context of plagiarism. Researchers using AI tools must be cautious about the content generated and ensure it is appropriately attributed to its original sources.

While AI is indeed efficient and fascinating, it must be used carefully taking into account the ethical considerations. Potential risks and challenges may arise with the use of AI in HPE, including data gathering, anonymity, privacy, consent, data ownership, security, bias, transparency, responsibility, autonomy, and beneficence.[31] Since the introduction of generative AI (e.g., the release of ChatGPT at the end of November 2022), many have jumped on the bandwagon without understanding its pitfalls. It is clear from the feedback received after the AI workshop held at International Medical University (IMU), that some faculty members get thrilled about the potential of the AI tools to assist them with their daily academic tasks, including lesson planning, assessments, research, and administrative tasks. There appears to be a lack of consideration regarding the ethical concerns and potential risks associated with widespread use of AI. This article highlights the need for policy on the use of AI for education, training and support for students, as well as guidelines on the management of academic integrity breaches, at all higher education institutes. There is a need for improvement in equipping the educators with digital literacy and assessment design skills to keep up with the rapid advancements of generative AI.

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Conflict of Interest

The authors declare that no conflict of interest is involved in this editorial article.

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Navigating the world of academic mentoring

Shamala Ramasamy, Joo Hou Ng, Cheryl Sin Yi Tham, Serena In

Navigating the World of Academic Mentoring

As students traverse from their academic to professional life, academic mentoring is a useful tool that can offer direction, support, and encouragement. The academic mentor-mentee system has a long history and has been applied in different ways at different times. In this globalised era, students must be able to quickly adapt to new information and ideas because information is more readily available than ever. Also, the increasing importance of interdisciplinary learning in the 21st century presents another difficulty. An academic mentor can be especially helpful in this situation by guiding students through complicated information and pointing them toward reliable knowledge sources. Mentoring, like any tool, if misused or abused, could have detrimental effects on students. Therefore, contextualisation of mentoring system is necessary due to the specific opportunities and problems of the 21st century.

Acknowledging Psychosocial Challenges

According to Erik Erikson theory of psychosocial development, there are eight phases that people go through during their lifespan. A psychological crisis occurs during each stage, which may or may not have an impact on how an individual develops his/her personality. "Intimacy vs Isolation" refers to the sixth stage of this model, which typically occurs between the ages of 18 and 35. During this stage, the main conflict is establishing close and significant relationships with others such as passionate love, deep friendships, and social connections.[1] Those who are in this stage may, however, also feel isolated or lonely if they are unable to develop these deep connections with other people. In the absence of these relationships, they would find it difficult to establish a healthy sense of personal identity and self-worth, which could further result in feelings of emptiness and alienation.[2] It would benefit mentors to be aware of these psychosocial challenges that occur during this stage in order for them to relate more effectively with their mentees.

Establishing "Shared Identity"

According to Social Identity Approach,[3] one's self-concept is associated with one's group membership. Group membership facilitates a sense of belonging and intrinsic motivation to achieve personal and group goals in life. In general, people tend to favour their own group (i.e. ingroup), and distrust others who are not part of their inner circle (i.e. outgroup). Also, people tend to be more open in sharing their struggles with their ingroup and accepting feedback from own ingroup (compared to outgroup).

Academic mentors are responsible to establish trusted and credible mentoring relationship with their mentees.[4] When mentor and mentee have a solid relationship, this "shared identity" serves as the base for mentees to be transparent of their own academic struggles and receptive of their mentors' advice in learning and improving themselves. This is vital for academic learning, especially in the Malaysian context that is collectivistic, academic-oriented and shamed-based.

In this collectivistic, academic-oriented and shamed-based culture,[5] many students bottle up their struggles in academics as they want to save face, and simultaneously, force themselves to live up to family expectations. This often leads to poor mental health outcomes such as low self-esteem, anxiety, depression,

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insomnia and paranoia. With a strong mentoring system in an academic institution, students would perceive their respective mentors as part of the trusted ingroup. They would be more comfortable in voicing out their struggles and taking actions to overcome different academic challenges. This would facilitate a safe learning environment within that academic institution.

Setting Clear Goals and Purpose in the Mentoring Relationship

Upon establishing the mentor-mentee dyad, the setting of clear purpose and goals becomes a crucial determinant of success in the mentoring relationship. The role of a mentor may, at times, be confused with the role of a therapist, counselor, buddy, personal coach, etc. Such confusion inevitably leads to unrealistic expectations being held towards one another. Inevitably, needs are likely to be unmet and frustration or disappointments are likely to ensue within the partnership. A discussion on the purpose and goals from the outset of the mentoring relationship helps prevent such confusion and provides direction, as well as clarity on future potentials.[6]

Mentoring effectively using psychological markers

To begin with, one must comprehend Erik Erikson's underlying psychological theory of adolescence in order to understand their mentee's viewpoint, emotions, and needs. Below are some markers:

• *Self-awareness*

First and foremost, the mentor must be self-aware and conscious of their own biases and limitations while always working to further enhance their mentoring abilities.

• *Establishing Trust*

The mentor and mentee must establish a mutual trusting connection that enables the mentee to openly discuss their difficulties and concerns without worrying about being judged or subjected to punishment.[5]

• *Active Listening*

In order to fully comprehend the mentee's concerns and goals and to be able to offer personalised assistance, the mentor needs to be able to actively listen to and understand the mentee's verbal, as well as nonverbal communication. Incongruent observations shall be noted by the mentor and clarifications of the incongruence should be tactfully done.

• *Maintaining Positive Regard*

The mentor must have an open, accepting and forgiving attitude toward the mentee to foster a safe and nurturing environment that is conducive to learning and development.[7]

• *Celebrating Happiness*

As the mentor witnesses the mentee's growth, celebrate the milestones, which serves as a protective factor for the mentee to be resilient when facing academic challenges.

• *Being Flexible*

Psychologists believe in individual differences. Mentors must be adaptable in changing their methods to fit the needs and learning preferences of the mentees.

• *Providing Constructive Feedback*

Appropriately and providing timely constructive feedback, stating explicit aims and objectives, yet setting forth clear expectations.

Challenges to Mentoring

Educators and mentors alike should be aware of the many potential risks associated with mentoring. Below are some challenges:

- Mentors may unintentionally take on tasks that the students should be handling themselves if they become overly involved in their students' life. Some mentors may fail to set boundaries in their professional mentoring relationship and go above and beyond what is expected of them in their overzealousness to assist. As a result of these dynamics in their mentor-mentee relationship, students might experience learned helplessness and develop low self-esteem.
- Similarly, mentors who focus too much on providing positive reinforcement and providing overly optimistic feedback may not adequately encourage students to progress and flourish. The students' long-term development may suffer as a result of them starting to feel entitled or complacent.
- Another challenge is incompatible personalities and expectations. It can be challenging to create a positive and encouraging mentoring dynamic if both have different expectations for the partnership. Hence, clear expectations of both parties are mandatory from the beginning.
- Breakdowns in effective communication are often cited as a major cause of failure in mentoring relationships. Making progress can be difficult and frustrating if the mentor or mentee has trouble communicating adequately or if there are misconceptions.[8]
- Lack of commitment from either party leads to sluggish or non-existent progress if the mentor or mentee is not totally dedicated to the mentoring relationship.
- Power differentials and conflict of interest. Mentor may have a large amount of control over the mentee and a mentor act as the mentee's research supervisor. This may result in problems such as power abuse or exploitation. To differentiate the role, research supervision is a process in which academics guide and oversee research activities of students, while mentorship is providing guidance, advice, and encouragement to help the mentee navigate their academic journey.

Reciprocation and Establishing Mentoring Goals as Means of Overcoming Challenges

The idea that both the mentor and mentee need to experience a reciprocal giving and receiving in the mentoring relationship has often been cited in plethora of mentoring literature.[7] In other words, in a healthy mentoring relationship, a mentor need not be solely preoccupied with what the mentee needs all the time. Instead, the mentor also needs to derive a sense of receiving or deriving something from the relationship. Along with that, is the need to recognise one's personal purpose of serving as a mentor and openly expressing one's hopes and desires in the mentoring relationship. This, need not be perceived as a self-centered or demanding act, but rather, one that sets the stage for a committed mentoring partnership to flourish. It may also prevent burnout among mentors especially when mentoring load becomes overwhelming.

Apart from that, communicating clearly on factors such as duration of the mentoring relationship, time commitment and activity spread from each party also enables mentoring goals to be accomplished in a realistic fashion. It is also worth noting that regular interaction helps in fortifying the mentoring partnership.[7] In the context of a formal mentoring programme in a tertiary education setting, there may, at times, already be prescribed requirements in these aspects for academic staff and students. However, no two mentor-mentee relationships are the same and reinventing the wheel would be necessary to ensure success. As such, it would be helpful for this to be articulated and negotiated with close consideration for each party's personalities and personal preferences, as well as re-evaluate as the need arises.

Overall, mentoring is a useful tool that can promote students' growth and development, but it should be approached with an informed perspective, treaded with caution and an emphasis placed on granting students the autonomy to direct their own educational goals and personal development. By synthesising the knowledge of adolescent psychology, psychological markers on mentoring, and shared identity of mentor-mentee, and knowing the different challenges of mentoring, academic mentors can be intentional in establishing trusted and credible mentoring relationship with their students. This strong mentoring system plays an important role in creating a safe, humble and accountable learning culture within the academic institution.

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Navigating the horizon of mRNA vaccines: Tracing their evolution, ensuring safety, and unveiling therapeutic potential

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List of abbreviations

BNT162b1: Pfizer-BioNTech mRNA vaccine; **CNE:** cationic nanoemulsion; **DCs:** dendritic cells; **Hib:** *Haemophilus influenzae* type B; **HPV:** human Papillomavirus; **ID:** intradermal; **IM**: intramuscular; **IV:** intravenous; **IFN:** interferon; **IVT:** *in-vitro* transcription; **LAVs:** live attenuated vaccines; **LNPs:** lipid nanoparticles; **MHC:** major histocompatibility complex; **MMR:** mumps, measles, and Rubella; **mRNA**: messenger RNA; **mRNA-1273:** Moderna mRNA vaccine; **pDNA:** plasmid DNA; **PEI:** polyethyleneimine; **saRNA:** self-amplifying mRNA; **SARS-CoV-2:** severe acute respiratory syndrome coronavirus 2; **S-protein:** spike protein; **UTRs:** untranslated regions; **VRPs:** virus-like particles.

Abstract

Vaccines are vital tools in public health as they play critical roles in preventing and controlling infectious diseases. Vaccine technology has advanced from virus-infected lesions to live attenuated, inactivated or killed pathogens, toxoids, and subunits that consist of only specific pathogen parts needed to elicit an immune response. The progression of virus-like particle vaccines, recombinant viral-vectored vaccines, toxoids, protein or polysaccharide-based vaccines designed to conjugate with a distinct carrier protein to enhance immune reaction is a significant milestone. However, some infectious pathogens can avoid the adaptive immune system, while traditional methods may be unsuitable against non-infectious diseases like cancer. Recent studies have demonstrated the potential of messenger RNA (mRNA) vaccines as an alternative to traditional vaccine approaches. mRNA vaccines contain mRNA that encodes the specific antigen and triggers a directed immune response. The two main forms of mRNA used in the study of mRNA vaccines are conventional non-amplifying mRNA and self-amplifying mRNA (saRNA). This article discusses the mRNA vaccine structure, delivery strategies, and protective functions, focusing on mRNA vaccines' safety and therapeutic potential. Pre-clinical research has demonstrated the broad utility of mRNA vaccines in animal models. Human clinical trials, however, are still under validation. Hence, further studies will need to focus on adapting reliable results of pre-clinical trials to human applications. The evidence to date suggests that mRNA vaccines are promising next-generation vaccines and, in the future, clinical trials would transform basic research into mRNA therapeutics in medical practices.

Keywords: *COVID-19, mRNA vaccine, safety, therapeutic potential, vaccination*

Introduction

Vaccines serve a critical role in preventing and controlling communicable diseases.[1] The idea of disease prevention emerged in 1798 when Edward Jenner developed the smallpox vaccine. Vaccine technology has advanced from virus-infected lesions to live attenuated, inactivated or killed pathogens, toxoids, and subunits that consist of only specific pathogen parts needed to elicit an immune response. The progression of virus-like particle vaccines, recombinant viral-vectored vaccines, toxoids, protein, or polysaccharide-based vaccines conjugated

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with a carrier protein to enhance immune reaction are significant milestones.[1,3] Despite significant improvements towards vaccine development, some infectious pathogens can still avoid the adaptive immune system. Furthermore, traditional methods may be unsuitable against non-infectious diseases like cancer. Therefore, a more vaccine-related investigation is required to promote a novel vaccine development platform.[2,4] In recent years, nucleic acid therapeutics, especially messenger RNA (mRNA), have emerged as a new replacement for traditional vaccine approaches.[4] Although mRNA was discovered in 1961, the use of mRNA-based therapy only took off in 1989 when researchers showed that mRNA can be successfully expressed in eukaryotic cells.[5] Since then, mRNA technology has been used widely in studies for other diseases, and now this technology has moved to vaccine technology. The rapid advancement of mRNA technology has overcome some of the challenges associated with excessive immunogenicity, mRNA instability, and inefficient mRNA delivery systems.

This article discusses the different types of vaccines, including conventional and nucleic acid vaccine approaches, focusing on mRNA vaccine structures, delivery strategies, protection functions, and mRNA vaccines' safety and therapeutic potential.

Types of Vaccines

There are many types of vaccines currently available such as killed or inactivated pathogens, inactivated toxins (toxoids), or recombinant proteins of a part of the surface antigen, which can induce active immunity to a specific disease but, at the same time, does not cause any harm to the body (Figure I). Vaccines stimulate the host immune system to make memory cells and antibodies, which means the body will be able to develop immunity without being exposed to the disease first. Once the body develops immunity, infections can be avoided if the body is later exposed to a pathogen. So, clinically, vaccines are administered to prepare the immune system for "battle".

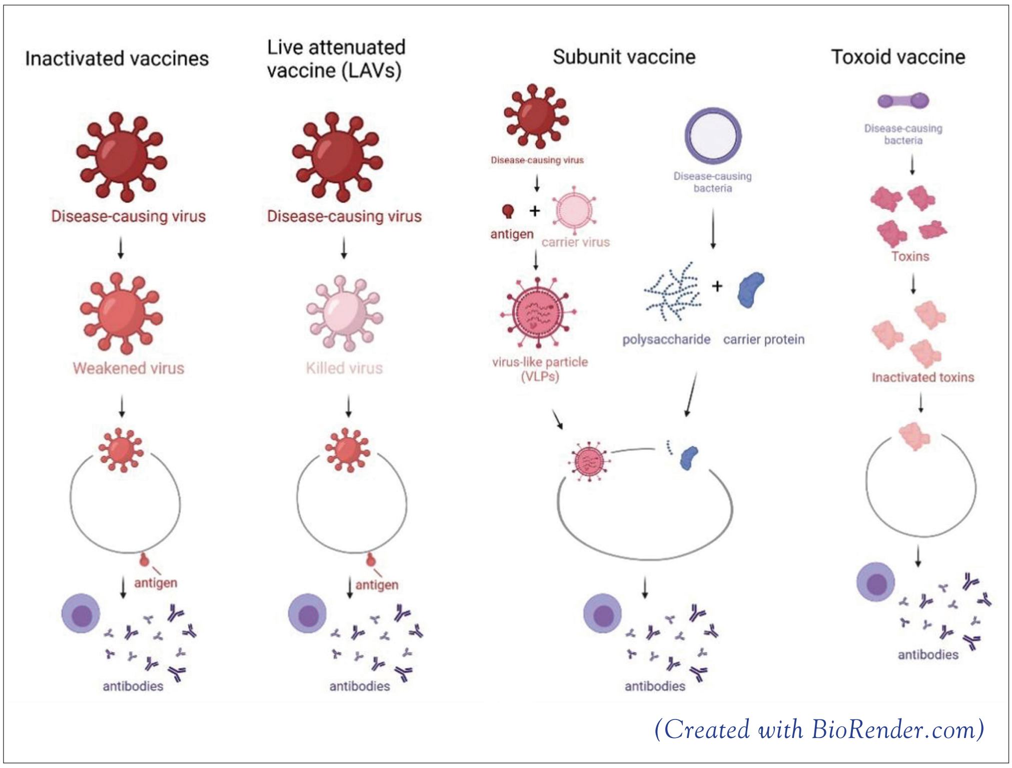

Figure I : Different types of traditional vaccines

Traditional vaccines

Traditional vaccines are categorised based on the process used to produce the vaccines, such as intact killed pathogens (inactivated vaccines) or weakened [live-attenuated vaccines (LAVs)] (Table I). The traditional vaccines can activate the host immune system and develop immunity but do not cause disease as they cannot replicate. Although these vaccines are robust and stable, some safety concerns are associated with the need to use whole pathogens and the lack of defined components of the vaccine. Other traditional vaccines include subunit and toxoid vaccines (Table I). Subunit vaccines use essential parts of the pathogen (proteins or polysaccharides) that can stimulate a specific immune reaction against the specific component. A conjugated vaccine is an improved version of the polysaccharide vaccine where the polysaccharide antigen is covalently attached to a carrier protein, which offers stronger protection.[6,7] Recombinant vaccines are created by inserting antigen-encoding DNA from a pathogen into a carrier virus or producer cells to produce the recombinant protein vaccine (virus-like particles).[8] Toxoids are chemically inactivated toxins which can provide immunity against the toxins released by bacteria. Regardless of the safety and stability features of subunit and toxoid vaccines, adjuvants are needed to achieve a strong protective immune reaction, as the antigens alone are insufficient to produce long-lasting immunity.[1,6]

Modern vaccines

Nucleic acid vaccines derived from plasmid deoxyribonucleic acid DNA (pDNA) or ribonucleic acid (RNA) have changed the production of the next-generation vaccines. Nucleic acid vaccines contain DNA or RNA-encoding antigens that are developed to link the benefits of live-attenuated and subunit vaccines. These vaccines are known to be safe as there is no risk of pathogenicity and do not require adjuvants.[7] In addition, nucleic acid vaccines can induce B- and T-cell adaptive immune

Table I : Examples of traditional, DNA, mRNA, and recombinant vaccines

VACCINE TYPE	EXAMPLES	REFERENCES
Inactivated (killed) vaccine	Polio vaccine (IPV), Hepatitis A, Influenza	8,9
Live-attenuated vaccines (LAVs)	Measles, mumps, and rubella (MMR), Smallpox, Yellow fever, Rotavirus	10
Toxoid vaccines	Diphtheria, Tetanus	6
Subunit vaccines: • Conjugate vaccines	*Haemophilus influenza* type B (Hib), Pneumococcal, Meningococcal	6,11
DNA vaccines	Influenza, Zika	6,37
Recombinant vaccines	HIV, Influenza, Ebola	15,38
mRNA vaccines	mRNA-1273 (Moderna), BTN162b1 (Pfizer-BioNTech), Influenza, cancer cells	18,19,39

responses specific to the encoded antigen.[12] The pDNA vaccines are plasmids that have the potential to express the targeted gene when injected directly into cells.[13] Another method to deliver pDNA vaccines is to utilise vectors such as adenoviruses to transfer genetic material because of their heightened immunogenicity.[14] Such combinations are known as recombinant vector vaccines. Both pDNA and viral vector vaccines are shown to be immunogenic and safe in clinical studies. A newer approach, messenger RNA (mRNA) vaccines, appears to possess some beneficial features over the pDNA and viral vector vaccines. The mRNA vaccines are reported to be able to overcome some drawbacks of poor immunity observed with some viral vectors and offer the versatility of pDNA vaccines with improved immunogenicity and safety.[16] It should be noted that the mRNA vaccines do not involve the production of infectious particles, and the RNA is not incorporated into the host genome.

Studies on the delivery of mRNA vaccines *in situ* showed that antigen expression occurs without the mRNA crossing the nuclear membrane, and there were no packaging limitations.[12] In addition, mRNA vaccines show effectiveness against various cancerous and infectious diseases, in which traditional vaccines may not succeed in evoking a defense mechanism.[20] Influenza vaccines produced using the mRNA-based approach showed reliable results and elicited strong immunity against homologous and heterosubtypic influenza viruses.[21] The mRNA vaccines have also been used to treat cancers. The targets for cancer mRNA vaccines include tumour-associated antigens that are preferentially expressed in cancer cells and can trigger cell-mediated immune responses. Some of the mRNA vaccines to tumour-associated antigens that are unique to malignant cells due to somatic mutations are shown in Table I.[22] For the mRNA vaccine approach to be successful, it would require some of the current advanced technologies that permit safer and more reliable mRNA delivery *in vivo*, inexpensive manufacturing process, and rapid, high-quality mRNA production.[17]

mRNA vaccines

The history of mRNA vaccines

The foundation of mRNA vaccines can be linked to the findings of mRNA in 1961 while investigating the mechanism of protein synthesis within DNA.[23] Two years later, it was determined that mRNA could trigger the production of interferons. Subsequently, in 1975, researches successfully revealed the mRNA cap structure.[24] In 1978, liposomes were utilised as protective carriers to encapsulate and protect the mRNA, facilitating its delivery of mRNA into the cells upon fusion with the cell membrane. Studies confirmed the induction of protein expression in both mouse and human cells through liposomal mRNA transport. Afterwards, the synthesis of mRNA was generated in 1984 using DNA-dependent RNA polymerase enzymes paving the way for *in-vitro* transcription (IVT) with DNA templates.[25-28] Following that, a study by Krieg and Malone in 1989 demonstrated that the transfection efficiency significantly improved when synthetic mRNA was enclosed within cationic liposomes for mRNA delivery. This method was introduced into frog embryos and human cells.[25,29,30] The first description of IVT mRNA in animals was reported in 1990, where reporter gene mRNAs were directly administered into mice intramuscularly, leading to the expression of the targeted proteins. This addresses prior concerns regarding mRNA stability *in vivo*, as IVT mRNA demonstrated its capability to convey genetic information for the production of specific proteins within living tissue without requiring a virus or non-viral vector.[30-32] Thus, experiments involving the administration of RNA vectors carrying reporter genes (luciferase, β-galactosidase) into murine muscle cells and transfecting vasopressin-encoding mRNA into rats were conducted later as treatments.[29,32] Only in 1993 did mRNA find its application as a vaccine in a preclinical setting, aiming to provoke a targeted immune response against a pathogenic antigen using lipid-mediated delivery (LNPs). This choice was made due to concerns about the potential harmful effects of liposomes in clinical use. These inonizable lipid-based LNPs are recognised for their considerably improved delivery efficiency in hepatocytes following intravenous (i.v) injection or in muscle cells after intramuscular (i.m) injection. In addition, recent discoveries have revealed that LNPs exhibits a strong adjuvant role, providing additional evidence of their advantageous contribution to vaccine development.[26] Martinon and colleagues showcased that an *in vitro*-produced mRNA vaccine encoding the influenza virus nucleoprotein stimulated the creation of virus-specific cytotoxic T lymphocytes in mice. Additionally, Conry *et al.* discovered that *in vivo* mRNA application also generated humoral immunity through B cells. They achieved this by administering a prophylactic vaccine comprised of or containing mRNA encoding a carcinoembryonic antigen, leading to the production of anti-tumoral antibodies.[29,30] However, the first clear demonstration of complete immunity against the influenza virus through mRNA vaccination was shown in 2012, where Petsch and his team illustrated that when unaltered conventional mRNA, encoding several influenza virus antigens, was administered via intradermal (i.d) injection along with protamine-complexed RNA adjuvant, elicited an immune response in mice. This response was comparable to the immune protection offered by a licensed inactivated virus vaccine.[33] Following multiple publications in 2015, influenza vaccines based on mRNA packaged in LNPs or cationic nanoemulsions (CNE) have proven to stimulate comprehensive immunogenicity in both T and B cells.[34] Therefore, mRNA has gained recognition as a potent vaccine platform and has found extensive use in the production of cancer therapeutic vaccines, as well as preventative vaccines for diseases.[27] In June 2020, the SARS-CoV-2 mRNA vaccine had entered the clinical trial stage, just weeks after the virus sequence was made available. Finally, in December 2020, mRNA vaccines for COVID-19 made history as the first FDA approved mRNA treatments for human use.[31,35]

The characteristics of mRNA vaccines/ the functioning or the operation of mRNA vaccines

The mRNA vaccines contain a piece of mRNA that encodes a specific antigen which can trigger the host immune response.[2] The two main forms of RNA used to develop the mRNA vaccines include the conventional non-amplifying mRNA and self-amplifying mRNA (saRNA). The conventional non-amplifying mRNA vaccines consist of a coding region surrounded by 5' and 3' untranslated regions (UTRs), which encode the desired antigen. In contrast, the saRNA vaccines consist of a coding region surrounded by 5' and 3' untranslated regions (UTRs). The saRNA vaccines encode the antigen of interest and contain an additional mRNA coding for the viral replicase enzyme, which amplifies the production of antigen by producing multiple copies of the antigen-coding mRNA.[4,36]

Understanding the mechanisms of mRNA vaccines

The mRNA vaccines introduce a fragment of mRNA that typically codes for a small part of the protein located on the virus's outer surface. The cells then use this mRNA instruction to produce the viral protein, which the immune system recognises and responds to, thereby building immunity (Figure II). Currently, mRNA vaccines against the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) are the only mRNA vaccines authorised by the World Health Organization (WHO) to be used to combat the COVID-19 pandemic. The mRNA COVID-19 vaccines carry a small part of the mRNA that encodes for the spike protein (S-protein) found on the SARS-CoV-2 virus. The S-protein is the vital surface protein situated on the coronavirus virion and serves as the main objective for neutralising antibodies. Upon administration, the mRNA will be internalised by target cells, and the COVID-19 mRNA vaccine will instruct the target cells to generate copies of the S-protein. The ribosomes will translate S-protein mRNA into S-protein in the cell cytoplasm, and this protein will then be expressed on the host cell's surface (Figure II).[40,41]

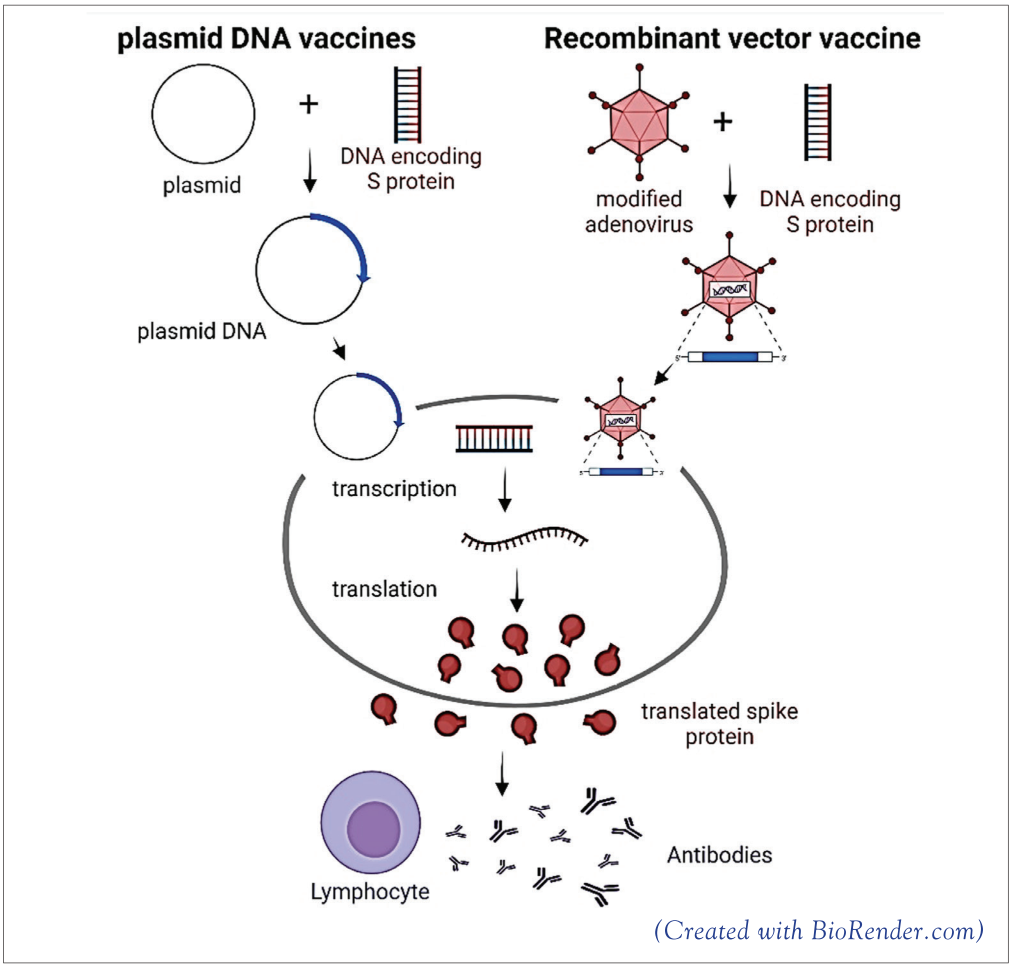

Figure II : DNA and recombinant vaccines

Detection of the S-protein by the innate arm of the immune system will cause the activation of the adaptive immune system, which will ensure a quick response for future encounters.[42] Pre-clinical studies proved that SARS-CoV-2 attacks relevant replication sites and mimics the characteristics of COVID-19-like infection in animal models, such as short-term viral replication in the respiratory system and light infections. Administration of a low dose of mRNA vaccine (mRNA-1273) in a mouse model induced a robust SARS-CoV-2 neutralising activity and high-level protective effects in the upper and lower airways without any pathologic changes in the lungs of non-human primates. This assessment of immunogenicity and protection of mRNA vaccines in a pre-clinical animal model helped identify clinically relevant doses of this vaccine.[43,44] Table II shows some of the advantages and disadvantages of mRNA vaccines.

Safety and therapeutic potential of mRNA Vaccines

The safety of mRNA vaccines

The mRNA vaccine uses a manufacturing process based on an *in vitro* cell-free transcription reaction. Hence, there were safety concerns about using mRNA vaccines on healthy individuals, which means that the development of mRNA vaccines limits the risks correlated with other vaccine approaches. In addition, the risk of contamination can be lowered due to the short manufacturing time, reducing the chance of the invasion of contaminants.[4] Compared with DNA vaccines, mRNA vaccines do not need to enter the cell nucleus to be translated into proteins. These will be rapidly degraded using cellular processes upon expression of the antigens. Also, the probability of genome integration is minimal because the virus gene sequences are used instead of the virus strains.[1,2] This means that the non-integrative feature and the short-term expressing mechanism inside the cell provide a protective profile of mRNA vaccines.[4] For these reasons, mRNA vaccines are thought to be a relatively safe vaccine format.

The remarkable achievement of the SARS-CoV-2 mRNA vaccine provides significant motivation for the field, yet numerous challenges persist in its future development as the distinctive properties of mRNA molecules require special strategies to ensure the efficacy, stability, and the safety of mRNA vaccines.[45]

Table II : Advantages and disadvantages of mRNA vaccines

ADVANTAGE	DISADVANTAGE
• Rapid research development and simpler manufacturing process	• Unstable and degrades easily
• Nuclear localisation signals and *in vivo* transcription are not required	• Strong immunogenicity stimulating an unnecessary immune reaction
• No risk of pathogenicity	• Safety is lower than inactivated vaccines
• Higher efficacy than inactivated vaccines	• Lower efficacy than DNA vaccines

adapted from [56]

To start, mRNA molecules are intrinsically unstable and susceptible to degradation primarily attributed to the widespread presence of RNAses.[46] Research suggests that most naturally occurring mRNA is rapidly broken down within 15 minutes.[29] In addition, both the mRNA and its delivery system displayed a notable level of immunogenicity, triggering innate immune responses while simultaneously reducing mRNA translation.[46] The inherent adjuvant properties of mRNA are associated with the activation of interferon (IFN) type I.[26] These properties can either enhance or inhibit the immune response, depending on the context and timing of IFN type I signaling. They regulate dendritic cells and cytotoxic T cells, affecting their maturation, survival, and translation. However, strong IFN signals may also trigger cytotoxic T cell apoptosis.[27] In addition to this, the delivery systems also possess adjuvant qualities either through their inherent characteristics or when they encapsulate other immune-stimulating agents. Adjuvants can induce local inflammation, which could potentially lead to rare allergic reactions.[46] Anaphylaxis, although rare, has been observed as a side effect of mRNA COVID-19 vaccines. While mRNA may not be the direct cause of allergies, trace impurities in mRNA vaccines may lead to delayed immunological reactions. It is suggested that the presence of PEGylated lipid in LNPs might be a potential allergen for anaphylaxis.[45,47,48] The most commonly reported adverse effects include localised injection pain and local or systemic reactions, such as fever and malaise.[49] Besides, other severe adverse events, including myocarditis, pericarditis, cerebral venous thrombosis, and cytokine release syndrome, have been documented after mRNA vaccination.[50] Current mRNA is modified to enhance stability and reduce possible immunogenicity. The methods employed to attain these objectives include modifying the 5’ cap, extending the poly(A) tail, adjusting the untranslated regions (UTRs), and introducing modified nucleotides. These approaches commonly involve altering sequences and structures to extend mRNA stability and improve translation to optimise mRNA vaccine effectiveness.[51,52] Another significant strategy in mRNA vaccine design involves the effective delivery of mRNA using nanoparticles, which will be discussed further below. In terms of thermal stability, the vaccine efficacy is strongly impacted by temperature sensitivity, making it crucial to maintain appropriate temperature conditions during storage and transportation throughout the entire process. While cold chain is typically essential for preserving vaccines (2–8°C), the demand for mRNA vaccines goes beyond standard cold storage requirements. Examples include anti-Covid vaccines (BNT162b2, mRNA-1273) require temperatures of -80°C and -20°C. However, recent studies reported that mRNA-1273 has shown thermostability for up to 12 hours at room temperature and up to one month at +5°C, while BNT162b2 remains stable for two weeks when stored at +5°C.[31,45] The necessity for extremely low temperature storage presents a limitation for mRNA vaccines due to the instability of the LNP-mRNA system, particularly in resource-constrained countries, where maintaining the ideal temperature range for vaccine storage and transportation can be problematic.[45,46] Furthermore, rapidly mutating antigens pose formidable challenges in developing effective vaccines, causing breakthrough infections and immune evasion in cancers. The emergence of variants, such as in the COVID-19 pandemic, exhibit varying mutation rates during transmission, ultimately reducing vaccine effectiveness even after a third vaccination. Various strategies including mixed mRNA vaccination and adaptive T-cell based immunity, are explored to address these challenges. In cancer vaccines, complexities arise from antigen loss, mutation, and immunosuppressive tumour environments. Combining mRNA vaccines with agents to reverse immunosuppression is more effective, but immune escape remains a concern.[45,53] Balancing antigen production, adjuvant effects, and side effects in current RNA vaccines presents a significant challenge, and this necessitates further investigation into the interactions between LNPs, mRNA, and the innate immune system.[45]

The therapeutic potential of mRNA vaccines

Advances in the structure of mRNA production and intracellular delivery systems have enabled clinical applications of mRNA-based therapeutics.[22] The mRNA must enter the cytoplasm to be translated into specific antigens. Hence, mRNA vaccines are delivered together with a carrier molecule to overcome the difficulties of transporting mRNA across the cell membrane owing to its negative charge, relatively larger size, and easily degradable by extracellular nucleases.[17] Carrier molecules include lipid, polymer, and peptide-based carriers, virus-like replicon particles (VRPs), and cationic nanoemulsion delivery (CNE). Nonetheless, other strategies of mRNA delivery include direct injection of naked mRNA vaccines and through transfection of dendritic cells (DCs) (Figure III).[1]

In the case of carrier-based vaccines, lipid nanoparticles (LNPs) are considered suitable mRNA vaccine vectors, whereby positive outcomes were seen in LNP-based mRNA vaccines for influenza and Zika virus.[1] Advantages of LNPs include protecting

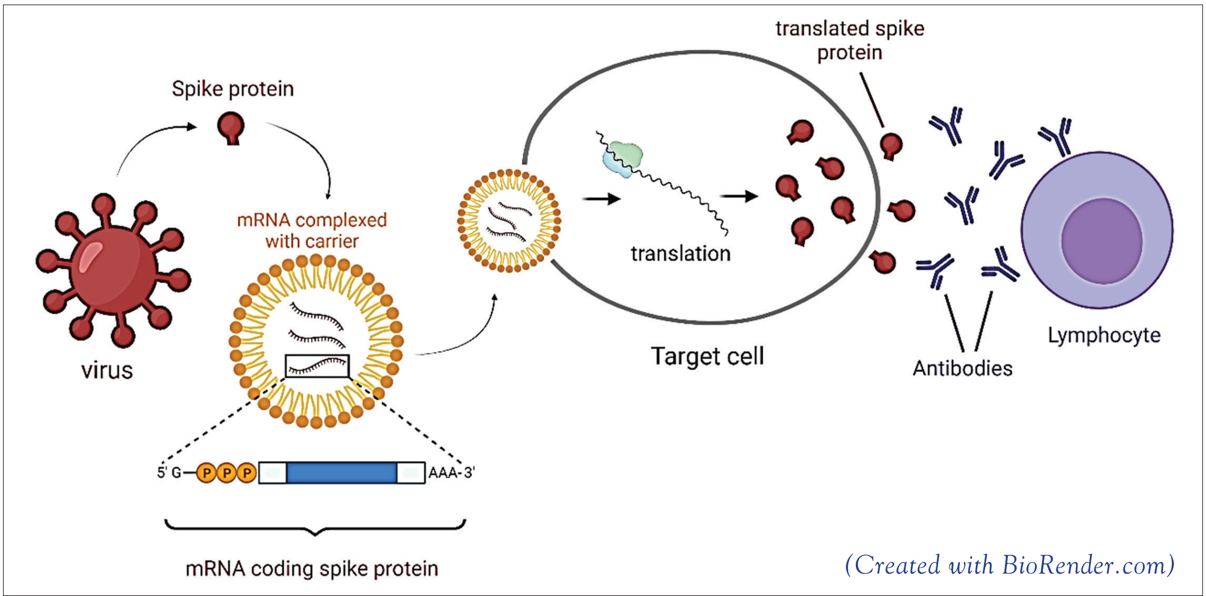

Figure III : Mechanism through which mRNA vaccines stimulate immune responses

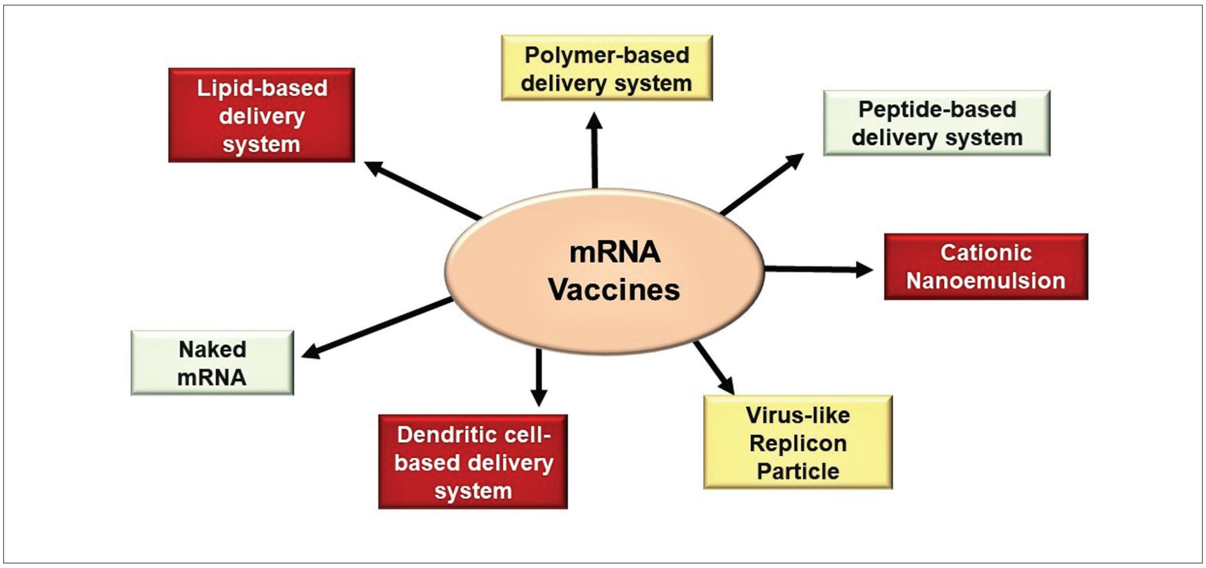

Figure IV : Major delivery methods for mRNA vaccines [1,2]

the breakdown of mRNA by endosomal enzymes, which ensures high encapsulation efficiency and having excellent biocompatibility to deliver mRNAs for expression. Polymer-based delivery systems such as polyethyleneimine (PEI) function like LNPs but to a lesser extent because of their polydispersity and the removal of large molecules, making them less clinically explored (Figure IV). This modification of polymer delivery materials with lipid chains is done to enhance the therapeutic effect.[54,55]

Protamines are cationic peptides delivering mRNA materials.[2,16] Protamine defends mRNA from degradation by serum RNases, while protamine-complexed mRNA results in strong immune responses from the leucocytes (monocytes, neutrophils), indicating that protamine can also be an immune activator.[4,5] The virus-like particles (VRPs) act similarly to a virus-infecting method, encapsulating the desired antigen-encoding saRNA to be sent into the cytoplasm.[2] A good example is the alphavirus-derived replicon RNA encoding SARS-CoV-2 S-protein inducing anti-SARS-CoV-2 neutralising antibody when tested in mice and primates.[57]

Cationic nanoemulsion (CNE) is a non-viral delivery method that binds to saRNAs to increase the effect of vaccines.[58] The CNE-based vaccine vector elicits more robust cellular immunity than the VRP-based delivery vectors.[2,59] Naked mRNA through direct injection is frequently used to regulate modified mRNA vaccines with other delivery methods.[5] DCs were meant to be the ideal vaccine design considering that they internalise, process, and display antigens to immune cells. An effective adaptive immunity comes from the upregulation of major histocompatibility complex (MHC) molecules for joining antigens, co-stimulatory molecules to give off secondary signals, cytokines for T cell proliferation, and the release of chemokines for T cell recruitment.[2]

Future Directions

To date, pre-clinical research has demonstrated the broad utility of mRNA vaccines in animal models. Human clinical trials, however, are still under validation.[4] Preliminary clinical targets were on cancer therapeutics vaccines, and the immunogenicity and safety profile was achieved. Additionally, preventive vaccines against infectious diseases have been tested in humans while other fields of mRNA therapeutics, including the treatment for cardiovascular disease, rare diseases, and personalised medicine, are also explored.[60] Since mRNA vaccines are new, different RNA platforms have insufficient clinical data for comparison and evaluation. Hence, further studies will need to focus on adapting reliable results of pre-clinical trials to human applications to determine how humans react to components of mRNA vaccine, signs of inflammation, and the most effective immune signalling passage.[61] Future improvements are addressed in mRNA formulations with various expressional and immunostimulatory profiles to gain high efficacy *in vivo* delivery.[62]

Conclusion

Following the initial publications on mRNA delivery in animal models and the development in pre-clinical and clinical phases in humans, this area has advanced rapidly. It is regarded as one of the vital and promising next-generation vaccines. The concern about this new type of vaccine arises from its rapid development capacity, safety, and flexibility compared to conventional approaches.[1] Therefore, advancing new mRNA vaccines as the technology improves will be critical. More in-depth studies concentrate on various delivery methods. LNPs, polymers, and peptides have made mRNA delivery more robust, while VRP and CNE also increase the delivery efficacy and widen the range of delivery strategies. Furthermore, antigen-encoding mRNAs delivered by DCs elicit antigen-specific immune reactions. The potential for mRNA vaccines is significant, and in the future, clinical trials will transform basic research into mRNA therapeutics in medical practices.[2]

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User experience (UX) and usability in completing a MOOC on emergency medicine core content course (iEM/Lecturio): A case study

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Abstract

This study evaluates a Massive Open Online Course (MOOC) on Emergency Medicine designed by iEM Education Project and Lecturio, using a validated checklist to assess its usability and user experience. The MOOC received a high score for cognitive connection (>4/5), in four components including interactivity, content and resources, media use, and instructional assessment. However, for learner guidance and support, the score was 2.75/5, indicating that the course did not provide clear instructions on how learners can get support or feedback from teachers when encountering problems in the course. For affective and functional connections, all components received a high overall mean score of more than 4/5. The course was impactful to the users who were in their early clinical years, as they were actively engaged and were motivated to complete the course. However, improvements should be made to better stimulate learning by improving learner feedback and providing space for collaborative learning online.

Evaluation of MOOC applying the heuristics of usability and user experience identifies specific components of online learning course apart from rating the severity of acceptance or violation of instructional design principles. The information derived from usability and user experience studies can improve design and delivery of online courses.

Keywords: *Usability, user experience (UX), instructional technology, Emergency Medicine, e-Learning, MOOCs.*

Introduction

The digital transformation in technology-enhanced learning led to several learning strategies which includes developing e-objects of learning and use of curated online learning resources. Since 2023, hybrid learning has evolved to be incorporated in delivery of the medical curriculum.[1,2] Asynchronous online learning is widely used through MOOC to reach a larger audience today. For effective learning, such courses must engage students and evaluate their experience in relation to cognitive, affective, and technical components of the course.

Additionally, online learning will require the learner to be motivated, self-regulate, and employ higher order thinking. The MOOC should provide a safe environment for peer-learning and collaborative social intercourse with teachers and fellow learners. These factors, together with the desire to complete the MOOC, constitute the affective component of usability heuristics.[3,4]

MOOCs have emerged as a new form of technology-enhanced learning in higher education, becoming especially relevant in supporting teaching and learning processes during the recent COVID-19 pandemic.[5] Learning can take place at the convenience of the learner using MOOC,[6] apart from self-development and upskilling learners. MOOC is considered a new initiative in both public and private higher education institutions.[7] The effectiveness of MOOCs in achieving the intended objectives depends on appropriate use of instructional design principles, content development, user experience and usability in the educational process. There are some disadvantages of online courses such as poor user interfaces and disorganised learning materials, which collectively lead to a high dropout rate of learners.[8]

Usability focuses on users' performance and satisfaction between task-oriented aspects and other non-task-

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oriented aspects such as aesthetic and stimulation. Usability is closely related to user interaction,[9] while user experience (UX) takes a more holistic view. UX i.e, the functional component of a MOOC, refers to "the subjective experience of the user when interacting with technology to perform some task or function to achieve a desired outcome and end goal".[10] To ensure optimal results in both usability and UX of MOOCs, the general design should be engaging, interactive, visually appealing, and allow the user to successfully complete the tasks. A well-designed MOOC will fulfill the needs of self-directed learning. Inclusion of assessment tools and award of rewards for completion of tasks are motivating factors.

The objectives of this research are to evaluate usability and UX to provide a report of a free online course on Emergency Medicine (iEM/Lecturio)[11] to reflect on all three learning connections i.e, cognitive, affective, and functional.

Methods

The study was carried out between 1st March 2022 – 31st December 2022 in the Clinical Sciences, International Medical University, in three phases (Figure I).

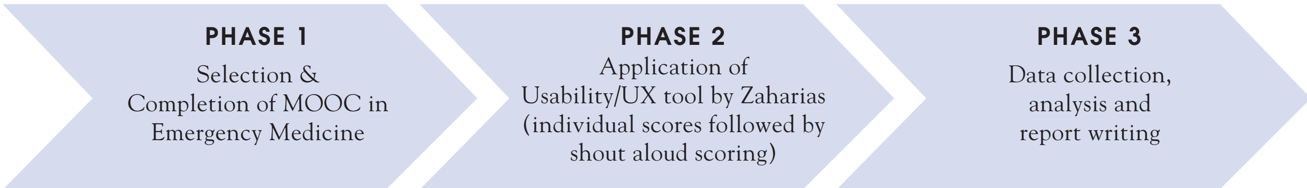

Figure I: Phases of Research

1. **Phase 1: Completion of MOOC on Emergency Medicine after training in UX scoring**

Six medical students who were in the 4th year MBBS programme volunteered to participate in the study as both subjects and researchers. They were tasked to access the MOOC and complete the module independently. They were under the supervision of the senior author (SN). Informed consent for the study was obtained.

The selected MOOC on EM was developed in accordance with the International Federation of Emergency Medicine and Society of Academic Emergency Medicine's standards for undergraduate emergency medicine curriculum.[11] There are a total of 11 lessons in the module, covering 37 subjects. Each lesson ended with self-check formative quizzes, reading assignments, and videos. The learner will receive a certificate of completion after completing all components of the course. All the participants, being fourth year medical students in IMU, were familiar with the use of e-learning platform used in delivery of the module. They were trained by the senior author to use a validated checklist for independent evaluation of the MOOC by each participant. Informed consent for participation was obtained from all subjects.

2. **Phase 2: Rating components of the MOOC on EM using a validated checklist on UX**

A framework checklist developed by Panagiotis Zaharias[12] was used to evaluate the usability and user experience of this MOOC. He had developed this tool based on Neilson's heuristic principles of user-design and studies on usability parameters to provide measurement criteria.[13] Written permission for use of this checklist was obtained from the checklist developer. The framework focuses on instructional design which has cognitive and affective learning connections; and usability which has functional connections (Figure II).[14]

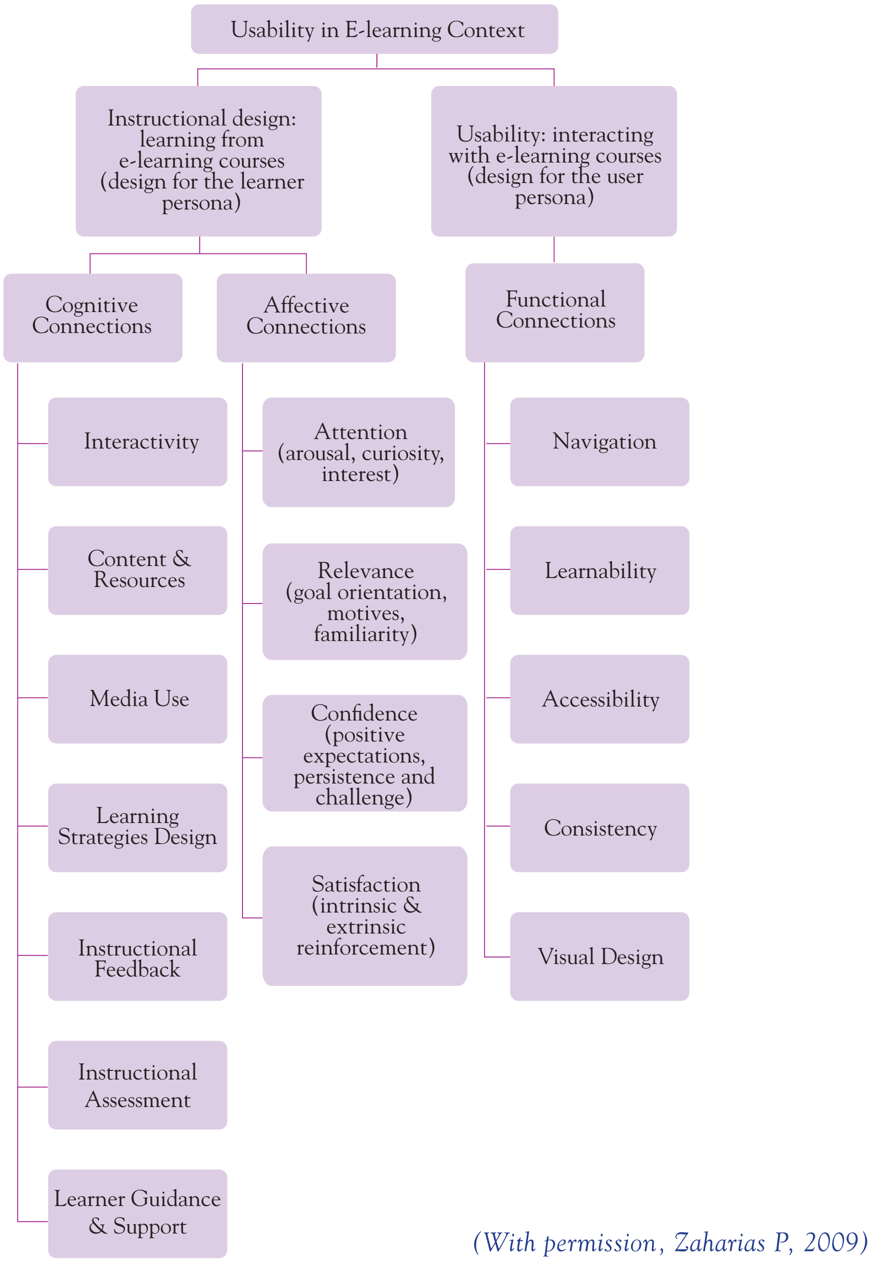

Figure II: A Framework that Integrates Usability and Instructional Design Parameters

Cognitive connections in the checklist used in the study are interactivity, content and resources, media use, learning strategies design, instructional feedback, instructional assessment, learner guidance and support. They focus on how the learner interacts with the course module, and how well the course helps the users achieve their learning goals.

Affective connections addressed are attention, relevance, confidence, and satisfaction. They focus on determining how motivated the learner is to complete the course.

Functional connections focus on navigation, learnability, accessibility, consistency, and visual design. They test the design of the course based on technological aspects to facilitate learning.

All six participants, tasked to complete the EM module online, conducted the usability study of the MOOC independently, before reaching a rating consensus for each component in the checklist.

3. Phase 3: Evaluation, consensus rating and comments

The MOOC was evaluated by each of the six participants independently. For each criterion, the researchers assigned a score that best reflects their reaction. To determine the final score, each researcher was expected to provide a justification for their response. A Likert scale (1-5, five being best), with a maximum score of 5, was used to determine the scoring. After completion of the MOOC, all participants met to develop final scores, applying the "shout-aloud" method. Justifications and comments were collated to reflect on the three main components of the evaluation tool for usability and UX. Recommendations to improve the MOOC based on its strengths and weaknesses were discussed.

Results

1. Cognitive Connections

Cognitive connection measures the degree of effectiveness to achieve students' learning goals in the MOOC. The results are summarised in Figure III.

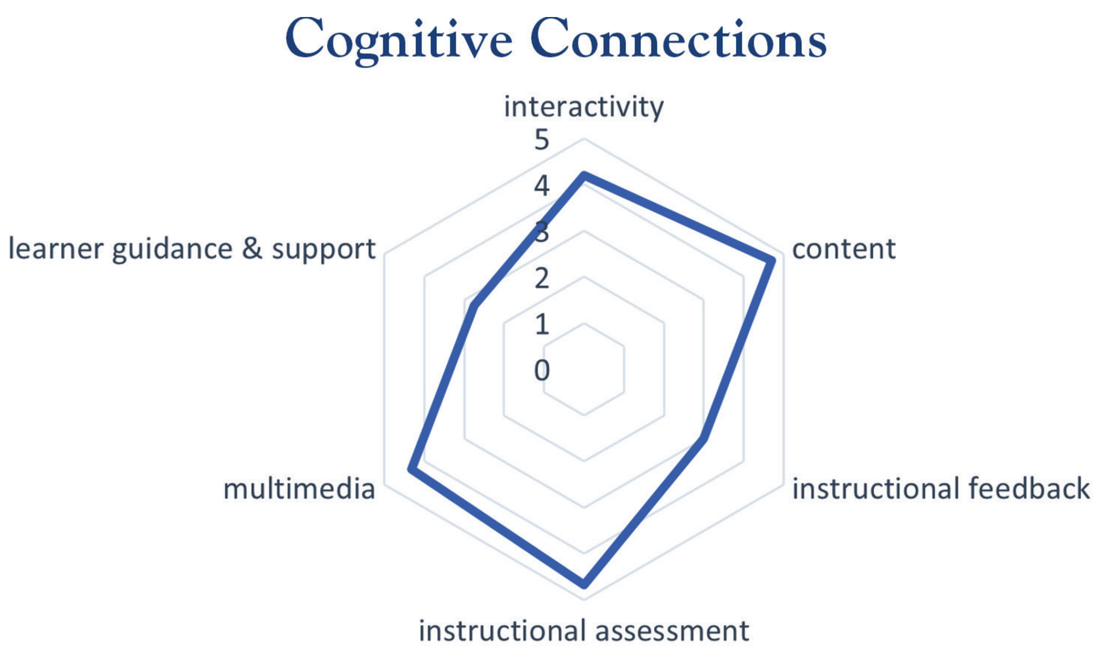

Figure III: Cognitive Connections Radar Chart

a) Interactivity/engagement

Interactivity measures how engaged and how interested the learners were in their learning experience. The results for the interactivity section are presented in Table I. The overall mean score is 4.2/5, with three out of five items given the full score of 5/5, whereas item number 2 received a score of 4/5. However, item number 1 was given a low score of 2/5 because there were little to no games, simulations, or role-playing activities which made maintaining motivation harder. Self-check was with quizzes.

Table I: Cognitive Connections in Emergency Medicine by Interactivity

NO	ITEM	SCORE (max. score: 5)
1	The courses use games, simulations, role-playing activities, and case studies to gain the attention, and maintain motivation of learners.	2
2	The courses provide meaningful interactions (for example, embedded quizzes, tests, etc.) when there are long sections of text.	4
3	The courses provide access to a range of resources (web links, case studies, simulations, problems, examples) appropriate to the learning context and for use in the real world.	5
4	The courses engage learners in tasks that are closely aligned with the learning goals and objectives.	5
5	Media are used appropriately, so as to assist in highlighting and learning critical concepts rather than merely entertaining or possibly distracting learners.	5
	Mean: 4.2 Mode: 5 Standard Deviation 1.3	

b) Content and Resources

This is a major part in the instructional design of the overall course. Table II shows the results from the analysis of the study, with seven out of ten items awarded the highest score of 5/5 while items 4, 8 and 9 were scored 4/5 each. The score for item number 4 was given as such because the researchers believed that the resources were accurate, albeit clinical management may be different locally, as the course is a USA based one. For items number 8 and 9, the researchers concluded that the concepts are well explained but could be better if more examples were given. With a mean score of 4.7/5 and a standard deviation of 0.48, the researchers quite strongly agreed that the MOOC contained relevant and accurate information originating from reliable sources.

Table II: Cognitive Connections in Emergency Medicine Core Content by Content & Resources

NO	ITEM	SCORE (max. score: 5)
1	Content is organised in an appropriate sequence and in small modules for flexible learning.	5
2	The material in the course is accurate and current.	5
3	The course covers the subject in sufficient breadth and depth to meet the learning objective.	5
4	Resources are provided in a manner that replicates as closely as possible their availability and use in the real world.	4
5	Text blocks are written in minimalist style: compact, yet useful.	5

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6	The course provides access to a range of resources (web links, case studies, simulations, problems, examples) appropriate to the learning context.	5
7	Vocabulary and terminology used are appropriate for the learners.	5
8	Abstract concepts (principles, formulas, rules, etc.) are illustrated with concrete, specific examples.	4
9	All units/modules in the courses include an overview and a summary.	4
10	Learning objectives of each module are quite (obvious) clear to the learners.	5
	Mean: 4.7 Mode: 5 Standard Deviation 0.48	

c) Instructional Feedback

This segment had an overall mean of 3/5 and standard deviation being 1.41. Item number 1 rated 2/5 because the course had no "space" where the learner could be motivated to request feedback. Figure IV shows that there was only an email mentioned briefly at the beginning of the course for feedback to the course designers. Although the feedback on questions were good, further explanation would have been better (Figure V).

Table III: Cognitive Connections in Emergency Medicine Core Content by Instructional Feedback

NO	ITEM	SCORE (max. score: 5)
1	The courses motivate learners to request feedback from instructors, experts and peers, through e-mail or other online communications.	2
2	Feedback given (by exercises or simulations, etc.) at any specific time, is tailored to the content being studied, problem being solved, or task being completed by the learners.	4
	Mean: 3 Mode: – Standard Deviation 1.41	

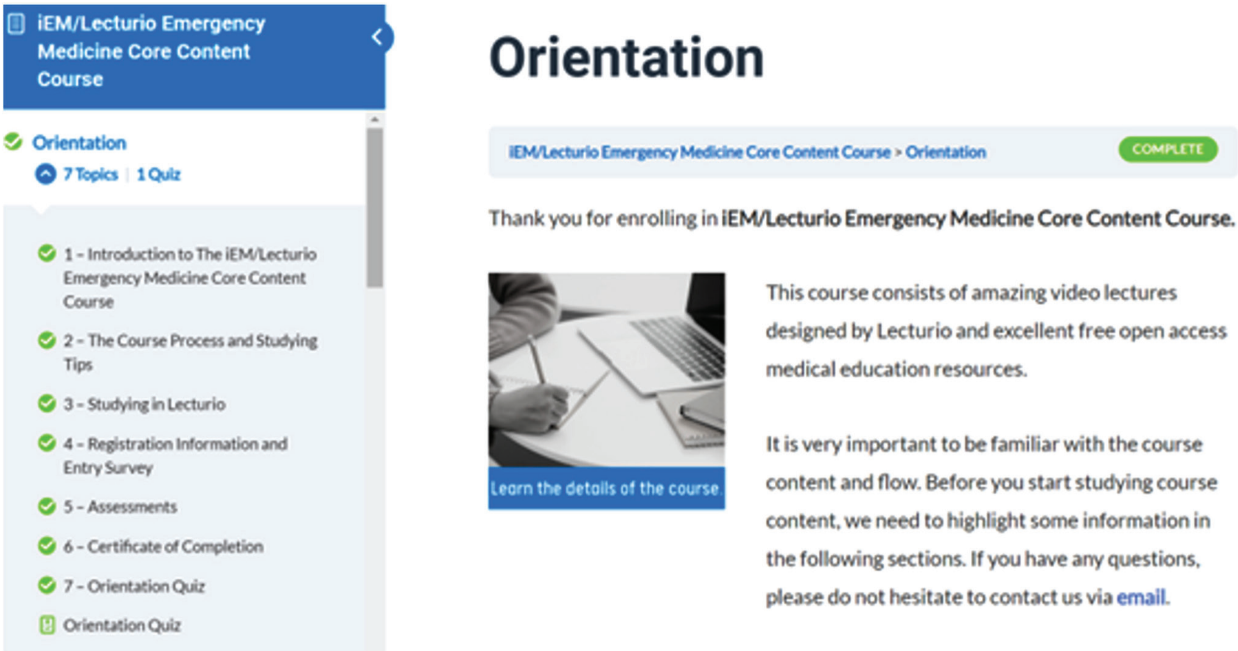

Figure IV: Screen shot – Emergency Medicine Core Content Course by Instructional Feedback

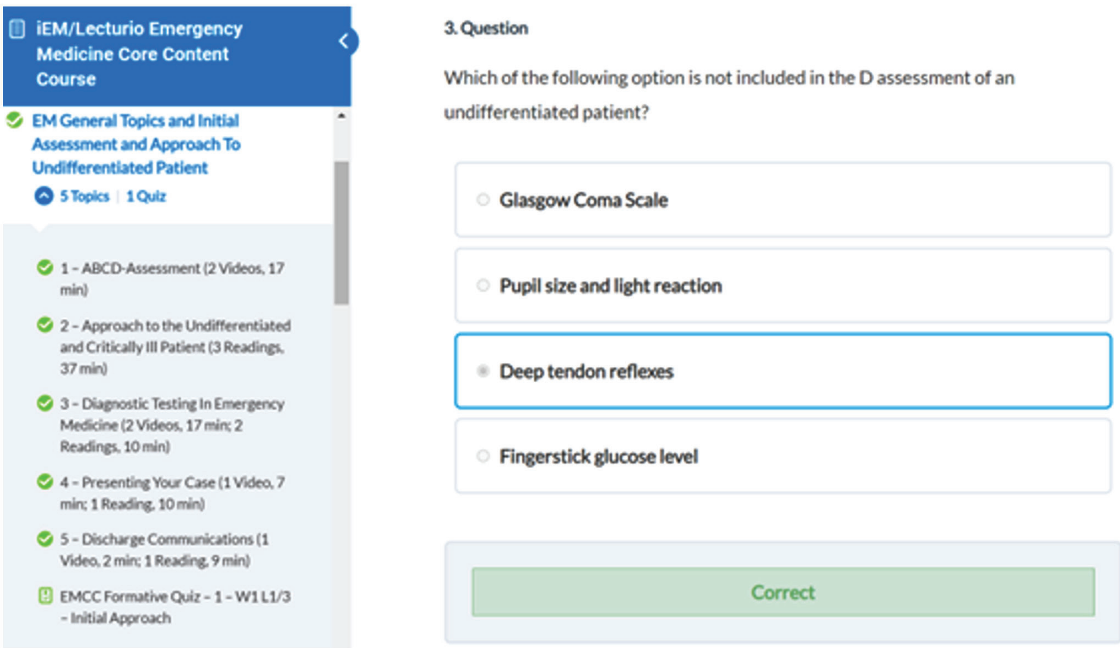

Figure V: Emergency Medicine Core Content Course by Instructional Feedback

d) Instructional Assessment

Table IV shows the descriptive results for the instructional assessment. The overall mean of 4.67/5 suggested that participants were generally satisfied with the instructional assessment component of the course. Participants also agreed that the course was able to provide excellent self-assessments and tests that would adequately measure the accomplishment of the learning objectives.

Table IV: Cognitive Connection in Emergency Medicine by Instructional Assessment

NO	ITEM	SCORE (max. score: 5)
1	The courses provide opportunities for self-assessments that advance learners' achievements.	5
2	Wherever appropriate, higher-order assessments (for example, case studies, business simulations, discussion topics, etc.) are provided rather than lower-order assessments (for example, simple quizzes and tests).	4
3	Post-tests and other assessments adequately measure accomplishment of the learning objectives.	5
	Mean: 4.67 Mode: 5 Standard Deviation 0.58	

e) Multimedia Use

Table V below shows the results of multimedia use in the Emergency Medicine Core Content Course, with a mean score of 4.3/5, and a mode of 4. Participants agreed that the course used appropriate multimedia when trying to highlight or emphasise a certain concept to its learners. Participants also agreed that the media used was always related to the objectives of the lesson, which proved to be helpful when trying to learn a new concept.

Table V: Emergency Medicine Core Content by Multimedia Use

NO	ITEM	SCORE (max. score: 5)
1	Graphics and multimedia assist in highlighting and learning critical concepts rather than merely entertaining or possibly distracting learners.	4
2	Graphics (illustrations, photographs, graphs, diagrams, etc.) are used appropriately (for example, to communicate visual and spatial concept).	4
3	Media (text, images, animations, etc.) included have a strong connection to the objectives and design of the courses.	5
	Mean: 4.33 Mode: 4 Standard Deviation 0.58	

Figure VI below shows the use of media in emphasising the steps to stabilise sick patients in the emergency department, which shows a strong connection to the learning objectives.

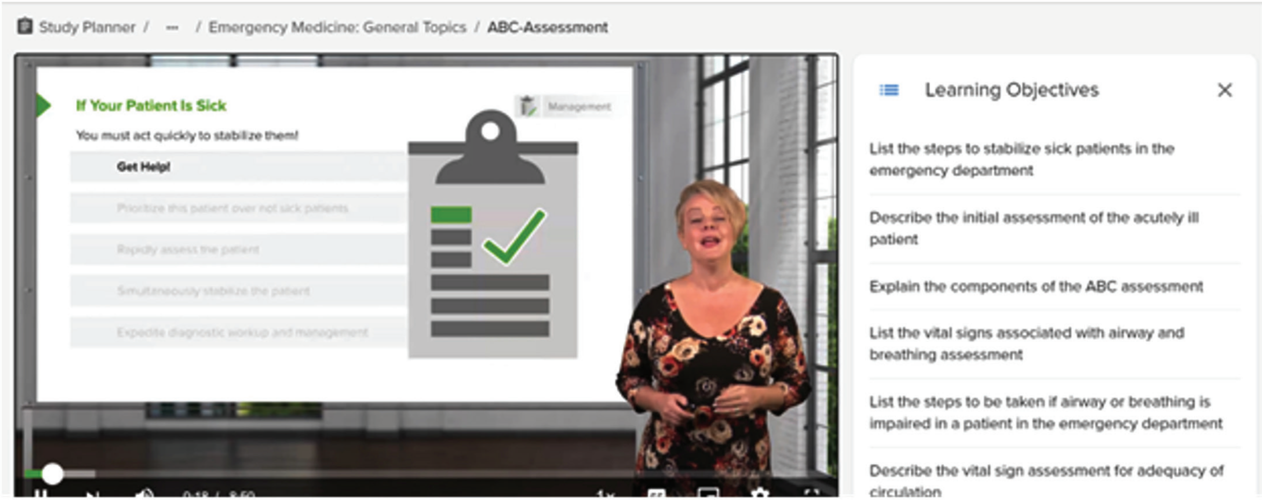

Figure VI: Emergency Medicine Core Content Course by Multimedia Use

f) Learner Guidance and Support

Table VI shows the score for the learner guidance and support component of the Emergency Medicine Core Content Course. The overall mean for this component is 2.75/5, with a mode of 2. Participants collectively agreed that if online help were offered while taking the course, it would be more convenient as participants would understand the topic better should they have any questions. However, the course did offer tools that support learning, e.g, a note taking tool.

Table VI: Emergency Medicine Core Content by Learning Guidance and Support

NO	ITEM	SCORE (max. score: 5)
1	The online help or documentation is written clearly.	2
2	The online help is screen- or context-specific.	2
3	The course offers tools (taking notes, job-aids, resources, glossary, etc.) that support learning.	3
4	The course provides support for learner activities to allow working within existing competence while encountering meaningful chunks of knowledge.	4
	Mean: 2.75 Mode: 2 Standard Deviation 0.96	

2. Affective Connections

Section 2 of the checklist evaluates the affective learning dimension which relates to how participants gain motivation to learn while interacting with MOOC. Figure VII summarises the results of affective connections. In general, all of the items achieved a high score (4 and above) and the overall mean is 4.5 which is high with a very small dispersion of data (standard deviation 0.52) (Table VII). The participants agreed that the course increases their motivation level to complete it. Overall, they were satisfied with how the application incorporates activities that are enjoyable and helps the learner gain new skills at the same time.

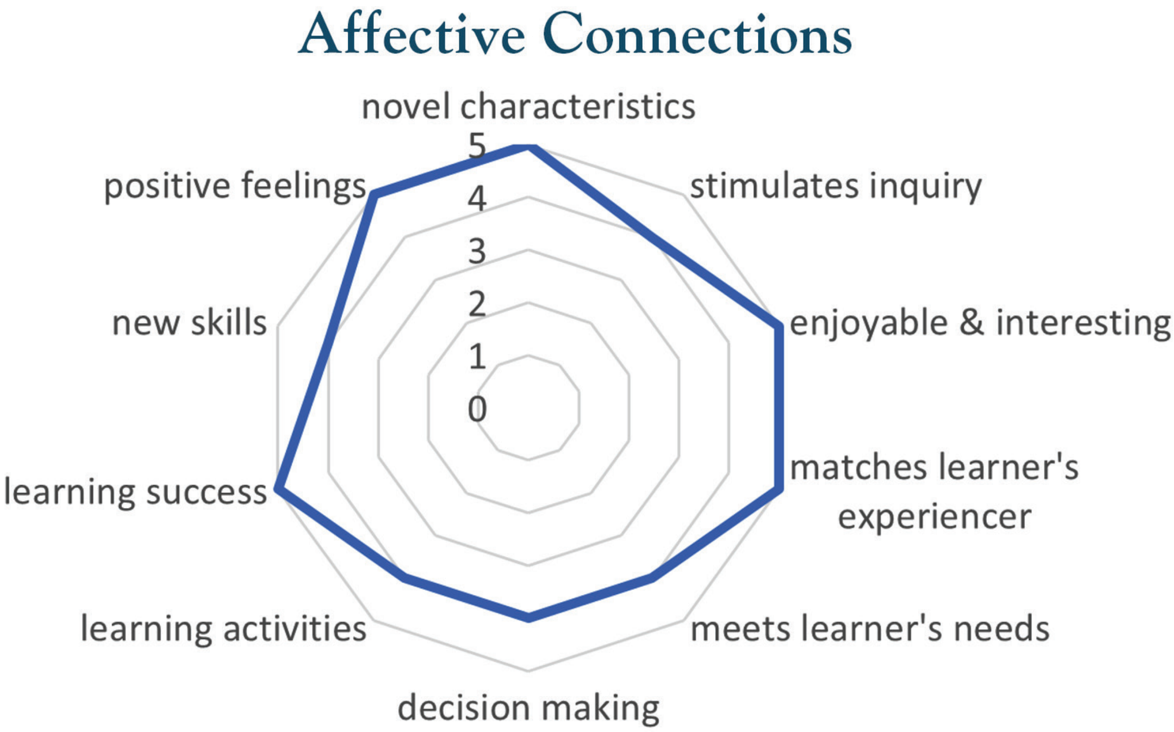

Figure VII: Affective Connections Radar Chart

Tabel VII: Emergency Medicine Core Content by Affective Connections

NO	ITEM	SCORE (max. score: 5)
1	The e-learning application incorporates novel characteristics.	5
2	The e-learning application stimulates further inquiry.	4
3	The e-learning application is enjoyable and interesting.	5
4	The e-learning application provides instruction/training that matches with learners' experience.	5
5	The e-learning application meets learners' needs.	4
6	The e-learning application provides learners the chances to make decisions.	4
7	The e-learning application provides learners with frequent and varied learning activities that increase learning success.	4
8	Learning requirements, criteria for learning success are clear within the e-learning application.	5
9	The e-learning application provides learners the opportunities to use new skills in authentic situations.	4
10	The e-learning application assists learners to have positive feelings about their accomplishments.	5
Mean: 4.5 Mode: – Standard Deviation 0.52		

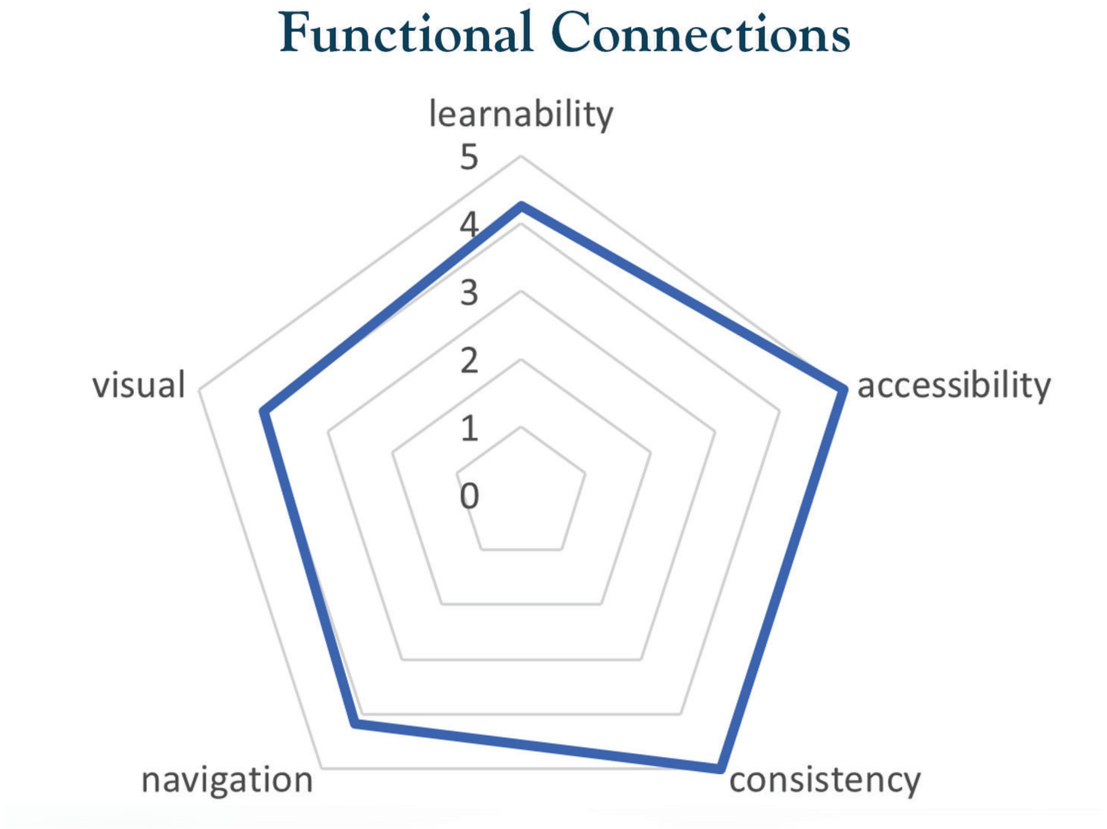

Figure VIII: Functional Connections Radar Chart

3: Functional Connections

Figure VIII summarises the details of Tables VIII-XII.

a) Learnability

Learnability can be closely tied to the effectiveness of a website. According to Table VIII, the feedback of the participants is positive with a mean score of 5, mode of 5 and standard deviation of 1.5. The only feedback is that more clear instructions should be given when the user gets stuck or unable to understand something. However, some participants suggested that clearer instructions should be provided when they get stuck or have trouble understanding something. Optimising a website's learnability is crucial for retaining visitors and achieving its intended purpose.

Table VIII: Emergency Medicine Core Content by Learnability

NO	ITEM	SCORE (max. score: 5)
1	The e-learning application layout is sufficiently apparent so that learning can develop without extensive consultation of online help.	5
2	Learners can start the application (locate it, install plug-ins, register, access starting page) using only online assistance.	5
3	It is clear what learners should do if they get stuck or have questions.	2
4	Learners can predict the general result of clicking on each button or link.	5
	Mean: 4.25 Mode: 5 Standard Deviation 1.5	

b) Accessibility

Accessibility evaluates issues of accessing the MOOC. In Table IX, the mean score is 5, mode is 5 with a standard deviation of 0. Overall, participants did not face any problem launching the application and had no problem assessing the course.

Table IX: Emergency Medicine Core Content Course by Accessibility

NO	ITEM	SCORE (max. score: 5)
1	The pages and other components of the application download quickly.	5
2	The e-learning application is easy to install, uninstall and launch.	5
3	The e-learning application is free from technical problems (hyperlink errors, programming errors, etc.).	5
	Mean: 5 Mode: 5 Standard Deviation 0	

c) Consistency

Consistency ensures expected behavior and reduces user distraction. Table X shows mean score: 5, mode: 5, standard deviation: 0. All participants agree that the course layout is consistent, causing no additional mental load or distraction.

Table X: Functional Connections in Emergency Medicine Core Content by Consistency Results

NO	ITEM	SCORE (max. score: 5)
1	Terminology of the functions is used consistently throughout the e-learning application.	5
2	The fonts, colors and sizes are consistent throughout the e-learning application.	5
3	The application maintains an appropriate level of consistency in its design from one part to another.	5
	Mean: 5 Mode: 5 Standard Deviation 0	

d) Navigation

The research participants were requested to rate the ease of navigation while using the emergency medicine online course and the descriptive results are documented in Table XI. All the components under navigation were given a score of 3 and above, with the mean score being 4.17. Overall, the research participants had a positive review on the navigation which eased their learning process.

Table XI: Functional Connections in Emergency Medicine Core Content by Navigation

NO	ITEM	SCORE (max. score: 5)
1	Learners can choose (easily) what parts of the e-learning application to access, the order and pace of studying.	3
2	Learners have control of their learning activities (studying, exercising, collaborating with other peers, etc.).	4
3	Learners always know where they are in the application.	5
4	The e-learning application allows the learner to leave whenever desired, but easily return to the closest logical point in the course.	5
5	The application layout is sufficiently apparent so that learning can develop without extensive consultation of online help.	5
6	It is clear what learners should do if they get stuck or have questions.	3
Mean: 4.17 Mode: 5 Standard Deviation 0.98		

e) Visual Design

Table XII shows the score for the visual design of the Emergency Medicine Core Content Course which focuses on improving the UX of a web/app through visual elements and effects, including colors, illustrations, photography, typography, and layouts. The mean score is 4/5 while the mode is 5/5. Participants concurred on the good quality of the design.

Table XII: Functional Connections in Emergency Medicine Core Content by Visual Design

NO	ITEM	SCORE (max. score: 5)
1	The most important information on the screen is placed in areas most likely to attract the learner's attention.	4
2	Text and graphics are legible (readable).	5
3	Fonts (style, color, saturation) are easy to read in both on-screen and in printed versions.	5
4	The online help or documentation is written clearly.	2
Mean: 4 Mode: 5 Standard Deviation 1.41		

Discussion

Access to the internet and digital transformation in education has led to its widespread use of well-designed MOOCs that promote collaborative learning.[15,16] The application of heuristics to test usability and expression of user experiences improves the final product. The framework in the assessment tool in this study (Figure I) was useful in achieving the objectives of this study as it tested cognitive, affective, and functional components of the MOOC in Emergency Medicine objectively.

The participants who completed the online course asynchronously and independently were able to reflect on specific constructs and make recommendations for acceptance or improvement in certain elements. They were contented that learning objectives were carefully incorporated into the course design. Setting out the learning objectives before each lesson provides a plan for learning. These were outlined at the beginning of each module. There was congruity among the participants that the interaction and engagement with the online course was good (Figure III, VII, VIII). The participants were satisfied with the content and learning resources for its high caliber. The organisation of the contents followed established instructional design principles and the flow of the lessons were predictably arranged. (Figure III & Figure VII).[17] Additionally, information and learning objects provided were current, generally sufficient, and included additional reading resources. Although the e-contents are tailored for clinical practice in the USA, much of the learning materials applies to standard of care in Malaysia.

Text blocks were well-constructed, easy to read, and full of resources, that helped learners grasp essentials with ease. In designing MOOC, developers will take cognizance of the objectives of the course. They will apply the ADDIE principles of instructional design, apart from ensuring the on-line course fulfils the three domains i.e. (i) cognitive connections (ii) affective connections and (iii) functional connections. The initial prototype would undergo usability testing and evaluation of user experience before the final product is made accessible to learners. The learnable contents in the course was appropriate for medical students studying in the clinical phase of the MBBS programme; the concepts were clearly explained. Including clinical examples would enhance learning in specific areas. Overviews and summaries again help reinforce learning and retention; these were included after each module in the Lecturio videos, but not in the iEM website.

Applying the predetermined heuristics mentioned above to evaluate usability indicates satisfactory cognitive linkages. Self-check, with the inclusion of numerous tests and quizzes enhanced learning of concepts in EM and engaged the learner more effectively. Moreover, each session also included a wide range of learning resources like web links, articles, and videos.[18] Motivating the learner is an essential component; this could be achieved with inclusion of gamification, simulations, and role-playing activities, apart from MCQs used in self-check.

Providing a forum for discussion promotes collaborative learning and provides a space for clarification and interaction with all stakeholders. Student-student interaction has numerous benefits;

group activities and chat forums avoid boredom and promote community learning.[4,19,20] Feedback that is timely, specific, and focused, is integral to formative assessment. Engaging with the instructor through discussion forums, prevents the feeling of isolation and helps in formative assessment. These were shortfalls of the course, as learners could not relate to the instructors when queries arose. The course did not provide an option for feedback requests; instead, there was only an email, briefly mentioned at the beginning of the course.

Learner-support had the least favorable effects on cognitive links. The main course website also did not contain any note-taking tools whereas the Lecturio website did. The need for teacher support in MOOCs is essential in online courses.[21] To aid in the learning process, numerous reading and video options were offered. However, the course was not able to offer help when it comes to working within current competence at undergraduate level.

The marking schemes provided were good; including explanatory notes that would be valuable for learners. Instructional assessment of the course was also notable as the course provided excellent self-assessments for learners to test their knowledge, contributing immensely to the understanding of each lesson. Most of the assessments were of low difficulty, although a number of higher-order tests were also included along case studies to increase engagement. The success of the learning objectives could be accurately measured by post-tests and other assessments. The evaluation component of MOOCs is critical to its success. The assessment tools provided in this course were appropriate and relevant to enhance learning.[22]

Multimedia used in the online courses should appeal to learners; this was commendable in this MOOC, despite being simple and repetitive. The media used in the course also aided in sustaining interest and did not interfere with the learning process. The graphics in each lesson were helpful in reinforcing several of the important concepts. Appropriate images, such as diagrams and graphs, were utilised to illustrate a particular topic. The learning objectives of the lesson were relevant and tied to the material used in each course, which was beneficial to the learners.

Accordingly, the components of the affective connections garnered positive feedback from the participants. The online emergency medicine core content course exceeded expectations and provided sufficient knowledge to encourage learning. Because of the available media, the subject matter was interesting and engaged the learner. The participants concurred using quizzes with case scenarios, prompted them to make better decisions in managing patients, and made learning about the principles of emergency medicine easier. Upon completing the course successfully there was a sense of pride and accomplishment among the participants (users).

Functional connections (summarised in Figure VIII) relate to usability; the learnability of the course was deemed adequate, except there were no clear instructions given when the users got “stuck”. The e-learning application layout is sufficiently apparent for learning to take place. Accessibility of the course was exceptionally good as there were no problems encountered during application download, initiation of e-learning applications was smooth without any hassle, and little to no technical problems were encountered throughout the course. The online emergency medicine course was also exemplary for its consistency. For instance, the designs and terminology of the functions were used consistently throughout the e-learning application without any discrepancy. On the other hand, learners have control over their learning progress, but were unable to collaborate with their peers throughout the course.

Although the course is free for undergraduates, access is restricted to the first 45 days; there are certain restrictions in the frequency of re-visit by the learner for revision. Navigation was commendable, the titles and directions allowed learners to retrace their progress. Learners could exit and return easily to the course at any given time and resume from where they had previously left off. Lastly, visual design of the course was mostly satisfactory with the learners able to identify the important information on the screen as the text, fonts and graphics are easy to read.[23]

This usability and UX study used validated heuristics[12] (Figure I) to evaluate a MOOC on EM. The whole course in EM is clearly set out; it was both satisfying and enlightening to all the six participants, generally. The course was conducted asynchronously and functioned well, achieving learning outcomes in nearly all aspects. The study provides sufficient evidence to provide an unbiased, yet comprehensive report on both the content, construct, and delivery modes.

Limitations

This study using heuristic evaluation employing a validated checklist took over 4-6 weeks. This differs from other heuristic evaluations, which are done over 2-3 days. Nevertheless, we find the evaluation tool (Figure I) sufficient to address the study objectives.[12,24]

Conclusion

Applying specific heuristics enabled the participants of this study to evaluate the usability and UX of the iEM/Lecturio Emergency Medicine Core Content online course. Except for learner guidance and support and instructional feedback, all other elements of the e-learning construct, under cognitive and functional components were ranked good to above average. This study shows the value of using a validated heuristic tool in reflecting on UX and usability of the module on EM available online as a MOOC. Given the limitations and some shortfalls in space for feedback and support from teachers, the course appears to be suitable as a complementary teaching tool for undergraduates employing a "flipped classroom" approach.[25]

The results from this research may make positive changes to the Emergency Medicine online course based on constructional feedback when presented to the constructors of the course. Additional research may be conducted to determine its alignment to the current syllabus of IMU MBBS students.

Ethics approval and acknowledgement

This study was approved by the International Medical University Joint Committee for Ethics and Research. This study was supported by a grant given by the International Medical University to conduct the study.

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Conflict of Interest
All authors declare there is no conflict of interest.

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