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Research Article

The impact of healthcare digitalization on the medical education curricula and programs: Points of convergence and divergence

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ABSTRACT

This study analyzes how medical educational programs are evolving to address the digital transformation in healthcare. Surveys, curriculum analysis, and faculty interviews were utilized to examine technology integration. Findings indicate electronic medical records are considered the most significant digital achievement, though only 4% of beginner faculty emphasized telemedicine. Curriculum analysis revealed increasing modifications related to technology, informatics, and data analytics, especially in certain specialties like biochemistry and biophysics. Interviews provided insights into digital integration opportunities and challenges. A key theme was re-evaluating pedagogical strategies as students rely more on technology. Interviewees also envisioned emerging innovations enabling personalized, immersive learning, but cautioned against over-dependence on technology impeding development of clinical skills and humanism. Overall, while core medical fundamentals remain unchanged, curriculum content is adapting to incorporate new competencies like digital literacy. However, strategic integration remains crucial to balance technology's benefits and drawbacks. Challenges like technical difficulties, costs, and over-reliance must be addressed. The outlook is increased technology utilization, with solutions like AI-enabled adaptive learning on the horizon. However, investing in infrastructure and faculty development will be vital. Medical schools must leverage technology to elevate learning while retaining humanistic values. This study provides timely insights into medical education's digital transformation, laying groundwork for further research on optimizing technology integration while upholding the human core of medicine.

Keywords: digital competencies in medical education, healthcare digitalization, medical curriculum, medical education

INTRODUCTION

The burgeoning integration of digitalization in healthcare presents a pivotal shift in how medical education must be approached. Universities now operate in a dynamic educational environment defined by rapid technological advancement, requiring both students and educators to continuously adapt (Khurana et al., 2022). As the World Health Organization (WHO) underscores the importance of healthcare accessibility for global well-being (WHO, 2019), it becomes imperative for medical education to reflect the changes and demands of a digitally transforming healthcare sector.

Healthcare digitalization is becoming increasingly important to integrate into medical education. As the healthcare field adopts more digital technologies like electronic health records, telemedicine, and artificial intelligence (AI) diagnostics, medical students need exposure to these tools during their training (Althubaiti et al., 2022; Mesko et al., 2015; Randriambelonoro et al., 2018). Introducing topics like health informatics, data analytics, and digital literacy into the core medical curriculum can help ensure future physicians enter practice with competency using new healthcare technologies (Aungst & Patel, 2020; Bhyat, 2019; Kryukova et al., 2022).

Incorporating healthcare digitalization also keeps pace with changing patient expectations. Patients are seeking more personalized and technology-enabled care experiences (Khurana et al., 2022; Pugachev et al., 2021). Physicians prepared to leverage digital health innovations will be better positioned to provide quality, patient-centered care (Aungst & Patel, 2020; Waseh & Dicker, 2019). Overall, comprehensive integration of healthcare digitalization topics throughout undergraduate and graduate medical education is critical for training future-ready physicians equipped to practice modern medicine.

Recent global events, especially the pandemic, have effect on educational outcome and lifestyle (Zhdanov et al., 2022). So, they have accelerated the adoption of digital technologies in healthcare, ranging from telemedicine to specialized medical applications (Sharma & Bhaskar, 2020). This swift digital transformation has redefined the role of medical professionals, necessitating a new set of competencies including digital health literacy, technological adaptability, and social responsibility (Han et al., 2019; Jimenez et al., 2020). This change introduces challenges but also opportunities for medical educators.

The duality of professional education presents a unique dilemma. Historically, the design and full implementation of educational programs could lag years behind current industry practices (Lucey, 2013; Parker et al., 2017). However, with the rate of technological advancement in healthcare, such conservatism threatens the relevancy and efficacy of medical education. Thus, addressing this gap through curriculum modernization in light of healthcare digitalization is paramount.

While the benefits of healthcare digitalization are apparent, a significant gap exists in aligning these advancements with current medical curricula (Aungst & Patel, 2020; Machleid et al., 2020; Poncette et al., 2020). This discordance potentially leaves future healthcare professionals unprepared for a technology-centric medical landscape, emphasizing the need for curriculum reform. This study aims to analyze how medical educational programs have evolved in response to healthcare digitalization, primarily focusing on the adaptations or gaps in curriculum design and pedagogical methods.

LITERATURE REVIEW

Researchers from different countries have concluded in their studies that the implementation, process, and consequences of the globalization of healthcare digitalization for medical education are relevant and significant for integrating this technology into curricula for the entire medical community (Bhyat, 2019; Han et al., 2019). Theoretical analysis of scientific literature has revealed that the digitalization of healthcare involves a diverse range of activities in academic medicine. The competence of a modern doctor directly depends on his or her ability to utilize digital technologies.

Modern conditions require the transformation of medical practice focused on social networks, blogs and Internet applications, with the prospect of partial implementation in academic medicine (Goldie, 2016; Guraya et al., 2021; Jun Xin et al., 2021). Innovative digital medicine technologies will minimize increased risks of solving acute problems during remote monitoring of human health under certain restrictive conditions (Sharma & Bhaskar, 2020).

The comparison of the capabilities of medical universities and the study of the processes of digitalization of healthcare for the implementation of innovation policy was revealed in different international research studies (Aulenkamp et al., 2021; Cullen et al., 2019; Forde & OBrien, 2022; Khurana et al., 2022; Lazarenko et al., 2020; Litvinova et al., 2021). At the same time, for educational programs to be productive, a balance must be maintained between the results of digitalization of healthcare and theoretical knowledge, clinical and practical experience of medical students (Zis et al., 2021).

According to recent research results, digital health literacy and digital skills are key competencies for medical students to effectively utilize the potential of digital healthcare. There is a serious gap between the practical preparedness of future doctors, who are "the key players in the digital transformation of healthcare," and the education they receive in medical institutions (Machleid et al., 2020). To eliminate existing problems, a group of American scientists (Ragsdale et al., 2020) suggest using a reliable mechanism for tracking and monitoring the evaluation of the effectiveness of medical education programs, with training criteria based on the Kirkpatrick evaluation model.

The goals of integrating digital technologies into the teaching process include improving the quality and accessibility of postgraduate education, followed by improving the competence of medical specialists and the quality of medical care. The digital education system includes the availability of information resources, telecommunications, and a management system for healthcare components. Medical students in academia and during practical training should obtain the necessary skills and knowledge that will contribute to high-quality medical services in the future, which will increase the overall level and quality of care (Lazarenko et al., 2020).

Digital healthcare should be in constant integration with medical education to implement the significant potential of technological progress in the healthcare sector. Training programs should be designed considering the leading positions of digital healthcare (Khurana et al., 2022). An integrative analysis of research conducted in fifteen countries worldwide revealed the leading trends in medical education, which group into four categories: a humanistic approach to patient safety, early diagnosis and integration, society outside the outpatient clinic, and teaching students using advanced technologies like AI (Han et al., 2019; Secinaro et al., 2021). To increase preparedness for digitalization, it is recommended to increase classroom load and use of digital technology resources. Universities should have access to new technologies, and electronic assistants should be demonstrated in relevant courses (Jun Xin et al., 2021).

Existing literature provides valuable insight into the impact of digitalization on medical education, underscoring the need for further research. This study aims to develop preliminary knowledge by adopting a multifaceted approach, incorporating faculty members' perspectives through surveys, curriculum analysis, and in-depth interviews. In this context, the study aims to comprehensively examine the transition towards digitalization in medical education from multiple vantage points, highlighting opportunities, challenges, competencies required, and providing recommendations for smoothly navigating this transformation.

METHODOLOGY

Our study aimed to understand the influence of digital medicine in the professional realm of practicing doctors. We employed a three-pronged approach (**Figure 1**):

1. **Survey administration:** Initially, participants were provided with a survey. This aimed to gauge their perceptions on key achievements of digital medicine, any significant challenges they faced using these digital tools, and the necessary training processes when integrating new digital health technologies.
2. **Curriculum analysis:** We then conducted an examination of post-2017 curriculum modifications. This analysis sought to discern any visible impacts of digitization on the content and structure of the curriculum.
3. **Expert interviews:** To delve deeper, we interviewed six faculty members from diverse departments and with varied lengths of service. Their insights helped shed light on how digitization currently influences the curriculum and its potential future trajectory.

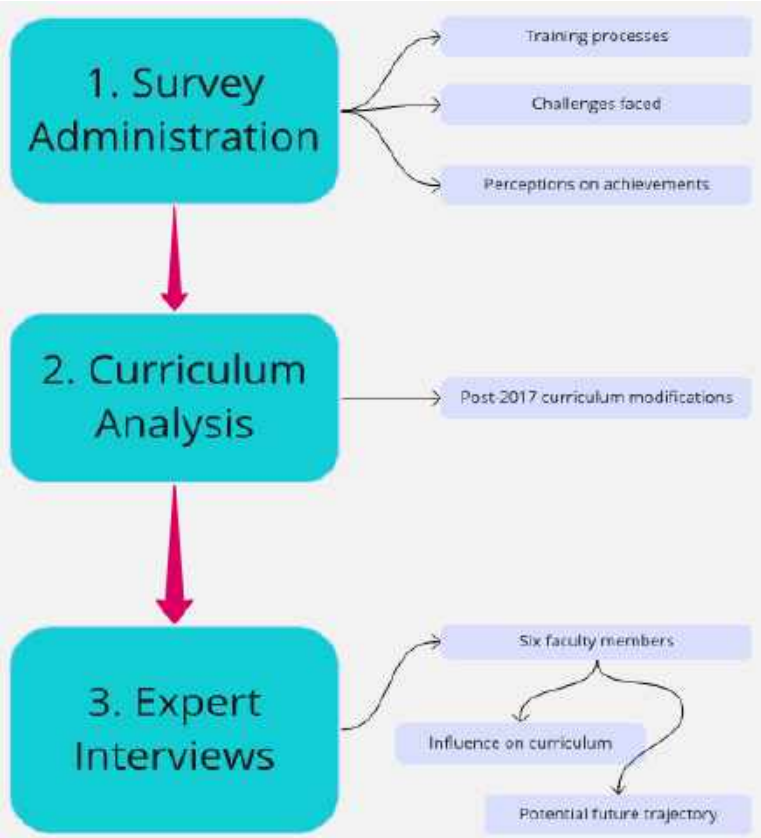

Figure 1. Research process (Source: Authors)

By integrating feedback from grassroots level practitioners with an academic perspective, our methodology offers a rounded view on the digital evolution in practical medicine.

Data Collection Tools

The survey

For the data collection phase of our survey, we focused on identifying key digital technologies that have been pivotal in healthcare advancements in recent years. Based on the literature, several components of healthcare's digital aspect were highlighted, each complemented by the opinions of respected authors in the field. The components, along with their respective author opinions are, as follows:

1. **Unified States health information system & electronic medical records**:** This system ensures that Russian citizens can access medical services online. It provides information on a healthy lifestyle, disease prevention, procedures for obtaining medical care, and details about medicine prescriptions, among other things (Hong et al., 2018).
2. **Digital diagnostic technologies:** This includes technologies like digital radiation diagnostics, accessible genetics, robotics, and wearable medical devices. These technologies contribute to a massive and continuous growth of data in healthcare (Pugachev et al., 2021).
3. **Personal digital medical assistant:** Mobile applications and electronic medical gadgets, such as smartwatches that monitor vital signs, remote ECG devices, glucose meters, and artificial pancreases, have been identified as foundational to the hybrid model of medical care (Pugachev et al., 2021).
4. **Telemedicine:** This represents the remote interaction between medical professionals and patients and supports the continuous process of medical education (Randriambelonoro et al., 2018).
5. **AI:** AI is revolutionizing medical visualization, diagnostics, rapid information processing, and interlinking various components of healthcare digitalization. Its introduction is driving the digital transformation in healthcare, leading to the development of systems such as clinical decision support systems (CDSS), which focus on digital image analysis, risk management, and more (Milkova, 2021).

To ensure the accuracy and relevance of our survey content, it underwent a validation process. Three experts, all with significant experience both in the medical faculty and in medical technologies, were consulted to validate the survey's structure, questions, and themes. Their invaluable insights ensured the survey was both rigorous and relevant to the current state of digital technology in healthcare.

The curriculum

For the second phase, we rigorously analyzed the curriculum changes from the Institute of Fundamental Medicine and Biology of Kazan (Volga Region) Federal University focusing on the integration and modification of digital health technologies in medical education. The extracted data detailed modifications across several specialties/qualifications, illuminating how digital transformations have impacted the time allocation and content of the curricula.

Interview

For our research aiming to understand the profound influence of digitalization on medical education, we developed an interview instrument tailored to solicit insights from medical faculty members. This tool comprises questions strategically crafted to unravel the intricate facets of integrating technology into the medical curriculum.

To bolster the robustness and relevance of our questions, we turned to a panel of four seasoned experts, drawing from their collective wisdom.

Expert 1, with a rich experience spanning over 15 years in medical education, has been instrumental in infusing curricula with the latest technological innovations. Expert 2 stands out as a stalwart in curriculum development, emphasizing the seamless integration of digital modules into medical training.

Expert 3, marrying their knowledge of medical pedagogy with technology, has contributed extensively to literature showcasing the synergy of these domains. Lastly, Expert 4, renowned for their strategies in enhancing medical education with technology, offers a perspective enriched by witnessing the digital evolution in medical academia.

Upon receiving the seal of approval from this esteemed panel, we undertook a pilot study by engaging two faculty members in an interview session. This exercise was pivotal, allowing us to refine any ambiguities and ascertain that our questions would indeed provoke detailed and meaningful responses.

Our interview tool encompasses the following queries:

1. We delve into the transformative influence of digital trends by asking, "in what ways has the rise of digitalization changed the way medical students approach their studies?"
2. Recognizing that the integration of technology is a strategic choice, we probe, "how do you decide which digital tools or technologies to incorporate into the curriculum?"
3. To understand curriculum evolution in the digital era, we question, "has digitalization led to a change in the topics or subjects covered in the curriculum?"
4. Acknowledging the challenges of this transition, we inquire, "what challenges have arisen due to the integration of digital tools into the curriculum?"
5. With the changing landscape, we explore the skills of the future: "are there new skills or competencies that today's medical students need to develop in light of the increasing digitalization?"
6. Finally, to envision the road ahead, we ask, "how do you see the role of digitalization in medical education evolving in the next five-10 years?"

This meticulously designed interview tool, fortified by expert validation and insights from the pilot study, promises a holistic understanding of the nexus between digitalization and medical education.

Participants

First phase

In the initial phase of our research, the participants comprised 152 practicing medical faculty members. From this extensive group, a representative sample was drawn, which included 37 respondents. These

participants were aged between 26 and 50, with a prominent 51.3% of them falling in the age bracket of 28-32 years.

Second phase

The subsequent phase of the study had a more focused group, consisting of the following individuals:

1. **Person A:** A seasoned veteran in the realm of medical education, he has been an integral part of the medical faculty for 25 years. His vast experience brings a depth of perspective to the study.
2. **Person B:** As a lecturer specializing in anatomy, her hesitancy towards adopting new technology offers a contrasting viewpoint. Her skepticism provides a unique lens to evaluate the effects and integration of technology in medical education.
3. **Person C:** A dedicated faculty member in the clinical laboratory diagnostics department, she boasts over a decade of expertise in the field. Known for her proclivity to be open to technological experiences, she represents the forward-thinking fraction of medical educators.
4. **Person D:** Affiliated with the department of medical biotechnologies, he possesses around five years of experience. Acknowledging his novice status, he nonetheless brings a dual perspective: having experienced the shift towards technology both during his time as a medical student and later as a doctor.
5. **Person E:** Representing the dentistry faculty, she is a crucial component of the modern technologies in endodontics department. With a professional journey spanning 10 years, her experience is twofold– she has witnessed technological advancements both as an educator and during her tenure as a practicing dentist.
6. **Person F:** Hailing from the medical cybernetics department, she adds another five years of expertise to our pool. Her insights are invaluable, having seen the rise of medical technologies during her active years as a practicing doctor.

Each participant in the second phase has been carefully selected to ensure a spectrum of experiences and perspectives, ensuring the comprehensive exploration of the topic at hand.

Data Analysis

The data procured from the survey responses have been presented as percentage distributions. Regarding faculty seniority, individuals with one-five years of experience are categorized as 'beginners,' those with six-20 years are classified as 'intermediate,' and professionals with more than 21 years of experience are denoted as 'seniors'. The visualizations were constructed utilizing the Tableau software.

In 2017, the curriculum texts of the medical faculty were examined on an annual basis. Alterations, additions, and eliminations within the course process were identified. Two researchers independently conducted the analyses. Subsequently, they reached a consensus regarding the identified changes.

The qualitative data acquired from interviews concerning digitalization in medical education was analyzed using a thematic approach. Initially, transcribed interviews were reviewed multiple times to gain a comprehensive understanding of the content. This familiarization process led to the generation of initial codes, highlighting patterns, ideas, and concepts discussed by interviewees.

Subsequently, the codes were grouped based on similarities, leading to the identification of overarching patterns or themes. These preliminary themes were rigorously examined against the dataset to ensure their validity, resulting in refinement or merging of some themes. Researchers agreed on naming the theme.

The finalized themes encompassed:

1. **Shift in pedagogical strategies:** The changing dynamics of teaching with digital tool incorporation.
2. **Evolving curriculum content:** Adjustments in curriculum to accommodate technological advancements.
3. **Tool selection and integration:** The process and decision-making in integrating specific digital tools.
4. **Integration challenges:** Difficulties educators face during digital integration.
5. **Digital competence development:** Imperative of fostering digital skills along with medical expertise.

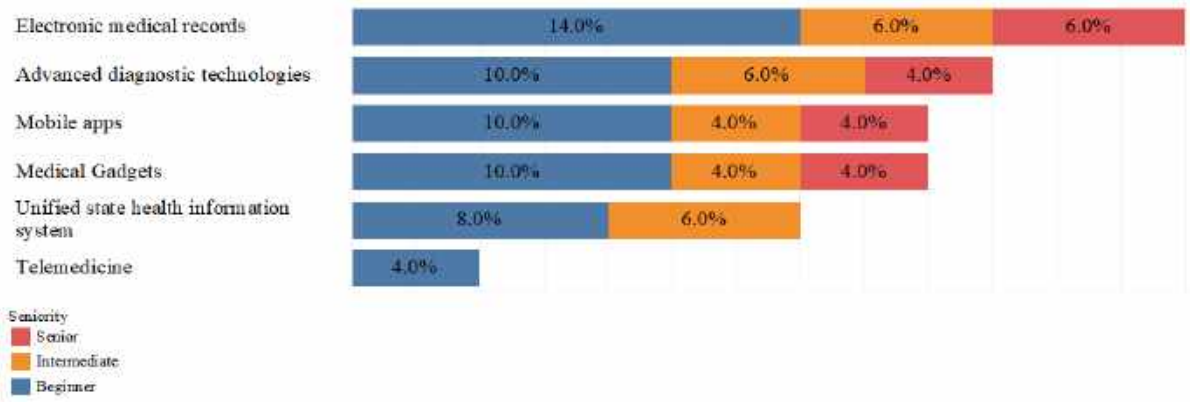

Figure 2. Distribution of significant achievements in digital medicine (Source: Authors)

6. **Future vision of digital integration:** Anticipated transformations in medical education due to digital tools.

Each theme was meticulously described, supported by pertinent interviewee quotes. This analysis provides a concise yet holistic view of the impact of digitalization on medical education.

FINDINGS

Survey

Figure 2 presents the perceptions of faculty members in the medical field regarding the significant achievements in digital medicine that have facilitated the professional sphere of a practicing doctor. The results are divided based on the faculty members' seniority: beginner, intermediate, and senior.

Electronic medical records (EMRs) lead the chart in terms of significance across all faculty member categories. 14% of beginner faculty members consider EMRs as a pivotal achievement, followed by 6% of both intermediate and senior faculty. The high percentage among beginners suggests that the younger generation of medical practitioners or educators view digitized patient information as a game-changer, offering streamlined processes, reduced errors, and improved patient care.

Advanced diagnostic technologies have also garnered significant attention. 10% of beginners see their value, followed by 6% of intermediates and 4% of seniors. The diminishing percentages across seniority might imply that while all agree on its importance, the younger faculty perhaps have a more profound appreciation or reliance on advanced diagnostic tools in their practices.

Mobile applications in medicine, which may include tools for diagnosis, patient management, or continuous learning, are acknowledged across beginner and intermediate faculty members with 10% and 4%, respectively. However, senior faculty did not emphasize them as much, possibly due to a generation gap in the adoption and comfort with mobile technology. These technological tools, which can range from wearable health monitors to portable diagnostic equipment, hold consistent value across beginners, intermediates, and seniors with each group registering at 10%, 4%, and 4%, respectively. This suggests that irrespective of seniority, there's an appreciation for the direct, tangible benefits that such gadgets provide in day-to-day medical practice. Unified States health information system aiming to centralize health records and information on a state or national level, is considered vital by 8% of beginners and 6% of intermediate faculty. This might underscore its role in ensuring better data sharing, patient tracking, and research capabilities among hospitals and clinics. However, senior faculty did not reflect a strong inclination towards it, which may be indicative of either lack of exposure or a preference for more traditional methods of data handling.

Notably, only beginner faculty members highlighted telemedicine, and at a lower rate of 4%. Given the global push towards telehealth, especially in the wake of events like the COVID-19 pandemic, it's intriguing that this figure is not higher. It might suggest that while telemedicine is recognized, the traditional in-person consultations and treatments might still be the preferred modality for many, or that the faculty believe there's still some way to go before telemedicine realizes its full potential.

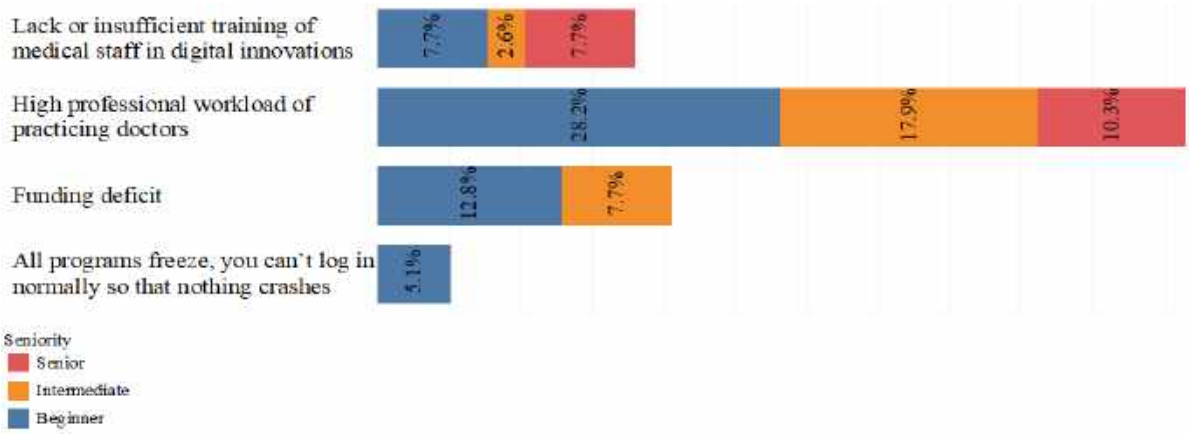

Figure 3. Problem of using digital medicine products (Source: Authors)

In conclusion, the digital revolution in medicine, as reflected by faculty members, leans heavily towards the incorporation of EMRs and advanced diagnostic technologies. While innovations like mobile apps, medical gadgets, and state health systems have made strides, there's potentially room for greater integration, especially in the view of senior faculty. Telemedicine, despite its growing global footprint, might need more advocacy or demonstrable success to make a more significant impact on this particular group of medical professionals.

Figure 3 showcases the concerns of faculty members in the medical field regarding potential issues with the use of digital medicine products in the professional domain. These concerns are segmented according to the faculty members' levels of seniority: beginner, intermediate, and senior.

Both beginner and senior faculty members highlighted the challenge of insufficient training in digital innovations at an identical rate of 7.69%. Interestingly, the intermediate faculty members reported a lower concern, at 2.56%. This observation might imply that while the newer and more seasoned professionals feel the pinch of adapting to fast-evolving technology, those in the middle phase of their careers might either have adapted better or may have had more exposure to training initiatives.

The concern about increased workload due to digital medicine stands out prominently among the beginner faculty, with a significant 28.21% indicating it as a problem. This number tapers to 17.95% for intermediate faculty and further to 10.26% for senior faculty. One interpretation is that younger professionals, while trying to acclimate to the demands of their roles, might feel overwhelmed with the added layer of digital tools. On the other hand, senior faculty, who might have established routines, possibly find digital interventions less burdensome or may not be using them as intensively.

The issue of funding for digital medicine solutions is reported by 12.82% of beginner faculty and 7.69% of intermediate faculty. The absence of this concern among senior faculty could suggest that they might not be directly involved in the procurement or financing aspects of these digital tools. Alternatively, they might perceive other challenges as more pressing than funding concerns.

A smaller proportion (5.13%) of beginner faculty pointed out technical issues, such as software freezes or login problems, as significant concerns. The absence of this issue in the intermediate and senior categories might suggest that either the younger professionals are using these systems more intensively and thus encountering more problems or that they may not have the same level of patience or troubleshooting skills as their older counterparts.

In conclusion, the use of digital medicine products, while offering numerous advantages, comes with its set of challenges. For younger faculty, the steep learning curve combined with the high professional demands can seem daunting, while those in the middle might be better positioned to navigate these challenges. Senior faculty, with their vast experience, have different sets of priorities, possibly focusing more on the core aspects of medicine than grappling with the nuances of digital tools. Addressing these concerns through better training, more intuitive software design, and appropriate funding can ensure smoother integration of digital tools in the medical sphere.

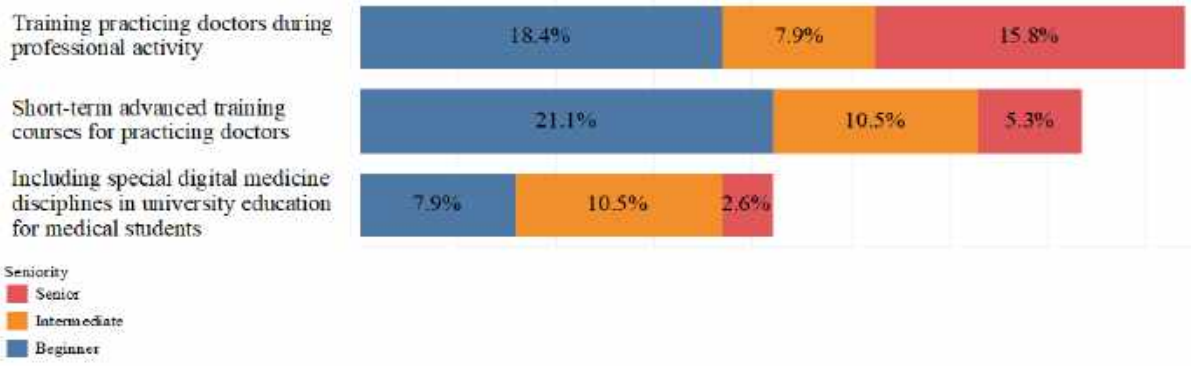

Figure 4. Training process in new digital health technologies (Source: Authors)

Figure 4 delves into the opinions of faculty members in the medical field regarding the optimal training processes needed when introducing new digital health technologies into practical medicine. The results are parsed based on faculty members' experience levels: beginner, intermediate, and senior.

Training practicing doctors during professional activity approach emphasizes on-the-job training, enabling doctors to learn about digital health technologies while engaged in their day-to-day clinical duties. Among beginners, this was a significant preference, highlighted by 18.42% of respondents. Senior faculty members also showed a notable inclination towards this method, with 15.79% advocating for it. In contrast, intermediate faculty members registered a lower interest at 7.89%. This pattern might suggest that both newcomers and experienced professionals value the practical, hands-on approach to training that directly integrates with their workflow. Intermediate faculty might prefer more structured or separate training sessions, which is reflected in the following category.

Short-term advanced training courses for practicing doctors, the emphasis is on dedicated training sessions, separate from the doctors' regular duties. This method was the most preferred among beginner faculty, with 21.05% in favor. Intermediate faculty followed with 10.53%, and only 5.26% of senior faculty members leaned towards this. The preference by beginners might be indicative of their recent experiences in educational settings and their belief in structured learning modules. The reduced interest in this mode by senior faculty can hint at their inclination to integrate learning within their routine professional activities, rather than allocating separate times for training.

Including special digital medicine disciplines in university education for medical students approach envisions the integration of digital medicine training directly into the core medical curriculum. Interestingly, intermediate faculty members showed the most interest in this, with 10.53% advocating for it. Beginners followed at 7.89%, while senior faculty showed the least interest at 2.63%. This could suggest that the intermediate faculty, possibly having recently navigated the transition from education to professional practice, recognize gaps in the curriculum and see the value in early, foundational training. Senior faculty members, on the other hand, might believe that the rapid evolution of technology makes it more suitable to be taught in a post-graduate or professional setting rather than at the undergraduate level.

In summary, while all faculty groups recognize the need for training in digital health technologies, their preferences differ based on their career stages. Beginners seem to lean towards both hands-on training during professional activities and dedicated short-term courses. Intermediate faculty show a balanced view, recognizing the value of early curriculum integration as well as advanced courses. Senior faculty, with their depth of experience, lean more towards integrating training into their professional routines. Addressing these diverse needs can help in the seamless introduction of digital health technologies into practical medicine.

Curriculum

Table 1 provides insights into changes made in the curriculum of various specialties or qualifications. The focus is on understanding the number, nature, and reasons for these modifications over different years.

Table 1. Changes in curricula of medical educational programs in 2017-2022

Specialty/qualification	Name of curriculum component	Dynamic parameter	Probable (presumed) reason for modification
30.05.01 medical biochemistry (biochemist)	Analytical chemistry	Since 2018 academic year, reduction of classroom load from 144 hours to 108 hours (-25%)	Necessary data analytics skills have been transferred to medical informatics component
	Pre-medical care	Implementation from 2021 academic year, 72 hours	Active implementation of telecommunication technologies (telemedicine) into practical medicine
	Medical informatics	From 2021 academic year, increase in classroom load from 216 hours to 252 hours (+17%)	Need to work with data, computer technology, & data analytics
	Internal diseases	From 2019 academic year, reduction of classroom load from 432 hours to 360 hours (-17%)	This component is needed by a specialist (biochemist) as an introduction, it does not require a large amount of classroom load
	Clinical laboratory diagnostics	From 2020 academic year, reduction of classroom load from 360 hours to 324 hours (-12%)	Due to transition of laboratory diagnostics to automated models, hours of classes are reduced
	Public health & healthcare	Implementation from 2021 academic year, 72 hours	There is an increasing need to identify & implement new technologies in healthcare, to have skill of advocacy
	Omix technologies in medicine	Implementation from 2021 academic year, 108 hours	Working with huge amounts of data to automate certain medical processes. Lack of qualified specialists in this field.
30.05.02 medical biophysics (biophysicist)	Omix technologies in medicine	Implementation from 2021 academic year, 108 hours	
	Medical informatics	Since 2018 academic year, increase in classroom load from 216 hours to 252 hours (+17%)	Need to work with data, computer technology, & data analytics
30.05.03 medical cybernetics (cybernetic doctor)	Basics of programming	From 2019 academic year, increase in classroom load from 180 hours to 216 hours (+12%)	
	Probability theory & mathematical statistics	From 2017 academic year, increase in classroom load from 180 hours to 360 hours (+50%)	Necessity to work with data, computer technology, & data analytics. There is an increasing need to identify & implement new technologies in healthcare, to have skill of advocacy.
	Medical biotechnologies	Since 2017 academic year, increase in classroom load from 144 hours to 180 hours (+20%)	Rationalization of professional activity, optimization of system of information data accounting & decision-making, treatment effectiveness, & reduction of medical errors
31.05.01 general medicine (medical doctor)	Internal diseases	From 2019 academic year, increase in classroom load from 396 hours to 468 hours (+18%)	Additional load is implemented at distance learning site of KFU as an electronic educational (digital) resource
31.05.03 dentistry (dentist)	Medical physics	From 2020 academic year, increase in classroom load from 252 hours to 288 hours (+13%)	Increasing supply & maintenance of medical equipment for practical medicine
	Prosthetics on implants	Implementation from 2020 academic year, 72 hours	Visualization of process & work, reducing duration of dental work, improving quality of structure due to modern dental prosthetics technologies
	Modern technologies in endodontics	Implementation from 2020 academic year, 72 hours	Innovative, advanced technologies in diagnostics & treatment

Starting from 2017, there has been a noticeable increase in the number of modifications made to the curriculum components each year. While 2017 and 2018 saw relatively fewer changes with only two modifications each, the number rose to three in 2019, 4 in 2020, and peaked at five in 2021. This trend suggests that educational institutions have been actively reviewing and updating their curriculum components more frequently in recent years.

The overarching theme for modifications is to revolve around technology and its growing impact on the field of medicine. For instance, the most recurring reason for modification is the "need to work with data, computer technology, and data analytics." This underscores the increasing importance of data-driven decision-making in medicine. Similarly, other reasons like the "active implementation of telecommunication technologies (telemedicine) into practical medicine" and the transition of laboratory diagnostics to automated models highlight the rapid technological advancements in the field. These reasons indicate a shift towards a more tech-savvy approach in medical education, emphasizing the importance of integrating technology and data analytics into the curriculum.

While the dataset contains multiple specialties or qualifications, the most prominent one that stands out is "30.05.01 medical biochemistry (biochemist)." It is evident that certain specialties are experiencing more curriculum changes, possibly due to the evolving nature of the field or the increasing demands of integrating technology into the practice.

The dynamic parameters, essentially detailing the nature of the curriculum changes, show a mix of reductions and increases in classroom hours for various components. Notably, there is a trend of reducing hours for certain components, suggesting that some topics might be becoming less foundational or are being integrated elsewhere in the curriculum. On the other hand, the increase in hours for components like "medical informatics" in 2021 highlights the growing importance of data and technology in medicine.

The data paints a picture of a medical education landscape that's rapidly evolving, driven by technological advancements and the increasing importance of data analytics. Institutions seem to be making proactive efforts to update their curricula, ensuring that students are well-equipped to navigate the modern challenges of the medical field.

Interview

Impact of digitalization in medical education

The integration of digital tools and methodologies into medical education has instigated a revolutionary shift in pedagogical strategies. This transformative change has not merely reshaped learning environments; it has redefined them. From the reliance on online resources to the preference for digital texts, medical education is witnessing an evolution that's both profound and rapid.

Take, for instance, the perspective of a seasoned medical educator with 25 years of experience, person A, who notes:

> "As a medical educator with 25 years of experience, I've seen quite a shift in how students approach their studies due to the rise of digitalization. Reliance on online resources … Distractions from tech … Changes in problem-solving … In summary, while digitalization has enabled many new beneficial study methods, it has also fundamentally changed how students approach learning–for better and worse. As educators, we must adapt our methods to this new reality."

Such an observation underscores the seismic shift taking place in medical education. Digital tools are not mere add-ons to traditional learning methods; they have become central to the educational journey of many medical students. Further, digitalization is not limited to just tools and resources. It has paved the way for novel subjects and topics in the curriculum. Consider the realm of dentistry, where digital advancements are particularly noticeable. As person E from the department of modern technologies in endodontics elaborates:

> "Yes, the rise of digital dentistry and new technologies has definitely impacted the topics and subjects we cover in our curriculum. Expanded technology instruction … Informatics … Telehealth … Social media … Enhanced simulation … Digital practice management … Our curriculum evolves alongside digital dentistry itself!"

Such remarks highlight not just the incorporation but the vital integration of digital elements into the curriculum, ensuring students are aptly equipped to navigate the evolving landscape of medical professions in the digital age.

In conclusion, through a series of interviews, it becomes palpably clear that the impact of digitalization on medical education is multifaceted. The strategic decision-making behind tool integration, the evolution of curriculum content, the challenges faced, the imperatives of digital competence, and visions for the future all coalesce to paint a picture of an educational domain that's vibrant, dynamic, and constantly evolving.

Evolving curriculum content in medical education

The digital age, characterized by rapid technological advancements, has left no stone unturned, and the field of medical education is no exception. The curriculum, traditionally grounded in age-old practices, is now experiencing a metamorphosis. The induction of digital tools and methods has not only revolutionized learning methodologies but has also reshaped the content that forms the core of medical education.

Person C, reflecting on the myriad ways digitalization has sculpted the curriculum, observes:

> "Absolutely, the integration of new technologies in healthcare has expanded and altered the core knowledge and competencies addressed in medical school curricula. From a greater emphasis on health information technology, bioinformatics, AI applications, to the incorporation of virtual reality simulations, technology is transforming medicine. The fundamentals remain unchanged, but digital literacy and new technical capabilities are essential additions shaping the next generation of physicians."

Similarly, the world of dentistry is not untouched by this wave of digital transformation. Person E from the department of modern technologies in endodontics notes:

> "Yes, the rise of digital dentistry and new technologies has definitely impacted the topics and subjects we cover in our curriculum. We now provide extensive training on digital tools for imaging, treatment planning, CAD/CAM restorations, and more. While we still provide a strong foundation in traditional principles and hands-on dental skills, we ensure students also understand how to leverage cutting-edge technologies and tools to improve patient care. Our curriculum evolves alongside digital dentistry itself!"

Such sentiments echo the broader perspective in the medical education community, where new topics like digital dentistry are making their way into the curriculum, reflecting the advancements in the field. Meanwhile, traditional subjects, which once relied solely on textbooks and hands-on practice, are now enriched with digital tools and simulations, making the learning experience more immersive and comprehensive.

In conclusion, the evolving curriculum content, influenced by digitalization, underscores the need for medical educators to stay abreast of technological advancements. It's not just about introducing new tools; it's about integrating them in a way that enhances the learning experience, ensuring that the doctors of tomorrow are equipped to serve in a digitized world.

Tool selection & integration in medical education

Incorporating digital tools into the medical curriculum is a nuanced endeavor, driven by a blend of strategic considerations and pedagogical imperatives. This fusion ensures that the selected tools align with the curriculum's objectives, are easily accessible to students, and add genuine value to the learning experience.

Person D, a faculty member with experience in both medical biotechnologies and clinical practice, sheds light on this intricate process:

> "As a faculty member, there are several key factors I consider when deciding which digital tools or technologies to incorporate into the medical curriculum. Learning objectives, ease of use, and cost are paramount. The goal is to judiciously integrate digital tools that are validated, easy to adopt, affordable, and truly enhance medical education based on student needs and curricular goals."

Expanding on this, person F, a faculty member in medical cybernetics, delves deeper into the criteria that influence tool selection:

> "Deciding which digital tools to incorporate into a medical curriculum requires careful consideration of several factors. Pedagogical value, faculty input, and student feedback are vital. Additionally, ensuring adequate IT resources and cybersecurity protections is crucial. By considering these key factors, medical schools can thoughtfully select and implement the digital solutions that will truly enhance teaching and learning."

These insights offer a comprehensive understanding of the multifaceted considerations that influence tool selection and integration in medical education. It's evident that the decision is not merely about keeping up with technology trends but ensuring that each tool serves a distinct purpose, aligning with the curriculum's objectives and enhancing the overall educational experience.

Integration challenges in medical education

The path to integrating digital tools into medical education, while replete with opportunities, is fraught with challenges. These hurdles span the gamut, from logistical to pedagogical. Yet, it's essential to understand and navigate them effectively to ensure that digital integration enhances, rather than hampers, the educational experience.

Person B, a seasoned medical educator with a focus on anatomy, provides a candid perspective on these challenges:

> "Integrating all these new digital tools certainly does not come without growing pains. One major challenge is the steep learning curve required to effectively utilize new technologies in the classroom. And with so many digital resources available, sifting through them to select the most impactful ones for my curriculum is an arduous process. While the potential educational benefits make integrating more technology appealing, I'd be remiss not to consider how much added time and effort is required. As seasoned as I am, teaching anatomy in the digital age comes with its fair share of growing pains. But I keep an open mind, hoping these tools will enrich my students' learning when thoughtfully implemented."

Expanding on this, person D, who hails from the department of medical biotechnologies, delves deeper into the multifaceted challenges faced:

> "Adopting new digital technologies in medical education brings both opportunities and challenges. Some of the main challenges faculty face include technical difficulties, costs, learning curves, and student over-reliance. Technical problems can disrupt classes, digital tools can be expensive to implement, and it takes time for both students and faculty to learn how to use new technologies effectively. Furthermore, students may become overly dependent on digital aids, losing vital skills like handwritten note-taking. Overall, while digitalization offers many benefits, it also comes with logistical, financial, ethical, and pedagogical challenges that medical schools must thoughtfully address."

These insights offer a comprehensive view of the intricate landscape of challenges posed by digital integration in medical education. While the potential of these digital tools is undeniable, their successful and effective integration requires a thoughtful, well-planned approach. Medical educators and institutions must strike a balance, ensuring that while they ride the digital wave, the core tenets of medical education remain unshaken.

Digital competence development in medical education

In today's digitally-driven healthcare landscape, the definition of competence for medical students extends far beyond traditional clinical knowledge. As digital tools permeate every facet of healthcare, from diagnostics to patient communication, the imperative for digital literacy becomes undeniable. Medical educators and institutions are increasingly recognizing the need to inculcate a robust set of digital competencies alongside foundational medical knowledge.

Person B, who brings a depth of experience in anatomy, elucidates on this evolving paradigm:

> "The rapid pace of technology in medicine absolutely requires students to develop new competencies alongside their anatomical knowledge. They need information literacy skills to navigate the vast expanse of online content, identify trustworthy sources, and critically evaluate digital resources. Technological competence, too, is paramount. It's vital for students to be proficient in using EHR systems, medical apps, and telemedicine technologies they'll encounter in practice. Yet, while technology offers myriad advantages, it cannot replace the intrinsic human skills that medicine demands. Thus, alongside digital literacy, students must cultivate excellent communication abilities, clinical reasoning, compassion, and bedside manner. The most effective physicians seamlessly blend human skills with digital competencies."

Building on this perspective, person F, a specialist in medical cybernetics, provides a comprehensive breakdown of the competencies essential for the modern medical student:

> "Absolutely, today's digitally-enabled healthcare environment necessitates that medical students develop competencies beyond traditional clinical knowledge. This includes proficiency in using electronic health records, CDSS, and mobile health apps. Data analysis skills have become indispensable, as is the ability to communicate effectively through digital mediums while retaining empathy. Familiarity with the clinical applications of AI, understanding cybersecurity principles, and the ability to guide patients in using consumer health technologies are all part and parcel of a holistic medical education in the digital age. Adaptability, curiosity, and a commitment to lifelong learning are essential traits, ensuring that students can navigate the evolving technological landscape with agility."

In essence, the spectrum of competencies demanded of medical students has broadened considerably. The challenge for medical educators is to strike a harmonious balance - ensuring that while students are adept in the latest digital tools and technologies, they do not lose sight of the human touch that remains at the heart of healthcare.

Future vision of digital integration in medical education

The horizon of medical education is shimmering with the promise of deeper and more nuanced digital integration. As the digital wave continues to wash over academia, medical educators anticipate a shift that's not just technological, but also pedagogical. Digital tools, previously seen as auxiliary or supplementary, are poised to become central to the curriculum, impacting everything from content delivery to assessment methods.

Over the next decade, medical schools are expected to harness emerging technologies such as augmented reality, virtual simulations, and AI-driven diagnostic tools to provide students with immersive and hyper-realistic learning experiences. These tools will offer students the chance to dive deep into complex medical scenarios, practice procedures, and refine their diagnostic skills in a risk-free environment.

> "Virtual and augmented reality simulations will become more immersive, interactive and realistic for clinical skills training. This will supplement learning at patient bedsides ... AI tutors will help personalize and reinforce learning for each student's strengths and weaknesses" (person A).

Also, boundary between clinical practice and digital learning is predicted to become even more fluid. Future medical students might find themselves moving seamlessly between virtual classrooms, simulated labs, and real-world clinical settings, equipped with digital tools that enhance their learning at every step.

> "The learning management systems will integrate seamlessly with hospital EHR systems to provide student access to real (de-identified) patient cases. This bridges classroom and clinical learning" (person B).

> "More use of virtual and mixed reality to enable remote interaction with instructors and collaboration with geographically dispersed peers in a shared simulated environment" (person C).

However, with these advancements come challenges. Medical institutions will need to invest in robust digital infrastructures, ensure data privacy and security, and continuously update their faculty's tech prowess. There's also challenge of keeping human touch alive in medicine, ensuring that while students are tech-savvy, they remain empathetic, compassionate healers. In essence, next five-10 years in medical education will be a dance between tradition and innovation, humanity and technology. Goal is to produce doctors who are not only clinically excellent but also digitally agile, ready to serve in a healthcare landscape that is ever evolving.

DISCUSSION

This study aimed to analyze how medical education programs have evolved in response to the digital transformation in healthcare. Using a mixed methods approach involving surveys, curriculum analysis, and faculty interviews, we uncovered several key themes related to the integration of digital technologies into medical education. Our survey results indicated that EMRs are viewed as the most significant achievement of digital medicine across faculty members at different career stages. This aligns with previous research highlighting the pivotal role EMRs play in streamlining clinical workflows, improving care coordination, and enhancing data-driven treatment decisions (Khurana et al., 2022). However, our finding that only 4% of beginner faculty emphasized telemedicine was surprising, given its exponential growth amid the COVID-19 pandemic (Sharma & Bhaskar, 2020). This highlights a potential gap between telemedicine's expanding real-world implementation versus its perceived value among medical educators.

Analyzing curriculum changes revealed a clear pattern of increasing modifications related to technology, informatics, data analytics. This substantiates conclusions from other studies that medical curricula are rapidly evolving to address the digital transformation in healthcare (Han et al., 2019; Hong et al., 2018; Secinaro et al., 2021). However, most changes were concentrated in certain specialties like biochemistry and biophysics, versus being distributed across all programs. This could indicate that specific fields like biomedical informatics are pioneering curricular updates, while more traditional domains lag behind. Our interview insights echoed this, with dentistry faculties reporting significant curriculum changes, while anatomy faculties described gradual integration.

Our faculty interviews provided rich insights into the opportunities and challenges of integrating digital technologies into medical education. A key theme was the need to re-evaluate pedagogical strategies in the digital age, as students increasingly rely on online resources and digital tools for learning. This aligns with studies emphasizing that technology integration efforts must be accompanied by modernizing teaching methods to effectively engage digitally-immersed students (Khurana et al., 2022; Kryukova et al., 2022). Interviewees also predicted that emerging technologies like virtual simulations and AI tutors would enable more personalized, immersive learning. Similar conclusions have been drawn in research envisioning how tools like augmented reality and intelligent adaptive learning systems could transform medical education (Aungst & Patel, 2020; Sorakin et al., 2022; Uzunboylu et al., 2022; Zhdanov et al., 2023). However, interviewees cautioned that over-dependence on technology could potentially impede development of core clinical skills and humanistic values. This validates concerns raised in literature about balancing technology in education with nurturing essential qualities like critical thinking, empathy, and communication (Han et al., 2019; Kay & Pasarica, 2019; Parker et al., 2017; Ragsdale et al., 2020). Overall, our interviews provide timely qualitative insights into the multifaceted impacts of digital integration in medical education. The perspectives shared help identify promising directions while also highlighting areas requiring careful navigation to ensure technology serves as an enhancing, not inhibiting, force.

Overall, our triangulation of surveys, curriculum analysis, and interviews provides a multidimensional perspective on evolution of technology-enabled medical education. Our findings substantiate conclusions from past studies on need for holistic curricular reform addressing new competencies required of digitally literate physicians (Khurana et al., 2022; Kryukova et al., 2022). Moving forward, further research should analyze outcomes of curriculum changes, to help refine best practices for integrating emerging digital tools in medical education.

CONCLUSIONS

The data presents irrefutable evidence that medical education is undergoing a metamorphosis catalyzed by the digital revolution in healthcare. While the core fundamentals remain unchanged, curriculum content has evolved to incorporate emerging technologies, informatics, data analytics, and digital literacy. Medical schools are also grappling with the strategic integration of novel tools for simulations, visualization, and active learning.

However, this transformation is not without its challenges. The analysis reveals myriad roadblocks spanning technical difficulties, high costs, learning curves, over-dependence on technology, and more. Yet, the imperative for digital competence development remains clear, though balanced with nurturing humanistic skills. As medical educators poignantly observe, tomorrow's physicians must blend digital proficiency with compassion and empathy.

The outlook is for more pronounced technology integration, with innovations like AI-powered personalized learning and mixed-reality simulations on the horizon. However, investing in robust digital infrastructure and continuous faculty development will be key for its success. Medical schools will need to strike a fine balance between harnessing technology to elevate learning while retaining the human touch that forms the crux of medicine.

In essence, while digitalization is transforming medical education, integration must be strategic and measured. The end goal is not merely creating digitally-literate but socially-challenged physicians. It is about leveraging technology to nurture clinicians that combine digital competency with human compassion - the healers of tomorrow.

Our study had some limitations that provide opportunities for further research. First, our survey and interviews involved a small sample size of faculty from one university. Expanding this to multiple institutions could uncover more varied perspectives and experiences. Second, we focused only on curriculum analysis without evaluating the impacts of these changes. Follow-up studies could build on our findings by directly assessing how curriculum modifications influence learning outcomes, skills development, and preparedness among medical graduates. Lastly, our study was cross-sectional, providing insights at one point in time. Longitudinal evaluations could elucidate how medical curricula continue to evolve alongside advancing healthcare technologies. Overall, while our study offers valuable preliminary insights, further research with larger samples, outcome evaluations, and longitudinal approaches could provide a more comprehensive understanding of this complex, multifaceted issue. The digital transformation of medicine shows no signs of slowing, and medical education must keep pace by continuously adapting and enhancing technology integration. Our findings lay the groundwork, but more work is needed to unravel the intricate relationship between digital innovation and optimizing medical education for the modern era.

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