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Empowering Healthcare through Comprehensive Informatics Education: The Status and Future of Biomedical and Health Informatics Education

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Objectives: Education in biomedical and health informatics is essential for managing complex healthcare systems, bridging the gap between healthcare and information technology, and adapting to the digital requirements of the healthcare industry. This review presents the current status of biomedical and health informatics education domestically and internationally and proposes recommendations for future development. **Methods:** We analyzed evidence from reports and papers to explore global trends and international and domestic examples of education. The challenges and future strategies in Korea were also discussed based on the experts' opinions. **Results:** This review presents international recommendations for establishing education in biomedical and health informatics, as well as global examples at the undergraduate and graduate levels in medical and nursing education. It provides a thorough examination of the best practices, strategies, and competencies in informatics education. The review also assesses the current state of medical informatics and nursing informatics education in Korea. We highlight the challenges faced by academic institutions and conclude with a call to action for educators to enhance the preparation of professionals to effectively utilize technology in any healthcare setting. **Conclusions:** To adapt to the digitalization of healthcare, systematic and continuous workforce development is essential. Future education should prioritize curriculum innovations and the establishment of integrated education programs, focusing not only on students but also on educators and all healthcare personnel in the field. Addressing these challenges requires collaboration among educational institutions, academic societies, government agencies, and international bodies dedicated to systematic and continuous workforce development.

Keywords: Medical informatics, Nursing Informatics, Education, Teaching, Recommendations

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I. Introduction

1. Importance of Biomedical Health Informatics Education

Health informatics, fundamentally driven by data, has emerged as a cornerstone of the contemporary digital era. A worldwide consensus exists regarding the urgent need to accelerate digital advancements in healthcare. Biomedical and health informatics (BMHI) uniquely integrates health and medical practice with elements of information science, technology, and socio-behavioral sciences, facilitating the management and dissemination of data within healthcare settings [1]. The widespread impact of information technology, heightened by challenges such as the coronavirus disease 2019 pandemic and demographic changes like aging populations, highlights the necessity for healthcare professionals to go beyond basic computing skills to develop proficiency in data management, expertise in advanced digital healthcare strategies, and a dedication to personalized care solutions [2,3].

The World Health Organization projects a daunting deficit of 18 million healthcare professionals by the year 2030 [4]. This scenario is especially acute in countries experiencing rapid aging, such as South Korea. The horizon of healthcare is poised to be reshaped by breakthroughs in artificial intelligence and robotics. The industry is on the cusp of transitioning from the rudimentary use of electronic health records to a more enriched engagement with health data to refine patient experiences. This amplifies the urgency for comprehensive BMHI educational frameworks, an aspect often neglected in traditional pedagogies. Recognizing that living entities are fundamentally information processors and that healthcare is innately data-centric, technological progress will drive the evolution of health informatics [5,6]. As healthcare transforms into a more digitized and integrated domain, professionals must have a deep understanding of informatics to ensure superior care delivery. A thorough grounding in BMHI is imperative for stimulating interdisciplinary collaboration, deciphering the nuances of modern healthcare systems, and catering to the expanding digital prerequisites of the field. This report aims to shed light on the definition and development process of biomedical and health informatics education and its global trends. Based on this understanding, the report proposes future strategies for developing BMHI education in South Korea.

2. Development of BMHI Education

The development of BMHI began with hospital information systems. As BMHI is a newly defined and evolving field, its terminology has evolved. Similar to the challenges of translating terms like “genome” into Korean, defining informatics can be complex. Initially, the term “medical informatics” was popular in the United States until 2000. The emergence of bioinformatics led to a shift towards a broader term that encompasses various healthcare and life science disciplines, transitioning from “medical informatics” to “biomedical informatics.” Currently, “biomedical informatics” is more commonly used in the United States, encompassing all areas, including healthcare, clinical practice, and biomedical research. Clinical informatics focuses on areas such as medicine, nursing, and dentistry, while other subfields include public health, imaging, and biomedical informatics [7].

Global efforts have been directed toward defining the BMHI curriculum. These initiatives began in 1973 when German organizations took the lead. By 1992, Europe had established guidelines through EDUCTRA. The International Medical Informatics Association (IMIA) developed competencies for nursing in 1998 [8]. In 2000, IMIA provided recommendations for health informatics programs [9], and the American Medical Informatics Association (AMIA) launched the 10×10 program in 2005. By 2012, AMIA had outlined the core competencies for BMHI [10]. Additional efforts included TIGER’s contributions to the clinical field curriculum [11] and AMIA’s collaborative efforts in 2015 and 2019. The Baccalaureate Education Community emphasized basic competencies in 2019 and shared insights from a master’s-level analysis in 2023 [12]. In 2021, the American Association of Colleges of Nursing introduced core competencies for nursing education [13].

II. Current Status of International BMHI Education

1. IMIA Recommendations

The IMIA, established in 1967, is a leading global organization in the field of medical informatics. It is dedicated to developing international standards for education in medical informatics and regularly issues relevant recommendations. The goals of the IMIA include improving education in medical informatics, strengthening resources, courses, and certifications to enhance expertise within the field. Since its 2000 recommendations, IMIA has released two updated versions aimed at supporting curriculum development, identifying core competencies, and promoting roles in healthcare. The 2022 version introduces eight domains and outlines a framework of six core competencies in BMHI [1]. Depending on one’s primary area of study, the emphasis may vary, such as

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recommending an increased focus on computer science for healthcare professionals (Table 1).

The IMIA defines three roles in the BMHI field. First, BMHI users possess a basic education that enables them to efficiently utilize information technology (IT) in their professional tasks. This foundational knowledge can be integrated into undergraduate courses. Second, BMHI generalists, who often have backgrounds in healthcare or BMHI, bridge the gap between BMHI technology and medicine. They define user requirements, guide software development, and implement medical information systems. A year of full-time study in computer science or BMHI-related subjects is essential for this role. Lastly, BMHI specialists are graduate-level learners focused on specific fields such as nursing or dental informatics. They develop innovative medical information processing techniques, teach, and conduct research. Achieving this level of expertise requires a master's or doctoral degree in BMHI, or a specialized program in another area. Specialist education should cover domains such as biomedical imaging, clinical research informatics, global health informatics, and translational bioinformatics.

2. AMIA Recommendations

Founded in 1989, AMIA has played a crucial role in shaping US medical informatics through its educational programs and policy initiatives. In the 2000s, AMIA expanded its focus to include the training of informatics professionals, launching fellowship and certification programs. Between 2009 and 2012, it focused on standardizing graduate-level biomedical informatics (BMI) education. In 2012, a white paper recommended replacing the term "medical informatics" with "biomedical informatics" to reflect its broader scope, which now includes the increasingly important field of genomics [10]. This white paper also defined core competencies for BMI graduate students, covering a range from foundational to advanced skills and outlining the comprehensive knowledge required to become an expert in BMI. The graduate program in BMI welcomes students from diverse academic backgrounds, including but not limited to medicine, biology, mathematics, computer science, physics, information or engineering, and cognitive or social sciences. The program aims to equip students from these varied fields with common foundational and procedural competencies [10] (Table 2).

AMIA has diligently worked to develop professionals who are well-versed in healthcare clinical practices. A notable achievement was the introduction of the clinical informatics subspecialty in 2009, which integrates medical expertise with information science [14,15]. Specialists in this area assess the needs of healthcare professionals, improve clinical processes, and collaborate with clinical information systems. To obtain certification in clinical informatics, candidates must understand medical knowledge, information science, the healthcare environment, the influence of information systems on medical decisions, the lifecycle of information systems, and how clinical systems affect users. The clinical informatics fellowship, overseen by the Accreditation Council for Graduate Medical Education (ACGME), requires a program director and three faculty members for training purposes. From 2013 to 2019, 1,983 individuals achieved certification, with the majority coming from internal medicine (37%). AMIA serves as a central hub for healthcare informatics training, offering a variety of programs, including fellowships and the 10×10 program, an online course that has attracted over 5,000 participants since its inception in 2005 [16]. As of September 2023, 84 US institutions were providing education in healthcare informatics. Among these, 65 were universities, predominantly offering master's programs. Additionally, 18 hospitals and 36 schools offered clinical informatics fellowships. Doctoral programs were also available, with 28 currently active. Notably, the fellowships primarily featured face-to-face learning, whereas master's programs frequently employed online or hybrid formats (Figures 1, 2).

Table 1. Major areas and core competency framework related to biomedical and health informatics (BMHI) defined by the International Medical Informatics Association

Disciplines related to BMHI	Core competency framework
Information science	BMHI core principles
Data science	Medicine and medical services
Computer science	Computers, data, information science
Engineering	Social & behavioral science
Basic science	Business administration
Health science	BMHI expertise
Social behavioral science	
Legal, ethical, policy fields	

Table 2. Summary of the core competencies recommended for graduate students specializing in biomedical informatics in the 2012 the American Medical Informatics Association White Paper [10]

Core competencies	Details
Basic scientific skills	Acquisition of professional perspective: reading and critiquing key literature, understanding/analyzing relationships with other fields. Problem analysis: Analyzing, understanding, abstracting, and modeling a specific problem in terms of data, information, and knowledge components. Solution generation: Analyzing a problem and designing a solution for it. Rationale: Comparison of specific solutions with corresponding competing options. Implement, evaluate, and improve Innovation Collaboration Education, dissemination, and discussion
Scope and breadth of the discipline	Essential knowledge and skills: Knowledge of biological, medical, and population health concepts and general research problems. Basic knowledge: Understand the basics of biomedical data, information and knowledge. -Biology: Molecules, sequences, proteins, structures, functions, cells, tissues, organs, organisms, phenotypes, populations -Translational and clinical research: genotypes, phenotypes, pathways, mechanisms, samples, protocols, studies, topics, evidence, evaluation -Medical: examination, diagnosis, test results, prognosis, treatment (drugs, procedures), prevention, billing, medical team, quality assurance, safety, error reduction, comparative validity, medical records, personalized medicine, health economics, information security, privacy -Personal health: patient, consumer, provider, family, health promotion, personal health record -Population health: detection, prevention, screening, education, instrumentation, spatiotemporal patterns, health ecology, well-being Procedural knowledge and skills: Apply, analyze, evaluate, and generate solutions to practical problems related to scientific inquiry, problem solving, and decision making.
Theory and Methodology	Theory: Understand and apply syntactic, semantic, cognitive, social, and pragmatic theories used in biomedical informatics. Typology: Understanding and analyzing the types and nature of biomedical data, information, and knowledge. Framework: Understand and apply conceptual frameworks commonly used in biomedical informatics. -Modeling approach (belief network), programming approach (object-oriented), representation method (problem space model), or architecture (web service), etc. Knowledge representation: Encoding domain concepts and relationships using computable definitions. Methods light processes: Understand and apply methods and processes used in various contexts in biomedical informatics.
Technological approach	Prerequisite knowledge and skills: data structures, algorithms, programming, mathematics, statistics. Basic knowledge: Understand and approach technical approaches in the context of biomedical problems. -Imaging and signal analysis -Documenting, storing and retrieving information -Machine learning, including data mining -Networking, security, database -Natural language processing, semantic technology -Expressing logical and probabilistic knowledge and reasoning -Simulation and modeling software engineering Procedural knowledge and skills: Understand and apply inquiry methods and criteria for selecting and utilizing algorithms, techniques, and methods for practical problems.

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Table 2. Continued

Core competencies	Details
Human and social context	Required knowledge/skills: Knowledge of social, organizational, cognitive and decision science fundamentals. Basic knowledge: design, evaluation, social-behavioral communication and organizational science, ethical-legal-social issues, biomedical research, pharmaceutical and biotechnology industry, medical devices, economic and social-organizational context of medicine and public health. Procedural knowledge and skills: Apply, analyze, evaluate, and create systems approaches to solving practical problems in biomedical informatics. -Analysis of complex biomedical informatics problems in terms of people, organizations, and socio-technical systems -Understand the challenges and limitations of technology solutions -Design and implement systems approaches to biomedical informatics applications and interventions. -Impact of bioinformatics applications and interventions on people, organizations, and socio-technical systems evaluation

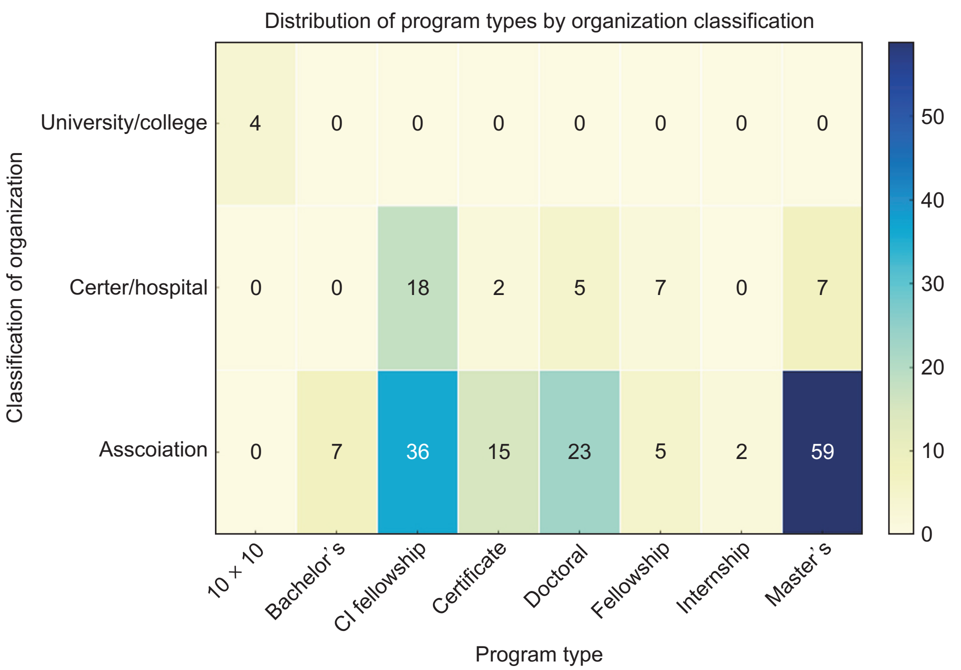

Figure 1. Degree levels according to organizations operating medical information curricula that are registered with the American Medical Informatics Association.

3. Other Cases in Europe

European health informatics education varies, complementing approaches from IMIA and AMIA. While these organizations primarily address postgraduate students, some countries have focused on integrating informatics training during or after medical school. Tudor Car et al. [17] evaluated health informatics courses for medical students through a literature review. Out of 34 documents, 59% incorporated health informatics as elective courses, primarily centered on medical informatics. These courses typically spanned the first 3 years of medical school, lasting 1–3 hours weekly. 18% of these courses were online, and a significant 88% reported competency improvement after course completion. The approach to training healthcare professionals seems consistent internationally but varies in structure and certification. In the UK, similar to Korea, postgraduate medical training incorporates health informatics for both interns and specialists. Jidkov et al. [18], in a 2019 study, explored health informatics implementation across 71 specialties. The study found that out of 50 core competencies, 29 were covered in various specialties. Pathology included the most, at 16 (32%), but many specialties, such as surgery, barely touched upon health informatics. The authors proposed a general health informatics education curriculum applicable to training subjects, as shown in Table 3 [15,17-29].

Furthermore, European initiatives such as the ERASMUS+

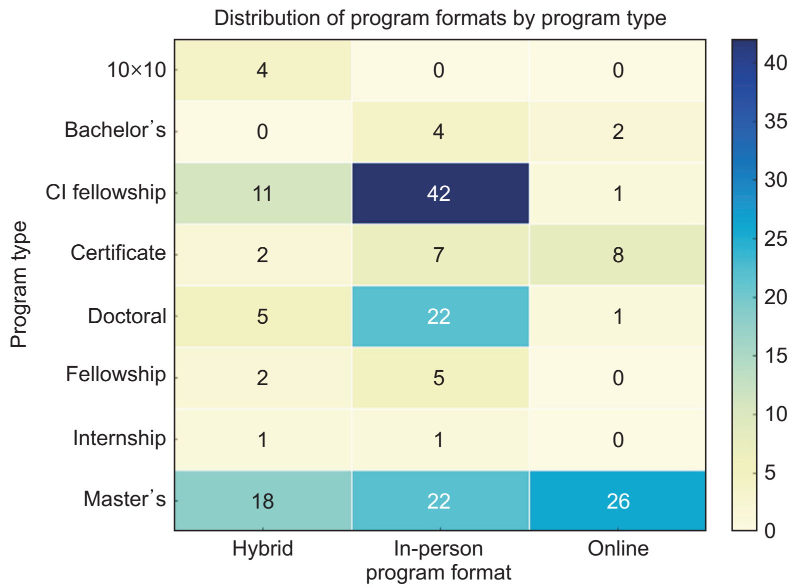

Figure 2. Education provision methods of the medical information degree programs registered with the American Medical Informatics Association.

program support educational projects in the field of health informatics. Alliances like CIVIS, a European Civic University, offer programs related to biomedical and health informatics, including special summer programs. Approximately 1,900 educational institutions offer 180,000 programs, with about 1,000 specialized programs designed for BMHI experts [30]. The Healthcare Informatics and Management Systems Society provides resources and programs in health informatics education, including a Certification for Professionals in Healthcare Information and Management Systems (CPHIMS).

4. Cases of Nursing Informatics Education

In the global healthcare environment, with the widespread adoption of information and communication technology, nurses are encouraged to utilize IT to uphold core values such as health equity and patient safety [31,32]. In 2013, AMIA projected that as many as 70,000 health informatics professionals would be required in the United States [33]. According to the job information website Zippia, approximately 12,534 informatics nurses are currently active in the United States as of 2023 [34]. Additionally, about half of these informatics nurses hold master's degrees, and 27% possess degrees in nursing informatics [35]. The United States has established the most systematic education in nursing informatics, whereas countries like Canada, Australia, Europe, and Japan have relatively limited educational opportunities in this field (Table 4).

III. Current Status of BMHI Education in Korea

1. Medical Education

Medical informatics education in Korea began in 1987 with the establishment of the Korean Society of Medical Informatics (KOSMI). Since then, in collaboration with KOSMI, several medical schools have created departments of medical informatics and have developed graduate programs that train professionals, following a model similar to that of the United States, which requires significant coursework or full-time study in BMHI. In response to the growing need for enhanced informatics skills among current healthcare practitioners, KOSMI launched the Certification for Physicians in Biomedical Informatics program in 2012 [36]. Designed specifically for physicians, this 18-month program includes formal coursework covering a range of topics from basic programming and biostatistics to artificial intelligence and genomics. The curriculum also emphasizes practical skills in Python, SQL, and R programming. Additionally, it incorporates clinical system rotations, research projects, conference participation, and journal presentations. Candidates who successfully pass the final exam receive an official certification. From 2018 to 2022, the Ministry of Health and Welfare supported the precision medical workforce development program. This initiative, which is centered around real clinical settings, addresses six key data topics, including electronic health records and genomics. The Certified Medical Informatics Expert program, another significant effort, has been effective in developing skilled informatics professionals across various disciplines. Due to the increasing demand for

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Table 3. International cases of nursing informatics education

Country	Nursing informatics education
United States	The first graduate program in nursing informatics was established at the University of Maryland in 1988, followed by the University of Utah [19]. In 1992, the American Nurses Association (ANA) designated nursing informatics as a nursing specialty, with practice scope and standards documented in 1994–1995 [20]. The American Nurses Credentialing Center (ANCC) offers the Informatics Nursing Certification (RN-BC), accredited by both the American Board of Nursing Specialties and the National Commission for Certifying Agencies. ANCC Certification is the only accredited informatics nursing certification in the United States, open to foreigners. The exam covers practice-based content, system design lifecycle, data management, and health IT. Upon meeting the qualification requirements (BSN, 2 years of RN experience, and informatics-related education) and passing the exam, the "Registered Nurse - Board Certified" credential is granted for 5 years. According to ANA, an informatics nurse specialist, having received graduate education, is distinct from an informatics nurse working in the field of nursing informatics. They serve in roles such as executives, managers, analysts, consultants, and educators. The heightened awareness of the need for informatics competencies after the 2006 "TIGER Initiative - Informatics Competencies for Every Practicing Nurse" [21].
Canada	In 2009, the University of Victoria introduced the first dual-degree graduate program in nursing and health informatics. This program offers graduate courses in nursing and health informatics, along with industry experience opportunities. Other universities in Canada offering a master's program in nursing informatics include University of Arkansas Grantham, East Tennessee State University, Thomas Jefferson University, Grand Canyon University, Western Governors University, and South University. A 2003 survey revealed that less than a third of 77 schools offered a course in nursing informatics [15]. Since then, the number of nursing informatics education and certification programs at both undergraduate and graduate levels has increased. The Canadian Nurses' Association and the Academy of Canadian Executive Nurses emphasize the informatics competencies of nursing leaders for the advancement of the healthcare system [17,18]. The Canadian Association of Schools of Nursing developed learning tools and resources like the Nursing Informatics Teaching Toolkit to enhance the informatics competencies of undergraduate nursing students [22].
Australia	A 1993 survey of all nursing colleges found that the challenges in teaching were lack of time, technical support, faculty capability, and appropriate software [23]. In 2017, the Health Informatics Society of Australia, Nursing Informatics Australia, and the Australian College of Nursing (ACN) partnered to develop a position statement on nursing informatics. This statement emphasizes the critical role of nurses in the digitization of healthcare and calls for optimized technology use for improved patient care [24]. In 2019, the ACN advocated for the establishment and expansion of the role of Chief Nursing Informatics Officer (CNIO). The CNIO is emphasized to possess the expertise necessary to support and lead the successful planning, implementation, and management of digital technologies and new management models across all healthcare settings [25].
New Zealand	In 1991, a national nursing informatics group, Nursing Informatics New Zealand (NINZ), was formed and published guidelines for nursing informatics. Subsequently, NINZ collaborated with the New Zealand Health Informatics Foundation to form Health Informatics New Zealand (HiNZ) [26]. From 2016, a 2-year project was initiated to develop guidelines for the informatics competencies of New Zealand nurses, resulting in the publication of "The Guidelines: Informatics for nurses entering practice" [27]. This project suggested four principles: professional practice, information management, ICT to enhance the health of New Zealanders, and general computer and ICT skills.

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Table 3. Continued

Country	Nursing informatics education
Europe	In 1996, the European Union initiated the NIGHTINGALE project for 36 months to understand the status of nursing informatics in Europe and develop a nursing informatics curriculum for clinical nurses and nursing students. The project surveyed the Netherlands, Sweden, France, Portugal, Germany, and Belgium, finding that out of 34 nursing colleges, 20 (59%) had a course in nursing informatics [28]. In Denmark, nursing education curriculum is determined at the national level by the Ministry of Education. According to the Departmental order 29, the nursing degree program includes theoretical and clinical/technical advancements: nursing terminology, structure of digitized nursing formats, EMR, clinical databases, digitized communication with patients/hospitals/primary healthcare institutions, etc.
Japan	In 2004, the Japanese Nurses Association published a standard textbook for nursing informatics as part of lifelong education forward managers. This was primarily used by clinical nurses working with hospital information systems. Informatics nursing education is mainly conducted in hospitals, with nurses actively participating in committees or working groups. Most of these nurses are involved not only in nursing-related tasks but also in medical information-related tasks. As of 2021, out of 65 universities where lecture plans are searchable, 13 universities operate nursing informatics courses. Twenty-four master's programs include nursing informatics. Topics covered include personal information protection and information ethics, information utilization in nursing, information systematization methods, organizational management and information management, quality assurance and information utilization in nursing services, and information utilization for evidence-based practice in nursing [29].

ICT: information and communication technology; EMR: electronic medical record.

Table 4. Areas and contents of medical informatics competencies required for doctors proposed in the UK

Field	Content
Information governance & security	With the rise of digital technologies, modern, clinically relevant governance (e.g., gray areas such as use of personal mobile devices to exchange patient information); practical cybersecurity knowledge (e.g., identifying email phishing scams, implications of security breaches, etc.).
System use & clinician safety	Utilization of EMR with emphasis on electronic prescriptions in routine clinical care. Ability to critically evaluate new technologies and recognize the effectiveness of system design. In hardware evaluation, clinicians must also be aware of the hardware's implementation plan in clinical practice by knowing how to adjust the battery life or infection control requirements of the hardware so that the hardware can be introduced into clinical practice.
Digital communications	Transfer and retrieval of digital patient data, including care sharing, data protection and security. Increased frequency of remote work (e.g., knowledge of remote data management and hardware use required when working from home). Understand the risks of under-communication (assuming others know) and over-communication (such as alarm fatigue).
Information & knowledge management	Understanding the characteristics of different media. Decision support. Secondary use of data (understanding digital data records, such as understanding terminology and nomenclature to capture high-quality data.
Patient empowerment	Helping patients utilize appropriate informatics resources to improve their health. Determine whether patients' use of social media, etc., affects their health. See how patient choice and engagement are affected by digitalization.
Emerging technologies	Keep up with rapid technological developments and updates. Doctors will check the direction of future medical technology development and plan how to utilize them in daily care.

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information science in medical academia, numerous medical schools have expanded their informatics courses within undergraduate curricula. In 2022, KOSMI established a consortium comprising major medical school departments to enhance collaboration and advance medical informatics education. This consortium aims to create a foundational, mandatory curriculum designed to cultivate IT-proficient physicians. Initial actions included surveys to assess the distribution of informatics-related courses across medical schools. Data analysis and medical statistics were identified as the most prominent subjects, followed by medical informatics and artificial intelligence. Courses such as medical statistics and electronic medical records have become standard offerings in many schools.

2. Nursing Education

The history of nursing informatics education in Korea dates back to the 1990s, when it was first introduced at several universities in Seoul. However, a low demand for nursing informatics majors and a shortage of qualified faculty in this field limited its expansion. In 2021, the Korean Accreditation Board of Nursing Education incorporated the "utilization of information and communication technology and new healthcare technology" into the program outcomes of nursing education during its fourth accreditation evaluation.

Research on nursing informatics education programs includes studies such as the analysis of the status of nursing informatics education in 2000 by Park et al. [37], and the development of a standard curriculum for nursing informatics in 2007 by Yom et al. [38]. More recent studies include research on nursing education programs in 2016 by Jeon et al. [39], and an analysis of the current status and curriculum of nursing informatics education conducted by the Nursing Informatics Special Working Group of KOSMI in 2020 [40].

An analysis of educational trends indicates an increase in undergraduate programs focused on nursing informatics [41]. Initially, the courses offered to first-year students have now expanded into specialized courses aimed at third and fourth-year students. However, the proportion of elective courses, as opposed to mandatory ones, remains high (Table 5). Challenges in nursing informatics education include a shortage of educational materials, insufficient university recognition of the subject's importance, and difficulties in conducting practicums. A survey of educators' needs highlighted a demand for training in information system utilization and the latest information and communication technologies. There was also a strong call for the standardization of educational programs and the sharing of educational practices.

Table 5. Trends in undergraduate nursing informatics programs (unit: %)

Item	2000 (n = 77)	2016 (n = 72)	2020 (n = 60)
Offering nursing informatics class			
Yes	20.8	52.8	83.0
Year of class			
First	43.7	2.6	3.8
Second	37.5	23.8	32.0
Third	6.3	31.6	30.2
Fourth	6.3	36.8	34.0
Required course			
Yes	-	31.6	21.2
Number of credits			
1	12.5	21.0	24.0
2	75.0	71.1	68.0
3	12.5	2.6	8.0

To meet the demands of both practice and educational settings, the Nursing Informatics Special Working Group of KOSMI has been developing learning objectives for undergraduate programs since 2019 and recommended these guidelines nationwide in 2022 [41] (Table 6).

IV. Discussion

1. Challenges and Strategy for Medical Education

The digitization of the healthcare field is an irreversible trend, and advances in artificial intelligence are accelerating this transformation [42]. Consequently, there is an urgent need for medical informatics education across the entire healthcare and welfare workforce [43]. This underscores the importance of not only enhancing digital literacy but also strengthening the skills needed to utilize digital technology beyond mere data handling capabilities [44]. Additionally, even in a digitized healthcare environment, deep empathy and compassion for patients remain crucial values, and education in these areas should be emphasized [45]. Furthermore, addressing ethical and legal issues arising from the use of digital healthcare technologies requires the development of effective strategies and policies. Future developments and strategies will make it possible to nurture healthcare professionals who are well-adapted to the digitized healthcare environment [46]. The development of both technical competencies and the cultivation of human values and ethical considerations are essential for the training of healthcare

Table 6. Standardized curriculum recommended by the Nursing Informatics Special Working Group [41]

Domain	Main category	Subcategory
Introduction of nursing informatics	1. Overview of biomedical health informatics (BMHI)	History of BMHI Scope of BMHI
	2. Overview of nursing informatics (NI)	Concepts of NI History of NI NI competencies
	3. Healthcare data and data science	Healthcare data Big data Data science
	4. Standardized terminologies	Information standards Standardized nursing terminologies
	5. Protecting personal health information (PHI)	Law and ethics in PHI Scope and technology in PHI
	6. Health information systems	Understanding health information system Use of health information system
Nursing informatics applications: nursing practice	7. Nursing information system	Understanding nursing information system Use of nursing information system
	8. Clinical decision support system	Understanding the clinical decision support system Use of clinical information system
	9. Information technology in evidence-based nursing	Information technology to support evidence-based nursing Information technology to support practice-based evidence
	10. Nursing informatics in community and population health	NI in community and population health nursing
	11. Digital healthcare	Social media and patient participation Telehealth Mobile healthcare
	12. Human-technology interface	Applying user-centered design Improving user experience
Nursing informatics applications: nursing administration, research and education	13. Information technology in nursing administration	Nursing administration system Nursing resource management system Patient safety and quality system
	14. Information technology in nursing research	Literature review and research problem Collecting and managing data Processing and analyzing data
	15. Information technology in nursing education	Understanding digital educational technology Use of digital educational technology in nursing education
	16. The future of nursing informatics	Technology trends and future perspectives

professionals. Amidst these changes, healthcare professionals must possess both technical skills and human values, along with the ability to make ethical judgments.

Traditional medical education has long focused on patient care, disease diagnosis, and treatment methods, a system that has been in place for centuries [47]. This approach is deeply rooted in the historical philosophy of medicine. However, the healthcare landscape in the 21st century is increasingly defined by digitization and the extensive use of data. In particular, the rise of artificial intelligence underscores the need for healthcare professionals to move beyond mere knowledge acquisition. It encourages a deep understanding of underlying principles, the ability to apply knowledge effectively, and the recognition of the importance of lifelong learning [48]. Despite these shifts, many educational institutions have yet to fully adapt to these changes. Future medical education must prioritize a variety of curriculum innovations and the development of integrated education programs. These should focus not only on students but also extend to all healthcare personnel in the field. Additionally, while it is important to develop technical skills among healthcare professionals, there should also be a strong emphasis on improving communication and empathy skills with patients. Education should not overly depend on artificial intelligence and digital technology; instead, it is vital to uphold an educational philosophy that prioritizes person-centered healthcare services and remains adaptable to change.

2. Challenges and Strategy for Nursing Education

The history of nursing informatics education in Korea, introduced in 1987 and initiated at some universities in Seoul in the late 1990s, has experienced limited expansion. The primary barriers have been the low demand for nursing informatics courses at universities and a limited number of scholars in the field. These factors have contributed to a shortage of qualified faculty and inadequate educational environments. Significant improvements at the level of individual universities would require considerable time. Consequently, nursing informatics professionals are collaborating to pool their expertise to support future educators in the field. The Nursing Informatics Special Working Group within KOSMI serves as an exemplary collaboration among experts from academia, industry, and various healthcare stakeholders. However, reliance on individual enthusiasm or short-term academic support is insufficient. A systematic policy development for future healthcare informatics education is essential and should be implemented at the governmental level.

The nursing informatics competencies outlined by Staggers et al. [49] in 2002 include computer skills, informatics knowledge and skills, human information processing skills, and information management competencies. These competencies are divided into four levels: beginning nurses, experienced nurses, informatics specialists, and informatics innovators. An informatics specialist at the master's level is expected to possess advanced knowledge and skills in information management and computer skills, and should be capable of understanding information needs, managing data, and utilizing knowledge and tools. At the Ph.D. level, an informatics innovator should be equipped to conduct informatics research, generate theories, and creatively present a vision for the development of informatics utilization. These competency levels are crucial for the development of educational programs at the undergraduate, master's, and Ph.D. levels. The recent inclusion of informatics competency in nursing program outcomes by the Korean Accreditation Board of Nursing Education has heightened interest in nursing informatics across universities [50]. However, it lacks clear criteria regarding the specific content to be included in the outcomes, the interconnection of courses, instructors' qualifications, and how the content should vary by academic year.

The Nursing Informatics Special Working Group of KOSMI has developed standardized curriculum guidelines. Further efforts are required to classify the content within the curriculum and to develop measurable learning outcomes. In terms of program outcomes, there should be a focus on skill development within the domains of knowledge, attitudes, and skills. Students should have opportunities to acquire and internalize the latest technology through practicum experiences. For instance, education on nursing records can be facilitated using electronic medical record systems. Additionally, simulation training environments should be made available, enabling students to search and explore clinical data, understand patient conditions, and apply the nursing process.

In conclusion, to advance BMHI education, a roadmap for the following challenges is needed. First, there should be a shared understanding of how the information competencies of healthcare professionals can reduce medical errors, improve patient safety, and increase job satisfaction. Second, given the rapid advancement of information technology and evolving demands in the field, educational programs must be updated regularly and in a timely manner. Third, the development of leadership, particularly at the doctoral level, is vital. Leadership skills that foster change and innovation are just as critical as technical competencies. Fourth, as healthcare information technology finds applications across various domains, it is important to improve the basic competencies of existing professors in healthcare information. Additionally, there is an urgent need to train educators who specialize in health informatics. Addressing these challenges will require collaborative efforts among educational institutions, academic societies, government agencies, and international organizations.

Conflict of Interest

Kye Hwa Lee and Mona Choi are editors of Healthcare Informatics Research; however, they were not involved in this article's peer reviewer selection, evaluation, and decision process. Otherwise, no potential conflict of interest relevant to this article was reported.

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