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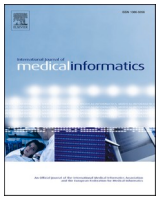

Recommendations of the International Medical Informatics Association (IMIA) on Education in Biomedical and Health Informatics: Second Revision

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ABSTRACT

Background: The purpose of educational recommendations is to assist in establishing courses and programs in a discipline, to further develop existing educational activities in the various nations, and to support international initiatives for collaboration and sharing of courseware. The International Medical Informatics Association (IMIA)

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has published two versions of its international recommendations in biomedical and health informatics (BMHI) education, initially in 2000 and revised in 2010. Given the recent changes to the science, technology, the needs of the healthcare systems, and the workforce of BMHI, a revision of the recommendations is necessary.

Objective: The aim of these updated recommendations is to support educators in developing BMHI curricula at different education levels, to identify essential skills and competencies for certification of healthcare professionals and those working in the field of BMHI, to provide a tool for evaluators of academic BMHI programs to compare and accredit the quality of delivered programs, and to motivate universities, organizations, and health authorities to recognize the need for establishing and further developing BMHI educational programs.

Method: An IMIA taskforce, established in 2017, updated the recommendations. The taskforce included representatives from all IMIA regions, with several having been involved in the development of the previous version. Workshops were held at different IMIA conferences, and an international Delphi study was performed to collect expert input on new and revised competencies.

Results: Recommendations are provided for courses/course tracks in BMHI as part of educational programs in biomedical and health sciences, health information management, and informatics/computer science, as well as for dedicated programs in BMHI (leading to bachelor's, master's, or doctoral degree). The educational needs are described for the roles of BMHI user, BMHI generalist, and BMHI specialist across six domain areas – BMHI core principles; health sciences and services; computer, data and information sciences; social and behavioral sciences; management science; and BMHI specialization. Furthermore, recommendations are provided for dedicated educational programs in BMHI at the level of bachelor's, master's, and doctoral degrees. These are the mainstream academic programs in BMHI. In addition, recommendations for continuing education, certification, and accreditation procedures are provided.

Conclusion: The IMIA recommendations reflect societal changes related to globalization, digitalization, and digital transformation in general and in healthcare specifically, and center on educational needs for the healthcare workforce, computer scientists, and decision makers to acquire BMHI knowledge and skills at various levels. To support education in BMHI, IMIA offers accreditation of quality BMHI education programs. It supports information exchange on programs and courses in BMHI through its Working Group on Health and Medical Informatics Education.

1. Introduction

The initial 2000 version [1] and the revised 2010 version [2] of the Recommendations of the International Medical Informatics Association (IMIA) on Education in Biomedical and Health Informatics have been widely used to guide curricula and establish international benchmarks for biomedical and health informatics (BMHI) educational content. Given the dynamic progress and evolution in the field of BMHI, which were accelerated during the COVID-19 pandemic, IMIA leadership concluded that the recommendations should be revisited regularly and revised, if required, to align with the current needs and future developments of BMHI.

The revised version, presented here and referred to as the second revised version, is based on the first revised version [2] of the recommendations and the work published since those recommendations.

Evidence continues to highlight the strong association between health information technology (HIT) and improvements in the delivery of healthcare and public health, and the conduct of biomedical research. Several recent systematic reviews have documented the evidence in favour of clinical decision support [3,4], telehealth [5–7], artificial intelligence and machine learning [8–11], Internet of Things [12], precision healthcare [13–15], participatory health [16], leading to the pervasive adoption of HIT [17]. In addition to a growing range of research and application fields in BMHI, there is also growth in the different sub-areas of BMHI, such as clinical research informatics [18,19], translational bioinformatics [20–22], and clinical informatics [23]. The growth of IT in healthcare delivery [24,25] has also led to the recognition of the need for educational programs to train both the healthcare and informatics workforce to collaboratively develop, implement, and evaluate these systems; this need has been recognized worldwide [26,27]. Studies have also highlighted challenges associated with HIT, such as workflow disruption [28], additional time taken to perform activities [29], and its association with clinical burnout [30].

Further, the use of information and information technology application of BMHI in healthcare has been referred to as eHealth [31] and more recently digital health [32–34]. Both terms are widely used in the implementation and application of information and communication technology (ICT) in healthcare, supported by the increasing use of mobile devices, telehealth, and personalized healthcare.

1.1. Why do we need BMHI?

The World Health Organization has highlighted the escalating divergence between the existing and required health workforce, predicting a global shortage of 18 million workers to achieve the health-related sustainable development goals by 2030 [35]. The healthcare environment in most countries is experiencing significant change – changing population health needs, the prominence of universal health coverage, multitasking of clinicians, and evolving care delivery models – and preparing a competent workforce to deliver safe and effective services is a priority [35]. The increasing use of digital health technologies has the potential to address these escalating challenges whilst also strengthening person-centred care and health workforce capacity [35]. Several countries have instituted reviews to address how they prepare a digitally ready health workforce. Specifically, the recent Topol review forecast that 90% of all healthcare positions in the United Kingdom (UK) within the next two decades will require digital skills to some extent [36], and this will only compound the significant challenges facing the recruitment of staff in an environment that is undergoing widespread digital transformation. Quality BMHI education will be needed to augment a digitally ready workforce capable of adopting and adapting new technologies to improve healthcare outcomes.

The potential of BMHI is far from being reached today. Despite documented benefits and expectations, there are still shortcomings regarding the clinical application of BMHI. Lack of implementation of international standards and semantic interoperability hamper patient-centric care [37] and represent obstacles to truly digitalized workflows [38]. Further, clinicians often perceive existing clinical information systems as cumbersome and disruptive rather than supportive of their work. Increasing the evidence base of describing the benefits and limitations of HIT, and using this evidence to further develop and implement HIT in clinical practice, still requires further research.

The situation in biomedical research is similar. Biomedical research requires integrating and/or linking data for an increasing number of different modalities. BMHI provides the foundations to access, manage, and visualize these data, and thus plays an essential role in data-driven

healthcare and biomedical and clinical research [39].

Another barrier that still exists in 2022 in some countries is the lack of characterization of the BMHI workforce and its required training to most effectively implement and maintain ICT systems [40–42]. Australia has recently responded to this lack of empirical evidence regarding the BMHI workforce by initiating a triennial workforce census. The 2018 data revealed that most workers within the field do not have any formal education in BMHI. Nearly a quarter approach their role alongside another health-related role, many are relatively early in their BMHI career, and the broad range of position titles and functions highlights the breadth within this workforce [43]. Countries of the Gulf Cooperation Council (GCC) have also experienced this lack of characterization of the workforce, adopting a 'career pathway skills model' whereby training and an annual conference are provided to a range of healthcare providers to create sustainable careers in BMHI [44].

An additional challenge is posed by the various definitions of the field of BMHI [17,45,46]. The field has difficulty agreeing on the adjective in front of the word informatics (i.e., medical, biomedical, and/or health) and on whether a practitioner should be called an informaticist or informatician (this paper uses the latter). The use of digital health has also gained traction in some countries, replacing the word informatics altogether. This paper, however, will use the term BMHI in all instances. Challenges also exist in appreciating where pure ICT ends and BMHI begins. For example, the individual who installs applications on a desktop computer in a hospital probably does not need formal training in BMHI, although the Chief Information Officer and project leaders certainly do. This distinction led to calls for BMHI to become a professional discipline nearly-two decades ago [47] and for it to acquire the attributes of a profession, such as a well-defined set of competencies, certification of fitness to practice, shared professional identity, life-long commitment, and a code of ethics [48].

1.2. Key principles of the recommendations

The purpose of these educational recommendations is fourfold - to support educators in developing BMHI curricula at different education levels, to identify essential skills and competencies for healthcare professionals and others working in the field of BMHI to certify their abilities to support the development and implementation of BMHI in healthcare, to provide a tool for evaluators of academic BMHI programs to compare and accredit the quality of delivered programs, and lastly, to motivate universities, organizations, and health authorities to recognize the need for establishing and further developing BMHI educational programs.

BMHI Curriculum Development.

Developing BMHI programs or courses require a curriculum aim, learning outcomes, content aligned to the skills and competencies necessary, a description of the intended implementation, resources and tools to deliver the program, and a detailed evaluation and quality assurance process.

BMHI Workforce Certification.

Developing certification procedures for specific BMHI skills and competencies amongst developers and/or the healthcare workforce requires an aim, a description of the target audience, curriculum content focused on the needs and scope of the specified audience, and a delivery platform that assures objective and quality procedures.

BMHI Program Accreditation.

Developing accreditation mechanisms for BMHI academic programs requires an internationally recognized body to ensure the objectivity, transparency, high academic recognition of the accreditors, and professional procedures across the entire process. The current IMIA educational recommendations play an essential role in mapping curricula content against internationally endorsed BMHI concepts.

The publication of revised versions of educational recommendations supports IMIA's Health and Medical Informatics Education Working Group in their goal of disseminating and exchanging information on BMHI programs and courses and augments IMIA's accreditation initiatives established in the last decade.

1.3. Entry into BMHI education

The nature of BMHI attracts both healthcare and ICT professionals as specialists to a highly interdisciplinary field. This necessitates an understanding of the complexity and diversity of the healthcare environment, as well as the complexity of managing data, information, and knowledge. ICT professionals further need to gain insight into clinical work processes and clinical decision making. Healthcare professionals, on the other hand, need to grasp the opportunities and limitations that ICT can bring to healthcare [17,49]. While some countries have recognized that education and training provided to the current and future workforce requires restructuring to meet the existing and emerging digital requirements, there is not always clear guidance on how it should be delivered.

There are several ways to enter BMHI education in different countries around the world, with the most common pathway being postgraduate (master's and doctoral programs) following completion of a bachelor's degree in health informatics or related degree in healthcare (e.g., medicine, nursing, pharmacy, psychology), life sciences, cognitive science, computer science and information technology, health information management, and others, with associated work experience [46,50–58]. Some countries are actively promoting practical training courses centred on actual data and procedures other than degree courses, focusing on theory, practice, and interdisciplinary team projects to train people with various majors (engineering, pharmacy, or other majors and medical fields) to become BMHI experts [59]. Another pathway gaining popularity in the United States (US) is fellowship-style training, such as physicians entering the clinical informatics subspecialty, who may or may not obtain a degree in the process [46].

1.4. Learning approaches to BMHI education

Historically, the traditional lecture style of teaching in a university program dominated the learning space and pedagogical approaches in BMHI teaching, however several competing demands have begun to change how the contemporary BMHI workforce can learn the discipline, particularly if already a practising professional. Certainly, the tensions and learning challenges caused by the COVID-19 pandemic created both an urgent pivot to and an opportunity for innovative modes of educational delivery. The practical importance, however, of designing, developing, and implementing BMHI technologies and scenarios in an interdisciplinary fashion (e.g., in a clinical, vendor or government setting) cannot be understated [26,51,60–62]. Current BMHI education includes a variety of learning approaches (Textbox 1).

Most countries have no formal requirements regarding qualifications for teachers of BMHI, while others have standardized the academic credentials of BMHI educators. In most instances, whether at universities, colleges, or through continuing professional development offerings, educators tend to be faculty members (with BMHI PhDs, physicians or other healthcare workforce degrees or degree candidates) and/or recognized professionals in the field. In some countries, a trend towards hiring faculty with BMHI PhDs has emerged as the number of individuals with this qualification grows, and the profession is now its own separate discipline [75].

1.5. Certification

While closely related to academic degree programs, the last decade has witnessed the emergence of regionally (i.e., country) supported professional credentialing programs, which allow individuals to both build competence in BMHI, but also have work experience and expertise in the field formally recognized [62,76,77]. The route of attainment for this mode of credentialing has traditionally been one of work

Box 1
Range of learning approaches to BMHI education.

- full-time and part-time delivery [50,58]
- face-to-face classroom teaching [51,53,58]
- synchronous and asynchronous online education [26,51,53,63,64]
- blended teaching (using technology-enhanced teaching in and out of class, both synchronous as well as asynchronous [51,56,58,64,65]
- flipped classrooms (learners develop knowledge before attending a class and concentrate on putting this knowledge into action during the class) [66]
- short courses, summer schools, and microcredentials [53,59,67]
- workshops and seminars [53]
- on-the-job work experience, practicums, tutorials, cooperative or experiential learning and exchanges [26,51,53,54,65,68,69]
- simulations [70,71]
- problem-based learning scenarios and case studies [69,72]
- massive open online courses [73,74]

experience, a self-study program, and successful completion of an examination. Individuals will have first completed formal university degree study in a field inside [51] or outside of BMHI [75,78].

Recommendations for BMHI education at the time of the previous revision suggested that more advanced courses in BMHI would only be of value if career opportunities and job descriptions in the field existed or began to more readily materialize [2]. Inherently across the globe, there are few required qualifications or certifications for working professionally in the BMHI field [79]. BMHI programs and specializations are increasingly being offered in several areas such as health information management, standards, clinical informatics, data science, human factors, artificial intelligence, and more. Professional qualifications for individuals who have studied in a BMHI program have begun to be recognized as essential credentials that signal the individuals' expertise to work in the field of BMHI [75,78]. Recently the European Federation for Medical Informatics (EFMI) has established an initiative and a process for certification in BMHI.

Various BMHI certifications exist for nurses, physicians, and other clinicians and non-clinicians [80–82]. These are often overseen by national professional organizations that provide a process that meets standards for certification program quality as defined by national or international program accreditation criteria. Certifications are voluntary efforts by individuals to demonstrate their expertise and leadership in BMHI. With this recognition of leadership, however, comes the obligation to maintain the expertise and required skills to practise BMHI at the highest level of competence. Thus, certificate holders have an obligation to take advantage of opportunities such as continuing medical education, regular high stakes examinations to demonstrate their knowledge, and continuing self-examination exercises. As long as individuals hold a certification in a BMHI specialty, they are obligated to work at the highest level of the specialty, which requires continued learning and demonstration of expertise. Many of the BMHI workforce come from healthcare professions, such as medicine and nursing, and may maintain those professional certifications, especially if their job also includes direct patient care [42].

2. Methods

The IMIA Board established a taskforce of 14 international experts in 2017 to update the first revision of the IMIA Recommendations in BMHI Education. It included representatives from all IMIA regions, with several involved in developing the previous version. A literature review was initially performed to elicit key publications on BMHI educational frameworks and competencies that were issued after 2010. Open workshops of 90 min each were held with 18 participants at MEDINFO 2017 to establish the structure for the revision, and with approximately 20 participants at the Medical Informatics Europe (MIE) 2018 conference to discuss necessary changes in competencies and how these relate to changes in current work roles.

In April 2019, a Delphi study with an international panel of 21 BMHI experts was performed as part of a master's degree thesis project [83]. The aim was to revise and update the proposed list of learning outcomes described in the first revision, and to compare the IMIA competency framework with the competency frameworks in three other countries (Australia, Canada, United States). Data were collected in two rounds, with 11 participants in round one and 13 participants in round two. The results of the Delphi study served as input to describe general trends and changes in learning outcomes. The comparison of competency frameworks was extended to include the European Union, UK, and Saudi Arabia in order to propose an adapted new IMIA framework.

Further, a third open workshop was held with approximately 20 participants at MEDINFO 2019 to discuss the results of the Delphi study.

3. Results

Being an interdisciplinary discipline per definition, BMHI draws upon different disciplines [84]. Professionals entering the field have diverse backgrounds, and BMHI education at various levels needs to support a range of work roles.

3.1. Literature review

Competencies in the field have been developed for various disciplines within BMHI. In Table 1, a total of 64 major publications on the development of such competencies are listed as examples, of which 27 were added since the publication of the previous version of the recommendations.

3.2. BMHI and related disciplines

The digital transformation in society has changed the content of many jobs, altering work roles and required competencies at different levels. This transformation has implications for both the education being provided and the curriculum design. Interesting differences exist, both within and between countries and programs, regarding curricula structures and expected learning outcomes. Multiple initiatives have been launched in the last decades to define standardized BMHI content aimed at developing sample BMHI curricula.

A clear trend in curriculum design is the integration of disciplines closely related to the core field of BMHI. Fig. 1 highlights and describes the most important disciplines related to BMHI, with the central white circle representing core competencies specific to BMHI and the eight outer sections depicting the disciplines that share knowledge, methods, and tools with BMHI but comprise additional competencies. The

Table 1
Some major publications on BMHI competencies.

Author/Organization	Year	Discipline
University of Heidelberg and the University of Applied Sciences Heilbronn medical informatics program [85,86]	1972	Dedicated BMHI programs
German Association for Medical Informatics, Biometry and Epidemiology (GMDS) and German Society for Computer Science (Reisensburg Conference) [87,88]	1973	BMHI and computer science
Association for Computing Machinery [89]	1978	BMHI and computer science
Association of the Medical Colleges [90]	1984	BMHI and medicine
GMDS [91]	1992	BMHI in general
Concerted Action on Education and Training in Health Care Informatics (EDUCTRA) [92]	1992	BMHI for health professionals
Council of Europe Committee of Ministers [93]	1995	BMHI for health professionals
NIGHTINGALE project [94,95]	1996	Nursing informatics
IT-EDUCTRA project [92]	1996	BMHI for health professionals
English National Board for Nursing, Midwifery and Health Visiting [96]	1996	BMHI for nurses, midwives and health visitors
National Advisory Council on Nurse Education and Practice [97]	1996	Nursing informatics
Association of American Medical Colleges [98]	1999	BMHI and medicine
International Medical Informatics Association [1]	1999	BMHI in general
Schleyer [99]	1999	Dental informatics
United Kingdom National Health Service [100]	2001	BMHI in general
Staggers et al. [101]	2001	Nursing informatics
Covvey et al. [102]	2001	BMHI in general
Mantas and Hasman [103]	2001	Nursing informatics
O'Carroll et al. [104]	2002	BMHI for public health professionals
Curran [105]	2003	Nursing informatics
American College of Medical Informatics [106]	2004	Bioinformatics
American Health Information Management Association (AHIMA) [107]	2004	Health information management
Hovenga and Mantas [108]	2004	BMHI in general
Garde, Harrison & Hovenga [109]	2005	Health informatics
Ivanitskaya et al. [110]	2006	Health information literacy
AHIMA [111]	2007	Health information management
Canada's Health Informatics Association [112]	2007	Health informatics
Medical Library Association [113]	2007	Health science librarians
Pigott et al. [114]	2007	Health informatics
Huang [76]	2008	BMHI in general
AMIA and AHIMA [115]	2008	EHR Clinical users
Gassert [116]	2008	Nursing informatics
United States DHHS and CDCP [117]	2008	PH informatics
AMIA [118]	2009	Clinical informatics
AMIA-OHSU 10 x10 Program [119]	2009	BMHI in general
TIGER Initiative [120]	2009	Nursing Informatics
Office of the National Coordinator for Health IT [121]	2009	EHR adoption
Otero and Hersh [122]	2011	BMHI in general
Canada's Health Informatics Association [123]	2012	BMHI in general
Hu, Sun and Li [124]	2013	BMHI for health professionals
Röhrig et al. [125]	2013	BMHI for health professionals
Hasman, Mantas & Zarubina [126]	2013	BMHI in general
Paton [127]	2014	BMHI in general
Mohan et al. [128]	2014	BMHI in general
Qian et al. [129]	2014	BMHI for health professionals
Hersh et al. [27]	2014	BMHI for health professionals
Valerius et al. [130]	2015	BMHI in general
Mantas [131]	2016	BMHI in general
Cummings et al. [132]	2016	Nursing informatics
Lei et al. [133]	2016	BMHI in general
Kannry et al. [134]	2016	BMHI in general
Gadd et al. [135]	2016	BMHI in general
Jaspers et al. [136]	2017	BMHI in general
Martin-Sanchez et al. [78]	2017	NMHI in general
Hübner et al. [137]	2018	Nursing informatics
Lehmann et al. [138]	2018	BMHI for physicians
Kolokathi et al. [53]	2019	BMHI in general
Silverman et al. [139]	2019	BMHI in general
Mantas [54]	2020	BMHI in general
Otero et al. [57]	2020	BMHI in general
Were et al. [58]	2020	BMHI in general
Gadd et al. [61]	2020	BMHI in general
Zoulias & Mantas [140]	2022	BMHI in general
The Korean Society of Medical Informatics [59]	2022	BMHI in general

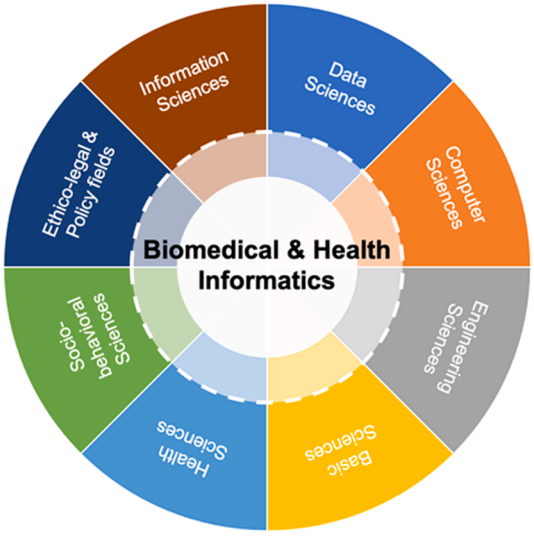

Fig. 1. BMHI and related disciplines.

overlapping areas within the dotted circle represent aspects of overlap and contribution to BMHI. It is acknowledged that the contributing disciplines also intersect between each other, but for simplicity, these intersections are not represented in Fig. 1.

Course learning outcomes should integrate these overlapping areas as optional elements, depending on the focus of the respective program. This integration assures graduates from BMHI programs know at least the basics of those related disciplines. It also gives various programs the flexibility to focus on one or more overlapping areas, depending on the institution's cultural, scientific and technical context and the healthcare system in the respective country.

3.3. BMHI knowledge domains

The IMIA recommendations from 2010 originally presented four knowledge domains:

1. BMHI core knowledge and skills
2. Medicine, health and biosciences, health system organization
3. Informatics/computer science, mathematics, data analytics, biometry

Table 2
Comparison of selected BMHI competency frameworks.

IMIA Framework 2022	IMIA Framework 2010	Australia	Canada	Saudi Arabia	European Union Horizon	United Kingdom – FCI	United States – AMIA
1 BMHI Core Principles	1 BMHI Core Knowledge & Skills	F Core Health Informatics	A2 Technology Ecosystem	1 Core Principles	Informatics	D2 Information Technologies & Systems	F4 Health Information Science & Technology
							F5 Human Factors & Sociotechnical Systems
			C5 Healthcare Transformation	4 Education & Research			F7 Social, Behavioral, & Information Science and Technology Applied to Health
2 Health Sciences and Services	2 Medicine, Nursing, Health & Biosciences, Health System Organisation	A Health Sciences	B3 Clinical & Health Services	3 Health Sciences	Direct Patient Care	D1 Health & Wellbeing in Practice	F1 Health
			B4 Canadian Health System				
3 Computer, Data, and Information Science	3 Informatics/ Computer Science/ Information Systems, Mathematics, Biometry	B Information Science	A1 Information Management	5 Health Data Analytics	Engineering/ Information Systems/ICT	D3 Working with Data & Analytical Methods	F2 Information Science & Technology
		C Information Technology	A2 Technology Ecosystem	2 Information & Communication Technology		D5 Decision Making	
						D2 Information & Technologies Systems	
4 Social & Behavioral Sciences		E Social & Behavioural Sciences	B3 Clinical & Health Services				F3 Social & Behavioural Science
							F6 Social & Behavioral Aspects of Health
5 Management Science		D Leadership & Management	C5 Healthcare Transformation	6 Leadership & Management	Administration	D4 Enabling Human & Organisational Change	F8 Professionalism
			C6 Project Management			D6 Leading Informatics Teams & Projects	F9 Interprofessional Collaborative Practice
							F10 Leadership
6 BMHI Specialization	4 Specializations				Research/ Biomedicine		

IMIA = International Medical Informatics Association | European Union Horizon = EU*US eHealth work project | FCI = Faculty of Clinical Informatics | AMIA = American Medical Informatics Association.

4. Optional modules in BMHI and from related fields

Today, BMHI competency frameworks from Australia, Canada, Saudi Arabia, UK, Europe, and the United States (US) use more than four knowledge domains (Table 2).

Following a comparison of the current frameworks, IMIA suggests the following six knowledge domains:

1. BMHI Core Principles
2. Health Sciences and Services
3. Computer, Data and Information Science
4. Social and Behavioral Sciences
5. Management Science

6. BMHI Specialization

This reflects the fact that knowledge domains such as social, organizational and ethical issues, that previously were covered under the BMHI core knowledge and skills, have gained importance and form a new knowledge domain. The same is true for management skills, that previously were partly covered under computer science.

Fig. 2 summarizes the six newly proposed knowledge domains. Comparing this with Fig. 1, it is apparent that some of the related sciences have now become more dominant.

Based on the competency descriptions in the previous version of the IMIA recommendations as well as the results of the Delphi study, different topics for each BMHI knowledge domain are listed in Table 3.

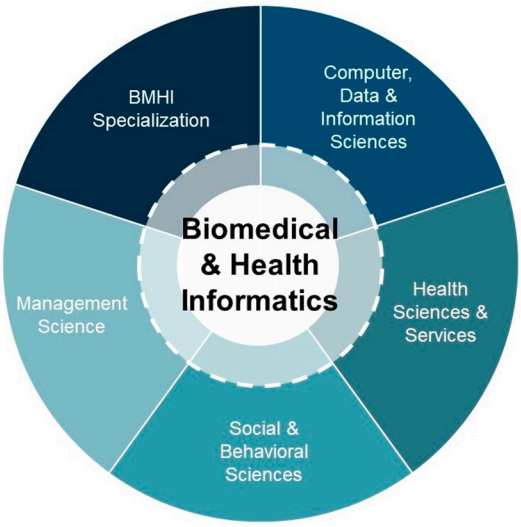

Fig. 2. BMHI Knowledge Domains.

3.4. BMHI learning outcomes

Both previous versions of the IMIA recommendations provided a list of recommended and optional learning outcomes in terms of levels of knowledge and skills required by the BMHI workforce. However, it is apparent that learning outcomes are changing rapidly to reflect the variety of emerging technologies and innovations entering the healthcare ecosystem. Additionally, several countries have developed their own BMHI frameworks that include learning outcomes relevant to the local environment. For these reasons, changes in learning outcomes compared to the previous version are highlighted rather than providing a revised list of learning outcomes.

This version, in comparison to the previous version of the IMIA recommendations, takes increased societal expectations of knowledge and skills in response to digitalization in general into account. The main focus of **BMHI Core Principles** is now on the understanding of principles for data management from different sources; how information models, terminologies, standards and system architectures relate to each other; and an awareness of the ethical and responsible use of sensible health and patient data. The **Health Sciences and Services** domain acknowledges that policies and regulatory frameworks for information handling need to be complemented with knowledge about information systems and digital services as medico-technical and healthcare products. It is evident that digitalization impacts not only clinical work processes and delivery of care, but also illness prevention and the patient-clinician relationship. Major additions to the domain of **Computer, Data and Information Science** relate to the understanding of the principles of new technologies, such as blockchain, Internet of Things, and cloud and edge computing. In relation to **Social and Behavioral Sciences**, evaluating and assessing clinical safety and risk associated with information to reduce harm to patients, examining ethical perspectives, ensuring staff competency, capability and empowerment, and appraising the changed role of the patient as an active team member in person-centred care are all major focal points. Under the **Management Science** domain, project and team management skills, as well as organizational information technology strategy, are highlighted, not least in the context of interdisciplinary environments with the ability to generalize or abstract and apply knowledge to local contexts. Lastly, whilst new fields are likely to arise, it is important for BMHI specialists of any **specialization** to demonstrate knowledge regarding interoperability, standardization, and the ability to apply research theory into practice.

3.5. BMHI roles

As previously mentioned, the pervasiveness of ICT in the health sector has resulted in all sections of the healthcare workforce needing some core BMHI knowledge, even at an early stage. The extent of knowledge depends on the employment position, healthcare role, degree of responsibility, level of education, and career progression. A junior healthcare professional, for instance, uses information differently than a senior healthcare professional, and educational components will vary in depth and breadth to suit specific learner groups. Most of the healthcare workforce will only need to know how to use ICT safely in their roles; however, other healthcare professionals may pursue a more active role in developing and implementing digital health solutions, whilst only a few will choose to achieve specialized certification in this field.

In addition to the healthcare workforce, informaticians, information technology professionals, engineers, and other scientists such as mathematicians or physicists intending to work in the interdisciplinary field of BMHI should be exposed to health science and systems content through specific BMHI education. While basic and intermediate BMHI concepts can be integrated within non-BMHI professional educational programs such as medicine, nursing, and computer science, biomedical and health informaticians require specialized BMHI education in vocational and university programs. Alternative routes to different types of specialization in BMHI will depend on career choice.

In contrast to the previous recommendations that identified two roles (IT user and BMHI specialist), the current revision of the recommendations now proposes three roles – user, generalist, and specialist. It is widely acknowledged that many countries have varying terminology for these roles, sometimes varying even within countries. The quantity and nature of the workforce are also unknown in most countries, as BMHI rarely appears in labor statistics. For these reasons, these three roles should be considered general categories of work and education rather than job descriptions.

The first role - **BMHI user** – involves learners of non-BMHI disciplines that deliver healthcare and use information systems to enter, store, retrieve, and analyze data. The education is mainly at an introductory level, comprising the fundamental topics from all BMHI knowledge domains, and should be included in every healthcare workforce curriculum, such as physicians, nurses, pharmacists, dentists, allied health professionals, healthcare managers, and health record administrators. The BMHI user needs to demonstrate familiarity with personal computers, text processing and spreadsheet software, commonly used database management systems, digital systems, and application software for clinical and scientific documentation, personal communication, including Internet access, for publication, biomedical knowledge management, and basic statistics. Furthermore, they also need knowledge about the possibilities and limitations of ICT, and to be able to use ICT efficiently and effectively. These goals can be achieved, for example, by completing one or two mandatory BMHI introductory subjects within undergraduate degree curricula, or by integrating mandatory aspects of BMHI into existing subjects.

The second role - **BMHI generalist** – involves learners of non-BMHI disciplines that deliver healthcare or contribute to healthcare services, learners of undergraduate BMHI degrees or learners of some BMHI master's degrees. The education is mainly at an intermediate level, comprising knowledge to assist in bridging information technology and healthcare aspects of BMHI. The BMHI generalist needs to demonstrate capability in eliciting clinical user needs, advising software analysts about the requirements for a new information system, developing and implementing clinical information systems, terminologies, and guidelines, and evaluating clinical information systems. Furthermore, they also need knowledge about the application and impact of emerging technologies on health services. These goals can be achieved by a set of complementary courses related either to computer science or healthcare services, with the addition of several BMHI subjects.

The third role - **BMHI specialist** - involves learners of postgraduate-

Table 3
BMHI Knowledge Domains and Corresponding Topics.

1 BHMI CORE PRINCIPLES	2 HEALTH SCIENCES AND SERVICES
Clinical decision support Data governance Education support through informatics methods and tools Evaluation and assessment of information systems Health informatics standards and interoperability Health record structure, design, and analysis principles History of BMHI Information literacy Information processing in healthcare Literature retrieval and analysis Nomenclatures, vocabularies, terminologies, ontologies, and taxonomies Regional networking and shared care Research methods and paradigms Telemedicine and telehealth	Biomedicine Care delivery models Clinical decision making Determinants of health Epidemiology Evidence informed practice Health policies and regulatory frameworks Health promotion Health sector roles Health terminology Healthcare service organization structure and function Human anatomy and physiology Participatory health Patient empowerment Patient safety Person-centred care Public health
3 COMPUTER, DATA, AND INFORMATION SCIENCE	**4 SOCIAL AND BEHAVIORAL SCIENCES**
Artificial intelligence Blockchain technology Cloud and edge computing Data and information analysis Data and information attributes Data and information visualization Design and development principles Information science theories Information structure and design Internet of Things Network architectures and topologies Robotics System design System lifecycle System security Wireless technology, sensor-based systems	Digital literacy and the digital divide Ethics, Security and Privacy Health literacy Indigenous data sovereignty principles Medical law Problem solving Sociotechnical aspects Stakeholder education Stakeholder engagement User experience
5 MANAGEMENT SCIENCE	**6 BMHI SPECIALIZATION**
Business alignment Change management Health economics Information culture Leadership Interdisciplinary team management Process reengineering Project management Quality management Resource management Risk management System governance Value management and benefits realization	Biomedical imaging and signal processing Biomedical modelling and simulation Chemoinformatics Clinical bioinformatics and computational biology Clinical research informatics Global health informatics Nanoinformatics Participatory health informatics Personal health informatics Public health informatics Translational bioinformatics

level BMHI disciplines. The education is at an advanced level, comprising concentrated knowledge in their chosen field, in addition to the knowledge required for all specializations, such as nursing informatics, dental informatics, public health informatics, health and human services informatics, and so on. The BMHI specialist needs to demonstrate capability in developing new methods for information processing in health, delivering training activities, and conducting research in the field. These goals can be achieved by learners receiving a master's or doctoral degree in BMHI or by graduated learners in other disciplines completing dedicated postgraduate programs in BMHI. BMHI specialists often work in academic settings and may be researchers.

3.6. Levels of BMHI education

BMHI programs are offered at different levels of education.

Bachelor's programs (often referred to as first degree or undergraduate program) usually require three or four years of full-time study, leading to the award of Bachelor of Science or Bachelor of BMHI (often called health informatics or medical informatics). As the program's intake comes directly from the secondary education system, the curriculum is designed to provide introductory and advanced content in mathematics, physics, chemistry, computer science, information systems, anatomy, physiology, and healthcare for the first one or two years, and health informatics, information science, decision support, imaging, healthcare systems, and health information systems for the final years.

Master's programs are more compact (one or two years of full-time study) and lead to a Master of Science in BMHI (also often called health informatics or medical informatics or more specific sometimes). The program intake comes with a bachelor's degree in health sciences, social and behavioral sciences, management science, and computer, data and information sciences. The curriculum is often adjusted to the backgrounds trying to convert the different backgrounds to acquire the skills and competencies required by a graduate in BMHI. The programs are often intensive, with courses such as health informatics, information science, decision support, imaging, healthcare systems, and health information systems, in addition to those background-specific courses. Methodologies in BMHI research are included, and the writing and defence of a dissertation under supervision in BMHI are required.

Doctoral programs (PhD or Doctorate) in BMHI are academic programs of at least three years that lead to the degree of Doctor of Philosophy in BMHI or a Doctorate in BMHI. It often requires successful participation in intensive courses for one year and pursuing research on an original theme under supervision. The result of the study is a thesis that requires public defending before examiners. Several original publications in scientific journals of this research are required before the defence to ensure the recognition of the originality of the research work.

The educational needs are determined by the type of healthcare professional and whether the individual is a BMHI user or wants to become a generalist or a specialist in BMHI (Fig. 3). The same applies to an informatics/computer science professional wishing to become a generalist or specialist in BMHI.

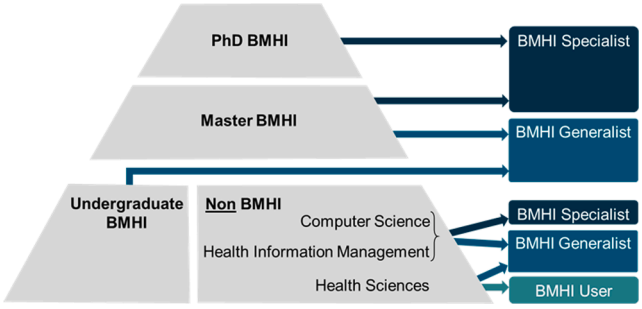

Fig. 3. Levels of BMHI education aligned with BMHI roles.

4. Recommendations for courses/course tracks in BMHI as part of educational programs

4.1. General remarks

The following text and tables differentiate between courses and programs. Courses can have the duration of a semester or academic term or be shorter and usually lead to a grade for the specific course. A program comprises many courses designed to meet specified graduate outcomes, mostly role related. These can be short or long courses undertaken as 'just in time' learning, undertaken on a full or part-time basis. Higher education programs are usually at least one year and lead to a specified qualification, such as a bachelor's or master's degree, in accordance with the relevant national educational framework. Specific courses are usually mandatory within a program, whereas others are elective.

Due to the variety of educational opportunities, there exist different perspectives for BMHI education [141]. The recommendations in Sections 4.2 and 4.3 are for healthcare-based approaches to BMHI, whereas the recommendations in Sections 4.4 and 5.1-5.3 are oriented towards a more technical informatics-based approach to support healthcare. For educational progression, especially bachelor's, master's, and doctoral degrees, the general distinctions in both depth and breadth of the health informatics knowledge domain should be considered. It is essential to recognize the need for teamwork and stakeholder collaboration, given BMHI is interdisciplinary in nature [84].

4.2. Recommendations for BMHI courses as part of biomedical and health sciences programs

4.2.1. Courses/course tracks for BMHI users or generalists

Under the umbrella of biomedical and health sciences programs are medical, nursing, dentistry, pharmacy, biomedical, public health, global health, and allied health programs, as well as healthcare management and health system administration programs. This group of programs are best divided to represent either clinical interdisciplinary patient-centred care (primarily undergraduate) or health service operations management and strategic leadership (mostly postgraduate).

Educational components in BMHI should be incorporated into the curriculum of undergraduate programs, building on key foundational BMHI scientific knowledge and skills. Entry requirements for these programs must specify the need for digital literacy, preferably including core foundational BMHI knowledge and skills that can be built on to reflect specific health disciplinary requirements.

To achieve the levels of knowledge and skills in BMHI, as recommended in Section 3.5 for BMHI generalists, the learner workload associated with these educational components in BMHI should be at least one year of full-time study with an additional specialization to follow during a second year. This approach is similar to dedicated master's programs in BMHI. In addition to the core knowledge and skills obtained in each program, the suggested percentage of learner workload for the different knowledge domains inside the BMHI program track appear in Table 4.

For all healthcare workers, domain area (2) should focus on health system organization in the digital age and domain area (3) on practical informatics, but also include basic modelling and database management. Domain area (4) should focus on human–computer interaction and evidence-based evaluation, whereas domain area (5) includes interdisciplinary teamwork modelling, and project management. For healthcare managers, knowledge and practical skills of information systems architectures, including characteristics required to achieve syntactic and semantic interoperability and/or interconnected information systems, should particularly comprise work and information flow supporting enterprise functions for administration, controlling, data asset quality management and executive decision making.

Table 4
Suggested percentage for the six BMHI domains within health science and services programs as BMHI User or Generalist.

Program	Medicine, nursing, healthcare management, dentistry, pharmacy, and public, global, and allied health
Program type	Undergraduate – non-BMHI, Postgraduate
Program length	At least 1-year full-time study
Program level	BMHI User or Generalist

Knowledge/Skill Area		Percentage
1	BMHI core principles	30
2	Health sciences and services	max. 10
3	Computer, data, and information science	40
4	Social and behavioral sciences	10
5	Management science	10
6	BMHI Specialization	0
∑		~ 100

4.3. Recommendations for BMHI courses as part of health information management programs

4.3.1. Courses/Course tracks for BMHI generalists or specialists

Within the past decade, the discipline of health information management has often enhanced its scope from document handling to managing healthcare information, considerably changing the scope of practice. From a BMHI perspective, the education of health information managers should include secondary health record data use to meet automated ecosystem data supply chain needs, with a strong focus on health data science and analytics, including:

- health data asset management, governance and stewardship
- health data standards, interoperability, health data quality control, and technical linkages (coding, mapping, clinical modelling, data values sets, health data exchange)
- cloud-based, ontologically-designed vendor/technology neutral health data repository management
- legal, ethical data use, data and record management security and governance
- statistical and performance management reporting
- advanced statistics and artificial intelligence-based data analytics

All BMHI generalists in this category need introductory knowledge and skills applicable to the knowledge/skill-domain medical, health and biosciences, health systems organization, and any required knowledge of the different aspects of global health or global digital health ecosystems and health data supply chains. For a BMHI specialist, particular emphasis should be given to data and information literacy, ontological data structures, information models, metadata, health terminology, coding and classification systems, the electronic health record, interoperability, and evaluation methodology, and the relationship between these concepts and the use of various BMHI technologies.

4.4. Recommendations for BMHI courses as part of informatics/computer science programs

4.4.1. Courses/Course tracks for BMHI generalists or specialists

To achieve the levels of knowledge and skills in BMHI for BMHI generalists, the length of study for educational components in BMHI should be at least one year of full-time study. In addition to the core knowledge and skills of informatics/computer science, the suggested percentage of learner workload for the different knowledge and skills areas inside the BMHI course track appears in Table 5.

The learning content comprises a general overview of BMHI; knowledge and skills in biomedical statistics; software engineering; application development; architectural design; technical, structural, semantic and process interoperability; ethics and security; and monitoring and evaluation methods. Learners with computer science backgrounds need to be knowledgeable about not only basic health science concepts but also the organization and management of healthcare services. Additionally, they need to be conversant with the relevant BMHI standards and terminologies. Applying methods and tools (including interdisciplinary development) of BMHI in healthcare institutions and for concrete problems in diagnosis, treatment, nursing care, and healthcare management should be emphasized.

Table 5
Suggested percentage for the six BMHI domains within informatics/computer science programs as BMHI Generalist.

Program	Informatics, computer science, data science, data analytics
Program type	Undergraduate – non-BMHI, Postgraduate
Program length	At least 1-year full-time study
Program level	BMHI Generalist or Specialist

Knowledge/Skill Area		Percentage
1	BMHI core principles	30
2	Health sciences and services	40
3	Computer, data, and information science	max. 10
4	Social and behavioral sciences	10
5	Management science	10
6	BMHI Specialization	0
∑		~ 100

5. Recommendations for dedicated BMHI educational programs

Whilst there is also a substantial variety of dedicated BMHI educational programs to train future BMHI specialists, all programs have the common aim of preparing graduates for careers as BMHI specialists in academic, healthcare, or industrial settings.

5.1. Recommendations for BMHI bachelor's programs

For programs leading to a bachelor's degree in BMHI, curricula should be application-related, serving the purpose of direct preparation for future health workforce activity. In addition, they should offer a solid foundation for studying in a BMHI graduate program or related fields. In some countries, such as the US, there is direct entry from a bachelor's to a doctoral program, whereby the graduate covers both master's and doctoral level content.

The objective of a bachelor's program is to impart specialized knowledge in the BMHI field as well as skills in a practice-oriented application of the acquired knowledge. The intention is to provide a practice-related education to qualify for translating expertise gained from research and practice in the BMHI field into practical activity, in conformity with the state of knowledge.

To achieve the levels of knowledge and skills for BMHI generalists as recommended in Section 3.5, and to achieve a broad depth and breadth of all educational components, the length of study for BMHI educational components should be at least three full-time years of study. Different types of extended programs, such as four-year honours bachelor's degree with an undergraduate thesis or research project component, may provide the foundation for entry into research-based master's and/or PhD programs.

The suggested amount of learner workload for the three knowledge and skills areas for the BMHI bachelor's program appears in Table 6. Depending on the desired learning outcomes, this composition can also be varied and may either focus on technical ICT skill acquisition (which may increase the percentage of area 3) or focus on a stronger health application focus (which may instead increase the percentage of area 1 or 2). To label a bachelor's program 'health informatics' or 'medical informatics', however, either the percentage of combined areas 1, 2 and 6 or 1, 3, and 6 should comprise at least 50% of the program content. To prepare learners for the practice-oriented application of their BMHI competencies, practically-oriented types of learning (e.g., experiential learning, industrial attachments, or professional internships) should be

Table 6
Suggested percentage for the six BMHI domains within BMHI bachelor's programs.

Program	Medical informatics, biomedical informatics, health informatics	
Program type	Undergraduate BMHI	
Program length	At least 3-years full-time study	
Knowledge/Skill Area		Percentage
1	BMHI core principles	15
2	Health sciences and services	30
3	Computer, data, and information science	30
4	Social and behavioral sciences	10
5	Management science	10
6	BMHI Specialization	5
∑		100

an integral part of the curriculum in all bachelor's programs.

5.2. Recommendations for BMHI master's programs

Master's programs provide comprehensive formal and methodological competencies in BMHI. The objective of a master's program is to provide an education of scientific character that includes theory, specialized knowledge, and practical skills. Graduates at this level should, apart from a practice-oriented application of methods and tools from health and medical informatics, be enabled to participate in research or evaluation of BMHI projects and the systematic advancement within the field of health and medical informatics. In North America, master's programs are in many cases terminal degrees, leading to professional employment at a higher level than a bachelor's graduate. There is still an expectation of demonstrating some research skills, but these are often for applied evaluation research, not academic or scientific research.

Various types of master's programs exist. For example, research-oriented programs prepare graduates for careers in academic settings or research-focused positions in healthcare organizations and industry. Professional programs prepare graduates for careers in healthcare or industrial settings and are more focused on applying knowledge rather than research. Consequently, entry requirements (e.g., type of bachelor's degree), program length (one or two years), curricula content, and instructional design may vary substantially between master's programs.

To achieve the levels of knowledge and skills in health and medical informatics as recommended in Section 3.5, and to achieve the desired broad depth and breadth on a master's level previously defined, the length of a BMHI master's program should be at least one-year full time. The recommended amount of learner workload for the six knowledge and skills areas for a one-year and a two-year master's program appears in Table 7. To label a master's program 'health informatics', 'biomedical informatics' or 'medical informatics', combined areas 1 and 6 should cover at least 60% of the content for the entire program. To prepare learners for their roles as BMHI specialists in different health ecosystems, project work in interdisciplinary settings and teams should be part of the curriculum in all master's programs.

5.3. Recommendations for BMHI doctoral programs

Doctoral program graduates should all be enabled to independently participate in and lead research and contribute to the systematic and scientific advancement within the field of BMHI. For programs leading to a doctoral degree, the learner should carry out comprehensive individual research independently.

To achieve the levels of knowledge and skills for BMHI specialists as recommended in Section 3.5, and to achieve the desired broad depth and breadth of the educational components previously defined, the length of study should typically be at least three to four years of full-time study.

As the length, admission, program, and organizational requirements may differ depending on institutional and country standards, quantitative recommendations are not provided.

Table 7
Suggested percentage for the six BMHI domains within BMHI master's programs.

Program	Medical informatics, biomedical informatics, health informatics	
Program type	Postgraduate	
Program length	Either 1-year OR 2-years full-time study	
Knowledge/Skill Area		Percentage
1	BMHI core principles	40
2	Health sciences and services	15
3	Computer, data, and information science	15
4	Social and behavioral sciences	5
5	Management science	5
6	BMHI Specialization	20
∑		100

6. Recommendations for continuing education

Continuing education opportunities are critical to those primarily educated in BMHI and clinicians or other healthcare workers who choose to acquire in-depth exposure to the field. A certificate of 'health informatics', 'clinical informatics', 'medical informatics', and/or 'biomedical informatics' should be offered in recognition of having acquired sufficient competence in BMHI from an academic, educational, and/or practical perspective relative to specific knowledge, skills, and roles within the health industry. Furthermore, for physicians, pharmacists, and nurses, who usually have well-established forms of continuing education, options should be available for receiving, in addition to their primary degree, the supplementary qualification of 'health informatics', 'clinical informatics, 'medical informatics', and/or 'biomedical informatics' [79]. This additional qualification or certification may be issued by any national medical or health professional association or other academic bodies and may be associated with examinations and/or related coursework to demonstrate competency [80].

It is recommended that specific entities are established to provide BMHI continuing education courses. These entities might be inside universities or, as academies of health/medical informatics established by any national association in BMHI or supplied by an independent private entity, provided the people responsible for course curricula, content, and educational delivery are suitably qualified [142].

Providing BMHI continuing health education free of commercial or political influence is critical, including all training aspects such as educational needs, assessment, learning outcomes, content, selection of persons managing the content, educational methodology, and evaluation [143].

Working in the field of BMHI and even using ICT requires lifelong learning, therefore opportunities for continuing education should be offered for BMHI specialists, as well as BMHI generalists or BMHI users. The ability of 'learning to learn' will become of particular importance. Some of the health workforce may be licensed or certified as BMHI specialists who require revalidation by offering a portfolio of accredited continuous professional development activities.

BMHI is a field that is constantly undergoing innovation and change. As new technologies, algorithms, and applications are developed, it is critical that experts follow and understand these developments and continue to evaluate them critically.

7. IMIA support for BMHI programs and courses

7.1. IMIA accreditation

To assure the quality and credibility of an educational provider and its programs and to facilitate the improvement of that provider or programs, faculty can voluntarily engage in regular accreditation. For these reasons, IMIA has established an accreditation service to establish worldwide benchmarks for BMHI education and to act as an

international adjudicator on whether programs meet these benchmarks. IMIA accreditation is in addition to the more extensive but frequently traditional endorsement procedures within the home country. Local accreditation committees may not have enough expertise in BMHI to judge the programs in terms of depth or whether the program is of comparable standard to international programs.

IMIA accreditation is designed to ensure that core competencies in BMHI are covered by the program, using these recommendations as a point of reference. Accreditation provides a competitive advantage to the program and gives learners and (potential) collaborators of the institution insight into the program's quality. In parallel with local and national accreditation agencies, IMIA accreditation focuses on ensuring that the contents of the curriculum match the objectives of the program and that the programs meet an international standard for BMHI education.

A program is considered accredited when the IMIA Accreditation Committee approves the quality of the educational program and the fulfilment of the IMIA recommendations. At this time, the program receives a written certificate signed by the IMIA President and the IMIA Vice President of Special Affairs, which is included in the relevant official register of IMIA. This registration signifies that the degree awarded by the program is recognized by IMIA for five years, after which the institution can decide on re-accreditation of its educational program(s).

Finally, the panel's assessment report and IMIA's approval of accreditation of the programs are published by IMIA on its website. In the new self-assessment report, the program has to show how it dealt with the recommendations made by the site visit committee on the prior review. Programs can be accredited on a provisional basis for two years, after which they are re-evaluated to determine if they meet the recommendations in the first review.

The IMIA Accreditation Committee continues to seek additional qualified, experienced biomedical informaticians willing to serve on the virtual and/or site visit committees of accreditation of BMHI educational programs. Potential candidates should have the following qualifications:

- Master's degree, preferably in biomedical informatics, health informatics or affiliated field
- Minimum of five years of teaching experience in a BMHI educational program at a master's level
- Minimum of three years of experience in establishing educational courses in the BMHI field at a master's level

Candidates should be willing and able to travel to a minimum of two site visits yearly and be familiar with the IMIA assessment framework for the BMHI education accreditation system.

To become a member of the IMIA site visit committees, candidates are asked to submit a curriculum vitae demonstrating achievement of the aforementioned qualifications. The IMIA Accreditation Committee decides on candidates to be nominated as site visit committee members. A letter of interest with a curriculum vitae should be submitted to the Chief Executive Officer of IMIA via imia@imia-services.org.

With the pilot phase having just been completed before the onset of the current COVID −19 worldwide pandemic, IMIA will be reorganizing the activities to a virtual service by mid-2022. Please refer to the IMIA website (https://imia-medinfo.org/wp/imia-accreditation-pilot/) for further details and updates.

7.2. International programs, international exchange of learners and teachers

IMIA's Working Group on Health and Medical Informatics Education (HMIE WG) (https://imia-medinfo.org/wp/imia-working-groups/) is devoted to strengthening BMHI education. Its activities include providing information on BMHI programs and supporting BMHI courses to advance the knowledge of BMHI offered:

- within the education of the healthcare workforce around the world
- to learners of computer science/informatics
- within dedicated BMHI curricula.

HMIE WG will publish and maintain a Resource Page on IMIA's website dedicated to listing BMHI programs. In addition, HMIE WG will facilitate a communication plan to ensure the ongoing promotion of the opportunity to participate to all persons interested in BMHI education worldwide, either by listing their programs and courses and /or utilizing the resource page.

IMIA encourages and recommends international activities in educating BMHI specialists. IMIA also recommends the international exchange of learners and teachers in this field. It promotes the establishment of international programs to support those activities, and to exchange courseware. Programs should be designed modularly, and international credit transfer systems such as the ECTS system in Europe [144] should be used in the respective national programs to support these international perspectives.

Examples are the many educational projects under the ERASMUS + program in Europe [145,146], the AMIA 10x10 program [147] which has 5000 participants since 2005, and the Joint European Universities initiatives (CIVIS) with programs and summer schools in subjects related to the BMHI domains [148].

8. Concluding remarks

These recommendations provide a framework that can guide BMHI curriculum development across the breadth of both healthcare and ICT professionals in the discipline. Given the dynamic advancement of BMHI in most aspects of health services and the pressing need by most countries to build capacity within their workforce to effectively and efficiently use various digital technologies, the recommendations propose the three levels of BMHI education to reflect the varying roles within the healthcare ecosystem. Opinions sought from international BMHI experts also identified the need to expand the knowledge domains relevant to BMHI education. A selection of significant publications addressing the development of BMHI competencies was also highlighted with the aim of contextualizing the considerable advances in BMHI education. Lastly, educational course components in various educational programs were outlined, with suggested percentages of learner workload for each knowledge domain.

International representation from six continents and 18 countries on the taskforce has resulted in a global BMHI perspective that is valuable to any country wishing to assess its approach to strengthening BMHI education. Individual countries, however, may want to develop more detailed or better-defined curricula guidelines to suit their specific needs and educational system, given there is no internationally recognized universal access to ICT in healthcare. It is also acknowledged that the recommendations support the voluntary IMIA accreditation process in matching the objectives of educational programs to an international standard for BMHI education. These recommendations will need reviewing within the next decade to ensure currency of knowledge within the BMHI environment and the need to embrace emerging technologies. All countries must develop a capable workforce to deliver safe, quality care to individuals using technology to improve health outcomes.

Summary table.

What was already known on the topic?

- International recommendations in biomedical and health informatics education previously published in 2000 and revised in 2010
- Recommendations support educators developing curricula, identify essential skills and competencies, provide guidance in program accreditation, and motivate education providers to establish and further develop programs

- Regular revision of the recommendations is needed given changes to science, technology, healthcare systems, and the biomedical and health informatics workforce

What did this study add to our knowledge?

- Educational needs are described for the three roles of biomedical and health informaticians
- Six biomedical and health informatics knowledge domain areas are described
- Recommendations are provided for dedicated biomedical and health informatics programs at an undergraduate and postgraduate level
- Recommendations are provided for biomedical and health informatics continuing education, certification, and accreditation programs

9. Authors' contributions

The manuscript is the result of the work of the IMIA Education Recommendation (2nd revision) taskforce. The taskforce was proposed by the IMIA Board and approved by the IMIA General Assembly in 2017.

Jen Bichel-Findlay (Taskforce chair since 2019): organized the writing of the manuscript, and edited the manuscript; Sabine Koch (Taskforce chair 2017–2019): organized workshops and Delphi study for data collection, and edited the manuscript; John Mantas (Taskforce Chair [1st revision] 2007–2010): edited the manuscript; Fernando Martin-Sanchez, Michael Marschollek, Mark Merolli: organized workshops for data collection, and chaired groups for writing parts of the manuscript; George Demiris, Elaine S Huesing, Najeeb Al-Shorbaji, Aviv Shachak: chaired groups for writing portions of the manuscript; All authors were involved in drafting parts of the article, revising the manuscript and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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