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Review article

Core competencies for clinical informaticians: A systematic review

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ABSTRACT

Background: Building on initial work carried out by the Faculty of Clinical Informatics (FCI) in the UK, the creation of a national competency framework for Clinical Informatics is required for the definition of clinical informaticians' professional attributes and skills. We aimed to systematically review the academic literature relating to competencies, skills and existing course curricula in the clinical and health related informatics domains.

Methods: Two independent reviewers searched Web of Science, EMBASE, ERIC, PubMed and CINAHL. Publications were included if they reported details of relevant competencies, skills and existing course curricula. We report findings using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement.

Results: A total of 82 publications were included. The most frequently used method was surveys (30 %) followed by narrative descriptions (28 %). Most of the publications describe curriculum design (23 %) followed by competency definition (18 %) and skills, qualifications & training (18 %). Core skills surrounding data, information systems and information management appear to be cross-cutting across the various informatics disciplines with Bioinformatics and Pharmacy Informatics expressing the most unique competency requirements.

Conclusion: We identified eight key domains that cut across the different sub-disciplines of health informatics, including data, information management, human factors, project management, research skills/knowledge, leadership and management, systems development and evaluation, and health/healthcare. Some informatics disciplines such as Nursing Informatics appear to be further ahead at achieving widespread competency standardisation. Attempts at standardisation for competencies should be tempered with flexibility to allow for local variation and requirements.

1. Introduction

Health informatics is a multidisciplinary field that combines computer and information sciences with a health focus [1]. The number of informaticians (those practising informatics) is growing, with an estimated 25–50 thousand informaticians in the UK's National Health Service (NHS) alone [2].

The purpose of this systematic review is to collate and synthesise the literature relating to the key competencies/skills and educational course requirements of biological and healthcare-related informatics disciplines. In this context, a competency can be considered to be the input which consists of skills, traits and knowledge, whereas a competence refers to the output (i.e. work performance) [3].

Previous reviews on informatics competencies (e.g. [4,5]) have either included little synthesis of the results, were semi-systematic rather than fully systematic in nature, or only covered a single informatics discipline. There has been significant development of competencies and associated curricula led by the US with earlier work by [5–7] culminating in the formation of Clinical Informatics training programmes in the US. Much of this work has been carried out by the American Medical Informatics Association (AMIA). Work has also been carried out from an international perspective regarding Health Informatics in developing countries. A systematic review of reviews (n = 11) was carried out in 2013 by [8] that focused on Health Informatics in developing countries. The review called for more research/development of methods, tools and guidelines. The authors cite a lack of available quality resources in this context. There has been comparatively little output from a UK perspective. The review presented here contributes to the existing literature by adding a UK perspective and by covering multiple informatics disciplines to synthesise over-arching

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competencies. It also identifies competencies that are shared or unique to specific sub-disciplines. Additionally, the present review updates the literature in this fast-moving area.

There are many different groups carrying out informatics activities throughout the bio-health domains, including clinical, health, bio, pharmacy and nursing informatics. In addition, many professionals do what might be described as the work of an informatician but hold different job titles. Douglas Fridsma, former president and COE of the American Medical Informatics Association (AMIA) discusses this in an editorial piece about the changing names applied to the field of informatics over the years [9]. Fridsma discusses the overlap between informatics and data science and how these similarities can be operationally defined via the development of core competencies [9].

Greenhalgh and Macfarlane [3] advocate the use of an iterative approach for the analysis of complex issues such as competency definition. This review forms one stage in a larger project which also includes job posting analyses, semi-structured expert interviews and a digital survey, building on initial work carried out by the UK's Faculty of Clinical Informatics (FCI) around the definition of Clinical Informatics [10]. The FCI's phase 1 report highlighted that the consulted experts expressed a preference for a single overarching competency framework [2]. The report also stipulates that a balance should be struck between the professional attributes of informaticians that are generic enough to include all potential clinical informatics disciplines, but granular enough to develop a meaningful and usable competency framework [2].

The present systematic literature review was carried out to explore the overlap (and areas of difference) between the different informatics disciplines as summarised in Box 1.

This review addresses the following research questions:

- **RQ1:** What are the common core skills and competencies across the medical and health informatics domains?
- **RQ2:** To what extent do the core skills and competencies vary by level and type of education and training?

2. Methods

The review protocol was based on findings from the FCI's phase 1 report [2] and the PRISMA statement [11,12].

2.1. Eligibility criteria

2.1.1. Literature focus

We included literature with a primary focus on informatics competencies, skills, course curricula, syllabi, or job descriptions of informaticians (Table 1). We only included other literature reviews that made clear recommendations or presented competency frameworks or curricula.

2.1.2. Publication types

Full-text, English-language publications published from 2015 (within the last 5 years) were included.

2.2. Sources of information

Web of Science, EMBASE, ERIC, PubMed and CINAHL were searched.

2.3. Search

We carried out the search using the informatics domains and concepts described in Box 1 combined with the following terms (and their variations): standards, competencies, skills, knowledge, curricula and syllabus. A full example of the search terms are shown in the Appendix.

2.4. Item selection

All publications returned from the search were imported into Mendeley (citation management software) and into Covidence (online software for review management). Two independent reviewers first screened publications by titles and abstracts (with 97.6 % agreement), and subsequently screened the full text of selected items. The reviewers discussed any discrepancies until consensus was reached.

2.5. Data extraction

Table 2 provides details of characteristics extracted from included publications.

3. Results

A total of 12,688 publications were retrieved, reduced to 10,044 after removal of duplicates in Mendeley (Table 3) and 8760 items following removal of duplicates in Covidence.

Fig. 1 provides an overview of the number of items screened at different stages. Eighty-two items were included in the final review.

3.1. Study characteristics

The most commonly used methods were surveys (n = 25), followed by narrative descriptions (n = 23) (Fig. 2, left). Study outputs mainly included the development of curricula/courses (n = 19), assessment of required skills, qualification and training (n = 15) and the definition or genesis of competencies (n = 15) (Fig. 2, right).

Fig. 3 details the number of publications per year per country. The USA consistently published the highest number of publications annually. A full summary of the 82 studies is provided in the Appendix.

Box 1
List of informatics domains/specialist concepts.

- Health (care) informatics
  - Clinical informatics
  - Medical informatics
  - Nursing informatics
  - Pharmacy informatics
  - Dental informatics
  - Citizen-driven informatics
  - Social (care) informatics
  - Personal health informatics
  - Consumer driven informatics
  - Health data science
  - Public health informatics
  - Clinical bioinformatics

Table 1
Inclusion and exclusion criteria used for the review.

Inclusion criteria	Exclusion criteria
• International reviews, studies, documents that contain details about informatics competencies, skills, curricula and course syllabi	• Items not written in English
• Job descriptions for informaticians	• Systematic and narrative literature reviews that did not make clear recommendations or presented competency frameworks or curricula
• Knowledge base for Clinical Informatics professionals	• Items in which the main or significant focus is not that which is defined in the inclusion criteria
• Continuing professional development requirements for Clinical Informatics professionals	• Articles reflecting Health Information Management unless Health Informatics was mentioned specifically
• Literature reviews where clear recommendations/frameworks/curricula for education, skills and competencies are presented (as opposed to just a summary of available literature)	• Literature items published more than 5 years ago
• Literature items published within the last 5 years	

Table 2
Data extracted from full-text literature items (note: not all fields were applicable for all publications).

Data extracted	Details
Study type	Empirical, Theoretical
Title	Title of literature item
Authors	Authors of literature item
Year	The year of publication
Source	Journal title, book title etc.
Affiliated discipline	Nursing, Pharmacy, Public Health, Bioinformatics, Medicine, Nutrition, Health Informatics, N/A
Skill level	School, Undergraduate, Masters, Fellowship, Doctorate, Basic/general skills, Mixed, Residency, N/A
Aims and objectives	The main aims and or objectives of the literature item
Participant details	Details about the population that the focus of the literature
Sample size	Number of participants/sub-groups
Setting	Country and/or location (e.g. hospital)
Name of course or programme	The name of the course of programme of education/ training (if applicable)
Type of course	Integrated/alongside degree, stand-alone, mixed
Methods	The methods used (e.g. survey)
Statistical test	Details of any statistical test(s) used
Outcome assessed	Any outcome measure that was specifically assessed
Main findings/results	The primary findings, results or recommendations of the publication
Limitations	Any limitations identified in the work

Table 3
Sources of literature and search results generated.

Database source	Number of items found
Web of Science	3165
EMBASE	6755
ERIC	39
PubMed	1414
CINAHL	1315
Total:	**12,688**
Total (minus duplicates):	**10,044**

3.2. Commonality among informatics disciplines

Table 6 summarises competencies and skills that co-occur across different informatics disciplines, grouped into broad over-arching domains and ordered by frequency of occurrence in the literature. Additional figures in the appendix detail the percentage of occurrence per informatics discipline. Following data extraction, the two reviewers familiarised themselves with the data by reading the data extraction sheets, and then jointly identified recurring topics and sub-topics, discussing any discrepancies until consensus was reached. For each topic/sub-topic, the reviewers denoted which sub-disciplines they related to according to the included papers (e.g. nursing informatics). Some of the competencies listed in Table 6 can also be considered as entire fields of study in their own right, such as 'governance'. In the context of the listed competencies; they were usually discussed in the literature in terms of gaining awareness of importance, or a general understanding and not as necessarily expecting practitioners to carry out the task in great depth. This was also dependent on practitioner level, for example 'leadership and management', which spans from an initial awareness, to actually leading/managing projects at later stages of one's career.

Fig. 4 shows, for each informatics discipline, the total number of occurrences of competencies related to particular domains. The most frequently described domains were data, information management and systems development and evaluation. Health Informatics was represented most frequently in the majority of domains with the exception of the data domain, where bioinformatics was represented most frequently.

To conclude, a core set of skills and competencies around data, information management and information systems are fairly generic to all informatics disciplines.

3.2.1. Competencies and skills

Thirty-five publications describe the competencies and skills required for different informatics domains (Tables 4 and 5). In this section we describe the key publications that reflect an attempt to generate or identify informatics competencies and skills relevant to the entire informatics discipline.

Jidkov et al. [13] identified a paucity of Health Informatics (HI) representation in clinical training curricula in UK postgraduate medical education and training. The authors applied a mixed-methods approach using a scoping review, curricula content analysis and interviews with experts, resulting in a set of 6 competency domains for Health Informatics: Information governance & security, system use & clinical safety, digital communication, patient empowerment, emerging technologies and information knowledge & management.

Attwood et al. [14] analysed commonalities between major global surveys on Bioinformatics and computational training needs, such as the 2013 Society of Experimental Biology (SEB) survey. Findings suggest the most important skills include data and statistical analysis, interpretation, and the management, storage and sharing of data [14].

Several publications focused on competencies and skills for Nursing Informatics (NI). Hübner et al. [15] present a core competency recommendation international framework called Technology Informatics Guiding Education Reform (TIGER), which aims to define globally accepted competencies for nurses. Hübner et al. conducted a survey among 43 experts in nursing from 21 countries along with a workshop at an international conference and the compilation of exemplar case studies [15]. The primary competency domains identified were data, information, knowledge, information exchange/sharing, ethical and legal issues, systems lifecycle, management, biostatistics and medical technology.

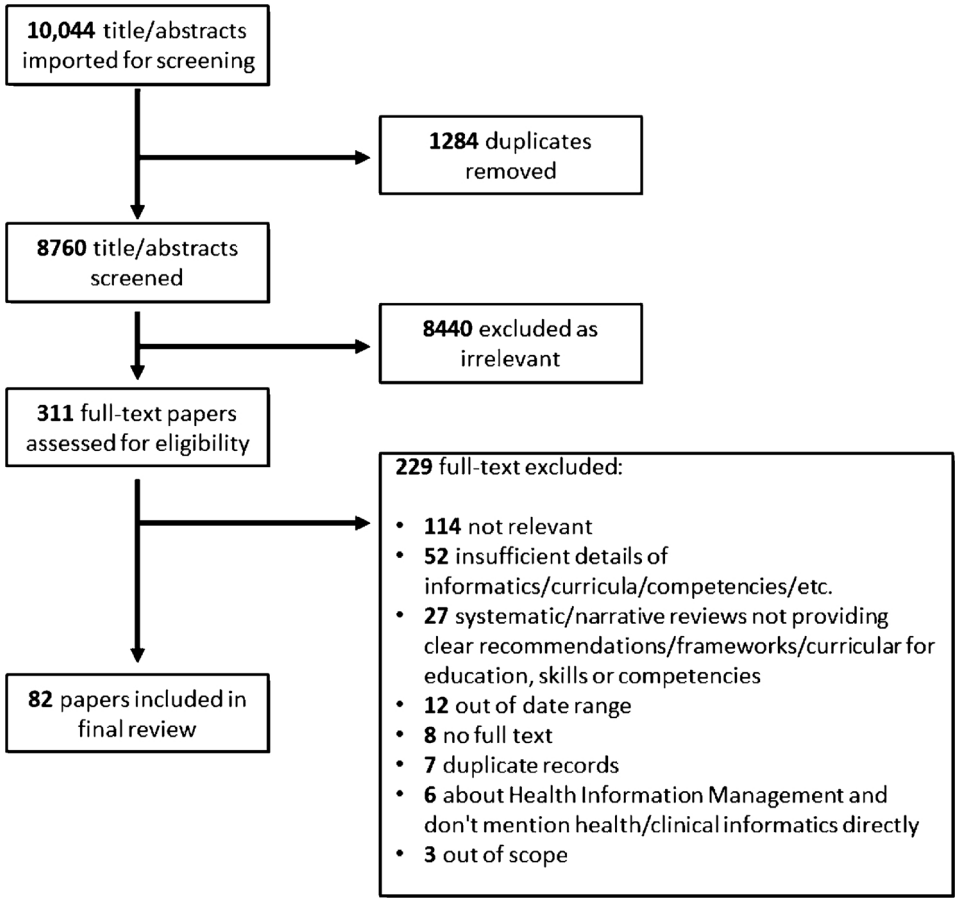

Fig. 1. PRISMA diagram for the literature screening process.

Honey et al. [16] describe the perspectives of 6 countries in relation to NI competencies for student nurses' entry to practice. The authors conclude that NI varies from by country and that the implementation must be compatible with local drivers to prepare nurses during the earlier stages of education [16]. Egbert et al. [17] describe an iterative method to develop national recommendations for NI. The proposed method involves the identification of publications relevant to a particular country, enhancing these with international literature, producing a survey containing the competencies, and conducting expert focus groups [17]. The method was applied to NI competencies in Austria, Germany and Switzerland with the resulting core competencies being synthesised into the TIGER project [17].

Finally, Kannry et al. [18] present an American Medical Informatics Association (AMIA) task force report concerning the required skills, knowledge and education for the role of Chief Clinical Informatics Officer (CCIO). The report states that AMIA's position is to standardize and define baseline knowledge and skills for the role, including clinical decision making, clinical care process improvement, health information systems and leading/managing change [18].

In conclusion, NI appears to be further ahead at defining and standardising core competencies than other informatics disciplines. This may in part be due to nurses making up the majority of the healthcare workforce in most countries and newer disciplines like Bioinformatics still finding their feet.

3.3. Existing competency frameworks

Many of the included publications referred to or mapped their curricula to existing competency frameworks, most notably the TIGER for Nursing Informatics initiative [16,42,49] and the ELIXIR for Bioinformatics [50,51].

The International Medical Informatics Association (IMIA)

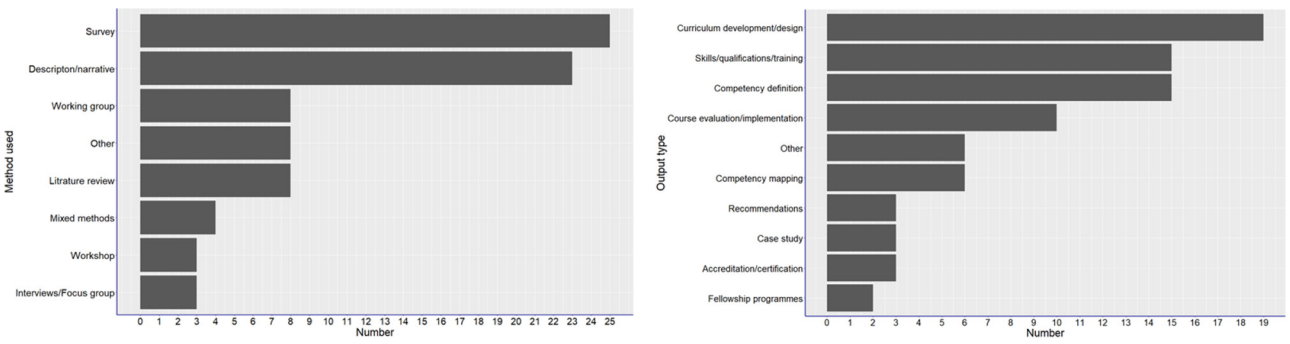

Fig. 2. (left) Summary of reported methods used, (right) Main output types described in publications.

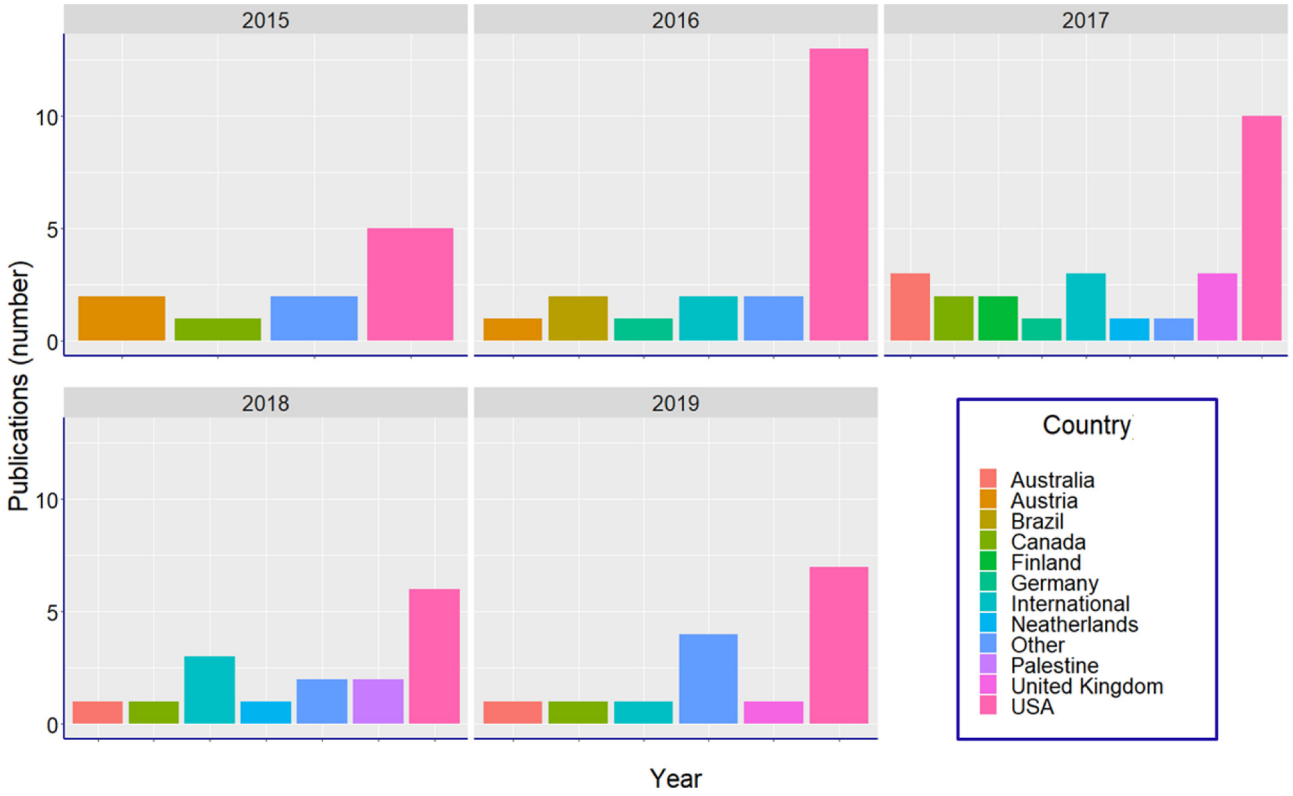

Fig. 3. Publications by year and setting/country of origin.

recommendations for education were also referred to in several publications [13,52,53]. For example, Mantas and Hasman [53] consider how the IMIA educational recommendations could be refocused for Nursing. The authors draw attention to nursing-related items that they believe should be added to the current required skills, including nursing information systems, nursing informatics management, nursing coding schemes, electronic health records that also include nursing records and evidence-based nursing [53]. Mantas and Hasman highlight that specific courses in and modules focused on Nursing Informatics are rare [53]. Jidkov et al. [13] mention that experts involved in their consultation stated that the IMIA framework, although a useful guide, is not comprehensive enough, and it is also not of relevance to all specialities [13].

In conclusion, some informatics disciplines have moved closer to wide spread, international competency definitions than others. The TIGER initiative used in Nursing Informatics, ELIXIR from Bioinformatics and the IMIA recommendations for education were mentioned most frequently in the reviewed publications.

3.4. Curriculum development and course design

Thirty-eight publications reported details of curriculum design.

For example, Smaradottir and Gerdes [54] discuss the implementation of a Health Informatics course on a Master's programme about "understanding technology". The course was designed to take into account the diverse professional backgrounds of its students [54]. Parker et al. [55] discuss their preference for subject-matter experts with research knowledge and experience in the field of Health Informatics for the purpose of curriculum development.

Wu, Raha and Zhang [56] customised their bioinformatics graduate programmes for diverse student backgrounds by allowing students to tailor their programme of study, for example by changing programming in Bioinformatics to several options, such as programming in R, Python or Perl [56].

Whether an educational programme works best as a dedicated or integrated one remains unclear. Haux, Marschollek and Zeisberg [57] discuss the use of dual degree options but also state that a drawback can be that graduates may not for example be considered 'full' Computer Scientists with a dual Computer Science and Informatics degree [57].

In conclusion, there is considerable professional diversity in the backgrounds of individuals undertaking informatics education. This may be related to the preponderance of informatics courses available at postgraduate level and few offerings at undergraduate level. It appears that optimal results are achieved when the educators themselves have diverse and specialised backgrounds and students can directly see or experience the application of technology on healthcare. Many of the courses and programmes presented were described narratively, making little or no reference to any formal evaluation or providing details of pedagogical theories.

3.5. Educational level

The majority of the courses and curricula developed were targeted at postgraduate Master's level (n = 16) followed by undergraduate (n = 12). Three of the 4 doctorate level courses were related to the doctor of Pharmacy (DPharm) qualification. Only 3 of the courses were aimed at basic introductory informatics courses. Three were fellowships and 6 were mixed level courses that covered multiple levels or were part of a residency program. Table 7 summarises the informatics domain and level of course for each publication. It appears that there are few informatics courses aimed at education levels below Masters and very few beginner and introductory courses. This is likely due to the fact that many of the informatics disciplines require previous completion of a health or science-based degree. This may also mean that there is a lack of awareness about the informatics disciplines before people have completed their first degree.

3.6. Job posting analysis

Six publications examined job listings [20,23,56,81,89,90]. A

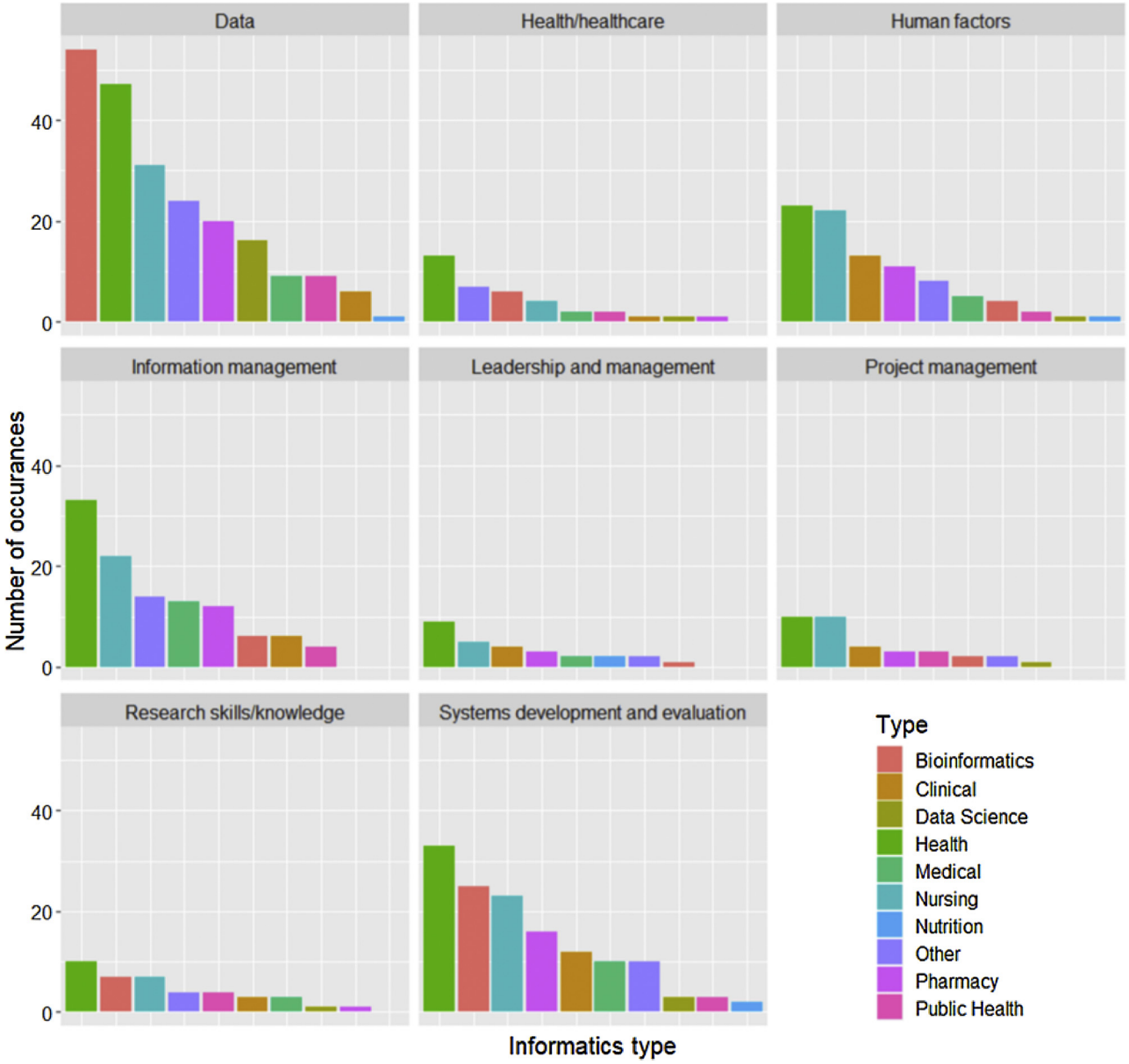

Fig. 4. Summary of competency domains by frequency of occurrence in the literature.

content analysis of job postings (n = 198) for healthcare data scientists in the USA identified the following primary skills: statistics, the programming languages R & Python, storytelling and machine learning [23]. The primary job focus areas were innovation, performance improvement and product development [23].

Ammenwerth and Hackl [89] examined job profiles of biomedical informatics graduates of both masters and bachelors programmes using a survey (n = 170). They found that roles of graduates in industry were varied and included system/user support, software engineering/customization/quality management, project & product management and IT consulting.

In their survey (n = 145) of job profiles for biomedical informatics undergraduates in Brazil, Macedoet al. [81] found similar results to Ammenwerth and Hackl [89] in terms of job activities. The authors highlight the following top five taught skills relevant to graduates' daily work: database systems, software engineering, object-orientated programming, data structures and introduction to computer science [81].

Wu and Palani [90] also investigated the US job market for bioinformaticians. The required skills most mentioned included programming, statistics, databases, big data analytics, biology knowledge, genomics, genetics and bioinformatics software tools and algorithms [90].

In conclusion, job listing analyses provide lists of skills and requirements that are similar to those described in the core competencies of courses and educational programmes, but job listings are more likely to mention specific tools, programming languages and database technologies. It also appears that the roles graduates partake in are diverse and tend to involve specialising in a smaller subdomain of practice.

4. Discussion

This is the first review to examine the core competencies and design of curricula for health-related informatics disciplines using a systematic approach and providing data synthesis. We identified eight competencies and skills that cut across the different sub-disciplines: (i) data, (ii) information management, (iii) human factors, (iv) project management, (v) research skills/knowledge, (vi) leadership and management, (vii) systems development and evaluation, and (viii) health/

Table 4
Publications focused on informatics competencies and skills (n = 35) by informatics type.

Author	Date	Informatics type	Curricula/competency type/other	Aims	Methods/Description
HITCOMP [19]	2020	Health	Database of competencies	To provide an online database of competencies and skills for healthcare roles and knowledge for educators, workforce developers, members and managers	An online searchable database with a web based front end
Attwood et al. [14]	2019	Bioinformatics and Data Science	Training needs	To review the main findings of a number of key surveys concerning worldwide bioinformatics and computational training	Qualitative discussion of survey results from: 1. SEB survey, 2013, 2. GOBLET survey, 2014, 3. ABPI surveys, 2008 and 2014, 4. ELIXIR-UK industry survey, 2014
Baig & Alzahrani [20]	2019	Healthcare Data Science	Skills	To identify skills (mandatory or desired) of data scientists to define the role of a health care data scientist	A skill set was produced by mapping the aspects of the data science mentioned in the papers introduction to a set of functions. This was used to define a job description
Jidkov et al. [13]	2019	Health	Competencies	To assess the UKs post graduate medical HI training across specialities against international standards	A mixed methods approach was applied with scoping review, content analysis of curricular, expert consultation and a scoping literature review
Martin et al. [21]	2019	Health	Competencies	To elicit focus group feedback on HI competencies for teaching of Doctor of Pharmacy (PharmD) curricula	Faculty feedback via 2 online focus groups from the American Association of Colleges of Pharmacy
McFarlane et al. [22]	2019	Public Health	Professional characterisation/ informatics needs of Public Health workforce	To provide characterisation of Public Health Informatics specialists and identify the informatics needs of the Public Health workforce	A cross-sectional study using PH WINS 2017 (Public Health Workforce Interests and Needs Survey) was analysed with descriptive statistics of primary demographics and informatics skills/needs and data required
Meyer [23]	2019	Health data scientists	Qualifications, skills and job focus	To examine the data science requirements of healthcare organisations including skills, qualifications and the focus of work	Data scientist job posting in the USA were analysed via content analysis of job postings using an inductive approach
Riley et al. [24]	2019	Health	Qualifications, skills and job focus	To map 4 domains of the health information management curriculum to a 5 year cohort of graduates. This will also capture the time from course completion to employment, as well as identify professional knowledge and skills used by graduates in their roles	Mixed methods descriptive approach using a survey
Strudwick et al. [25]	2019	Nursing	Informatics competencies	To obtain senior nurse leaders consensus on the priority of informatics competencies for national endorsement	A modified Delphi technique was used electronically over 3 rounds with nurse leaders who have substantial informatics knowledge. The first round participants had 26 potential competency statements from literature and commented on clarity/wording of each statement. Round 2 and 3 they rated remaining statements for priority using a 7 point Likert scale
Hübner et al. [15]	2018	Nursing	Core competencies	To both empirically define and validate a globally accepted core competency framework for HI	1. A survey carried out with experts for relevance of core competency areas 2. A workshop during the International Nursing Informatics Conference (NI2016) for clustering and validation of established areas and 3. Compilation of exemplar case studies to map findings to practice
Khader et al. [26]	2018	Health	Required Health Informatics skills	To provide an assessment of students' attitudes and beliefs around learning Health Informatics, as well as required skills needed, motivation and intention to learn	An online survey was used and analysed as a descriptive cross section of students taking part in various health orientated courses in 4 universities using an adapted version of the Technology Acceptance Model (TAM)
Mulder et al. [27]	2018	Bioinformatics	Core competency framework	To provide overview of status and use cases for a core competency framework that was designed to be relevant for multiple user personas and training programmes developed by the International Society of Computational Biology (ISCB) Education Committee task force	The ISCB ran several competency workshops at conferences and educational events. Three main steps were used: 1. Defining required bioinformatics competencies, 2. Defining user profiles and sub-groups requiring training and 3. How competencies can be applied to each user profile
Sayres et al. [28]	2018	Bioinformatics	Core competencies	Integrating bioinformatics into life science education via a core competency framework	Survey about teaching bioinformatics to undergraduate life scientists. Survey split into 3 sections. 1. Demographic data, 2. Real/perceived barriers to integration of bioinformatics into life sciences education and 3. Rating importance of 15 bioinformatics skills using Likert scale
Thye et al. [29]	2018	Interprofessional	eHealth competencies	To examine which competencies intersect different health care professional groups	A survey about eHealth competencies was used to assess their relevance to 12 professional roles using a scale of 0–100. Survey was analysed with logistic regressions for certain pairwise comparisons to look for differences between 1. Nurses and

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Table 4 (*continued*)

Author	Date	Informatics type	Curricula/competency type/other	Aims	Methods/Description
					physicians, 2. IT and executives and 3. Executives and direct patient care professionals
Valenta et al. [30]	2018	Health	Key competencies	Examples of competencies related to the foundational domains for both for curriculum development and accreditation for masters education in applied Health Informatics	Competencies were refined by the AMIA Accreditation Committee to create 10 foundational domains
Wholey et al. [31]	2018	Public health	Core competencies/curricular design	To describe a Public Health Informatics (PHI) curriculum (masters level) for the support of workforce development	Narrative description of how the curriculum is applied to the training of Public Health Informaticians via a Master's in Public Health and certificate program
Borycki et al. [32]	2017	Nursing	Nursing informatics competencies	To extend Nursing Informatics competencies to include technology-induced errors and Health Information Technology (HIT) safety	Extended literature review to include technology safety. This was built on a modified version of Stagger's framework [33]
Clay & Fisher [34]	2017	Bioinformatics	Baseline skills	Highlights the baseline skills required for pathologists for training in bioinformatics. To examine the barriers and proposed solutions to the incorporation of bioinformatics into general residency education	Narrative review examining the barriers and proposed solutions to the incorporation of bioinformatics into general residency education
Collins et al. [35]	2017	Nursing	Competency identification	To identify Nursing Informatics competencies that are perceived as both required and relevant to nursing leaders and nursing managers	A survey (with 3 rounds) using the Delphi method and an environmental scan
Dohan, Green & Tan [36]	2017	Health	Healthcare Informatics competencies	Exploration of the influence of Healthcare Informatics Competencies (individual level) on dynamic capabilities (organizational level) to determine their influence on healthcare organisations ability to innovate	Questionnaire with 27 competency items that were self-rated by participants for perceived proficiency. Factors were identified from competency models using Exploratory Factor Analysis aggregated at group level. Partial Least Squares was then used for impact measurement of groups on organization-level dynamic capabilities
Hersh et al. [37]	2017	Clinical	Competencies and Learning Objectives	To describe a curriculum that includes Clinical Informatics into an undergraduate medical course and lessons learned	Formed a working group to develop curriculum architecture, define competencies and learning objectives and to map these onto the Accreditation Council for Graduate Medical Education (ACGME)
Honey et al. [16]	2017	Nursing	Entry to practice competencies	Exploration of international competencies for the preparation of nurses for using technology when entering practice	Authors are members of the International Medical Informatics Association special interest group, Nursing Informatics (IMIA-NI) Education Working Group and present summaries of their countries development and use of informatics competencies to educate nurses
Martin-Sanchez et al. [38]	2017	Health	Competency role in certification	Highlights the impact of the Australian Health Informatics Competencies Frameworks impact on raising the profile of profile of Health Informaticians in Australasia	Produced a competency framework based on existing frameworks following removal of repetition, overlap and redundancies. A comparative analysis is also presented between the different organisations (AHIEC, IMIA, AMIA, COACH and CHIA)
McGregor et al. [39]	2017	Health	Workforce skills and e-health knowledge	Exploration of stakeholders' perceptions regarding e-health knowledge and workforce skills	Two focus groups with interviews analysed using Thematic Analysis. Participants had experience and/or expertise in e-health education
Sapci & Sapci, 2017 [40]	2017	Health	Informatics skills exercises	To evaluate a smart-home healthcare and lab course. Determine students' confidence in operating home health wireless monitoring pre and post lab course	Web based questionnaires pre and post training
Egbert et al. [17]	2016	Nursing	National recommendations for Nursing Informatics competencies	To develop a methodology for deriving national (country specific) recommendations for core nursing informatics competencies for 3 countries	A 3 step iterative method involving 1. National competency identification, 2. Survey based on these identified competencies and 3. Two expert focus groups
Greene et al. [41]	2016	Bioinformatics	Competency identification and proposing related courses	1. Identification of core competencies for scientists processing big data. 2. Subsequent to this to propose courses structured around those competencies for adaption into existing curricula	Not an empirical paper. Provides a narrative literature review
Jensen et al. [42]	2016	Nursing	Required abilities	Identification of informatics abilities deemed essential to nursing management decision making	Survey with HI and management specialist nurses based on competencies around both information literacy and information management from Technology Informatics Guiding Education Reform (TIGER), asking which of these competencies are essential to decision making in management. Rasch analysis was used presenting results in logits
Kannry et al. [43]	2016	Clinical			

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Table 4 (*continued*)

Author	Date	Informatics type	Curricula/competency type/other	Aims	Methods/Description
			CCIO Skill, scope, knowledge and education requirements	To delineate the education, knowledge, skills and scope of operation for a CCIO	Skillset and scope of operations recommendations formulated by AMIA task force for CCIO for professional development and hiring process
Massoudi, Chester & Shah [44]	2016	Public Health	Informatics capacity/needs for local health departments	To describe the various informatics development needs of staff of local health departments (LHDs)	Analysis of data from the Informatics Capacity and Needs Assessment Survey (2015). 650 LHDs were drawn from the survey as a representative sample using a secondary questionnaire (piloted with 20 informatics staff members) to explore the informatics capacity and needs of local health departments
Molinar et al. [45]	2016	Nutrition	Nutrition Informatics skills	Presents the findings of a Nutrition Informatics survey (third survey 2014) to determine value to students and professionals of electronic information	An anonymous web-based survey distributed by the Healthcare Information and Management Systems Society (HIMSS) on behalf of the Academy of Nutrition and Dietetics
Valenta et al. [46]	2016	Clinical/translational scientists	Core competencies	To describe the process relating to the updating of core competencies for Clinical and Translational Science (CTS) trainees and present new competencies endorsed by AMIA the Clinical Research Informatics working group	Evaluation of competencies by workgroup members against relevance. Missing competencies were added and existing ones refined, revised or removed. They were then rewritten to account for the skills and knowledge of CTS trainees (Masters level) based on Bloom's Revised Taxonomy of Educational Objectives
Gibson, Dixon & Abrams [47]	2015	Health	Convergence of competencies by comparison across fields	To provide a review of the definitions of Health Information Management (HIM) and Health Informatics (HI) with a comparison of domains and competencies, education and credentialing and where these areas converge	HIM and HI were compared using core competencies that were produced by principle bodies offering accreditation and credentialing. Core competency lists were produced iteratively and by discussion

Table 5
Characteristics of sample size, type and main outcomes measured (n = 35).

Author	Date	Primary target population	Setting/country of origin	Sample size	Main outcome
HITCOMP [19]	2020	Educators, workforce developers, managers, students	International	N/A	Lists of competencies are determined based on 4 factors. 1. Domain, 2. Competency quadrant, 3. Area of competency and 4. Level
Attwood et al. [14]	2019	Bioinformatics/data science trainers	International	N/A	A summary of the key training needs as reported in recent surveys. 1. Data analysis, 2. Data mining, 3. Data integration, 4. Cloud and HPC, 4. Programming/scripting, 5. Statistics and 6. Bioinformatics tools/ resources
Baig & Alzahrani [21]	2019	Healthcare data scientists/ employers	Saudi Arabia	N/A	A set of functions a data scientist should be able to carry out. 1. Domain knowledge, 2. Data management, 3. General Statistics/ Biostatistics, 4. Analytics, Data Visualization and 5. Machine Learning (ML) and AI
Jidkov et al. [13]	2019	Postgraduate medical educators/ students	United Kingdom	71 UK postgrad curricular 21 Curricular 7 UK HI experts	A framework consisting of 50 HI domains. Findings suggest that post graduate medical education in the UK neglects competencies reflected in international standards
Martin et al. [21]	2019	PharmD students	USA	8 focus group participants	11 sources were used to generate a list of pharmacy informatics competencies
McFarlane et al. [22]	2019	Public Health Workforce	USA	17,136 state health agencies central office employees and 26,533 local health department employees	Core Public Health that overlapped with Public Health Informatics competencies. A set of training questions around 1. Identification of appropriate data sources, 2. Data collection for decision making, 3. Participation in quality improvement process and 4. Evidence based approach identification to address Public Health issues
Meyer [23]	2019	Healthcare organisation using data scientists	USA	198 job postings	Primary skills identified from data science job postings with the primary skills being 1. Python, 2. R, 3. Machine Learning, 4. Statistics and 5. storytelling
Riley et al. [24]	2019	Employers and course providers	Australia (LTU and, previously, Lincoln Institute of Health Sciences)	167 Graduates of health information management courses from 2012 to 2016	Main duties were mapped to 4 taught knowledge and skills domain combinations (health classification and health ITC). Roles required use of 3 or 4 of the knowledge/skills domains (35.2 % and 26.4 %)
Strudwick et al. [25]	2019	Nursing leaders	Canada	Senior nurse leaders round 1 (n = 25), round 2 (n = 24), round 3 (n = 23)	Produced a list 24 competency statements of priority to senior nurse leaders
Hübner et al. [15]	2018	Nursing Educators, workforce developers, managers, students	21 countries worldwide; Americas (4 countries), Europe (10 countries), Asia (5 countries) and Australia/Pacific (2 countries)	43 nursing experts from 21 countries	A recommendation framework consisting of 10 core competency areas in 5 roles sorted by highest relevance. Identified roles: 1. clinical nursing, 2. Quality management, 3. Coordination of inter-professional care, 4. Nursing management and 5. IT management in nursing
Khader et al. [26]	2018	Health Informatics educators	Jordan and Palestine	30 students (pilot survey), 891 students in actual survey (Applied medical sciences n = 325, Nursing n = 273, Medical n = 196, Pharmacy n = 97)	Skills identified by students as related to Health Informatics and students areas of interest
Mulder et al. [27]	2018	Bioinformatics educators	International	Unspecified	A list of Bioinformatics core competencies, mapping competencies to user personas using Bloom's Taxonomy
Sayres et al. [28]	2018	Life sciences educators	USA	1260 faculty participants representative of 50 states in the USA	A Network for Integrating Bioinformatics into Life Sciences Education (NIBLSE) bioinformatics core competencies for undergraduate life scientists
Thye et al. [29]	2018	Inter-professionals	International	892 participants	A top 10 list of eHealth competencies for professionals clustered into 4 groups. 1. Direct patient care, 2. Executives, 3. IT and 4. Science/education
Valenta et al. [30]	2018	Curriculum developers	USA	N/A	10 domains with example statements of associated knowledge, attitudes and skills
Vincent et al. [48]	2018	Biology students	Universite Laval, Quebec City, Canada	N/A	Course overview: 1. Part 1 – Informatics, 2. Part 2 – Biological databanks and 3. Part 3 – Structural Bioinformatics

(*continued on next page*)

Table 5 (*continued*)

Author	Date	Primary target population	Setting/country of origin	Sample size	Main outcome
Wholey et al. [31]	2018	Public Health educators	USA	N/A	Lists of Public Health Informatics declarative and procedural competencies
Borycki et al. [32]	2017	Nursing informatics	International	Unspecified	Adds to the of Stagger's framework [33] by adding Health Information Technology Safety Competencies based on nursing informatics level (beginner, experienced, specialist, innovators and researchers)
Clay & Fisher [34]	2017	Anatomic and clinical pathology residents	USA	N/A	Core skills pathologists should know about bioinformatics. 1. Data structure, 2. Data pipelines, 3. Data manipulation and 4. Data regulations in the clinical laboratory setting
Collins et al. [35]	2017	Nurse leaders and/or nurse managers	Massachusetts and Rhode Island, USA	101 participants managers/practitioners (round one n = 34, round two n = 26, round 3 n = 41).	108 competencies were reduced to 74 during 3 rounds of a Delphi study
Dohan, Green & Tan [36]	2017	Paramedic leaders	Land-based paramedic services, Canada	502 paramedics from 43 organisations	The 3 factors identified were: 1. Technology Application Competencies, 2. Information Processing Competencies and 3. Understanding of the Workings of Technology
Hersh et al. [37]	2017	Undergraduate medical students	USA	N/A	A set of competencies and learning objectives
Honey et al. [16]	2017	Nurse educators	New Zealand, USA, England, Australia, Finland and Canada	Unspecified number of members of the International Medical Informatics Association special interest group, Nursing Informatics (IMIA-NI) Education Working Group	A summary of current status from each of the six countries regarding the development and use of informatics competencies to educate nurses
Martin-Sanchez et al. [38]	2017		Australia	N/A	
McGregor et al. [39]	2017	Clinical Health degree educators	University of Sydney, Australia	23 participants (large focus group), 4 breakout groups with 5−6 participants per group	Three primary themes with associated sub-themes. 1. Reinforce fundamental competencies, 2. Adapt and acknowledge existing competencies and 3. Introduce/provide opportunities for new learning
Sapci & Sapci [40]	2017	Nursing students/ educators	USA	64 students pre-training, 49 post-training	Course covers decision making with remote sensor data. Descriptive results presented for questionnaires
Egbert et al. [17]	2016	Those defining core competencies at national level	Austria, Germany and Switzerland	14 experts consulted. Survey 1 (n = 87), survey 2 (n = 81). Focus group 1 (n = 23 German experts), focus group 2 (n = 25 from Austria, Germany and Switzerland)	An iterative methodology used to define core competencies for specific roles for the 3 countries
Greene et al. [41]	2016	Unspecified	USA	N/A	Suggest the inclusion of 3 courses. 1. "The Flow of Biological Information", 2. "Statistical Challenges of Big Data" and 3. "Computational Challenges of Big Data"
Jensen et al. [42]	2016	Nursing managers	Brazil	18 abilities from information literacy and 38 abilities from information management	Abilities from both information literacy competency and information management identified as essential in nursing management decision making
Kannry et al. [43]	2016	CCIOs	USA	N/A	A derived set of Knowledge, Education, and Skillsets for a CCIO consisting of a derived set of Knowledge, Education, and Skillsets for a CCIO.
Massoudi, Chester & Shah, 2016 [44]	2016	Local health departments	USA	324 local health departments from 50 states	A list of the specific informatics development needs for staff
Molinar et al. [45]	2016	Nutrition Informatics professionals and students	USA	1140 academy members (Academy of Nutrition and Dietetics)	A Top 10 areas of involvement for decision makers related to activities around Information Technology
Valenta et al. [46]	2016	Clinical and Translational Science students and educators	USA	N/A	A list of informatics competencies for Clinical and Translational Scientists
Gibson, Dixon & Abrams [47]	2015	Those defining core competencies	Canada and USA	6 primary domains and 34 knowledge concepts that were relevant to either or both HIM and HI	1. Discussion on definitions of both HI and HIM. 2. Compared competency lists

Table 6
List of competencies/skills and frequency of occurrence in included publications.

Domain/competency or skill	n
Data	
Statistics/modelling and simulation	36
Data processing/analysis	30
Data security/ethics	28
Health data management principles	24
Databases	24
Decision support	23
Data visualisation	18
Data representation (reporting)	13
Big data	9
Machine Learning and Artificial Intelligence (AI)	5
Natural Language Processing (NLP) + text-mining	4
Cloud computing	3
Information management	
Regulatory frameworks and policies	24
Electronic Health Records (EHRs)	23
Awareness of privacy and governance	21
Use of information processing tools/systems in healthcare	16
Architectures of information systems	7
Management and implantation of information systems	5
Hospital/clinical IT systems	5
Clinical coding	5
Information systems to support patients and public	4
Human factors	
Socio-organizational and socio-technical issues	14
Patient safety	12
Stakeholder engagement/requirements gathering	11
Clinical decision making	10
Interdisciplinary/multidisciplinary cooperation	10
Digital communication	9
Human Computer Interaction (HCI)	7
User support	6
Usability (UX) testing	6
User/human centred design	5
Project management	
IT project management	17
Process management	9
Quality management	9
Research skills/knowledge	
Evidence based practice	20
Management of scientific research	13
Study design	7
Leadership and management	
Management and leadership skills	13
Change management	12
IT consulting	3
Systems development and evaluation	
Health technologies (e.g. telehealth/medicine, eHealth, mHealth)	30
Software engineering/development (programming)	22
Evaluate and select/implement appropriate systems	20
Interoperability	14
Basic ITC skills	11
Algorithms	10
Systems life-cycles	10
Systems quality management	8
Software customization	6
Data types/structures	4
Health/healthcare	
Biological concepts	9
Health economics	7
Health administration	6
Organisation of health institutions	5
Models of care delivery	4
Assistive technologies	4

healthcare.

Many of the included publications describing curricula and course design lacked robust evaluation. Different informatics disciplines varied considerably in their adoption of standardised competencies. For NI, for example, large-scale international initiatives like the TIGER project are available, whereas other disciplines do not yet have established initiatives. This also varies across countries. The USA consistently publishes larger volumes of work around defining competencies, skills and the design of curricula than other countries. This is contrasted with countries such as India that face restrictions to practical resources that can impact students' and educators' exposure to digital practice [61]. Sub-Saharan Africa is also developing its capacity in Data Science and Bioinformatics but still faces challenges such as lack of job positions, funding, access to software and low publication rates [60]. Due to the wide variation in working environments and the needs of trainees, it is unlikely that stand-alone and generic competencies will be effective [91].

Many of the included publications did not employ empirical methods, but instead provided narrative descriptions. This made it difficult to apply quality criteria and use established research critique frameworks. This also made synthesis difficult as many publications had large lists of competencies and little or no statistical results to use as a basis for comparison. There are many terms used for the different informatics disciplines, with some changing over time and others being umbrella terms, such as 'biomedical informatics', as discussed by Shortliffe and Blois [92]. This makes searching for relevant sources more challenging. However given the number of citations returned by our search strategy, a broad range of literature was captured by this review.

AMIA has expressed a desire for standardisation of roles like CCIOs, including the professional knowledge and skills they should possess [18]. More widely adopted and agreed standards and competencies can help to provide a baseline set of skills and standards from which individuals and educators can draw to create unified and consistent requirements for both education and industry.

This should be tempered with the flexibility to allow for adaptation to local needs and perspectives to be truly useful and widely adopted [13,15].

The findings of this review tally with those of Jidkov et al. [91] that highlight the lack of reproducible methodology reported in curricula. Additionally, informatics-related curriculum design is challenging due to the varied professional backgrounds of students and rapid industry changes [55,56]. Curriculum development can be aligned with industry needs by connecting to professional organisations and keeping in contact with and seeking feedback from former graduates [55]. There are many existing examples of good practice related to this, such as AMIA's Informatics Partnership Council (IPC) that receives input from the private sector to inform educational matters. In the UK, the national research institute, Health Data Research UK (HDRUK) will also be working with cross sector partners (including professional bodies) to shape and deliver programmes and opportunities that will increase skills capacity in clinical and non-clinical workforce.

In addition to peer reviewed academic publications, many organisations have opted to list their methods and details of curricular and competency development directly on their websites. Although this is not the main focus of this review, it should be noted that such details, including details of meeting accreditation standards for various organisations are provided (e.g. [93–95]).

Finally, informatics practitioners who carry out diverse job roles with specialisation in specific areas such as software engineering may struggle to meet all the competencies required of the informatics disciplines. Thought should be given to how such individuals can meet these broader competencies if they are required for professional accreditation or membership of organisations.

Based on the findings of this review, we make several recommendations for those considering applying competencies for course, curriculum design or for professional accreditation, many of which are already being routinely followed by various organisations.

4.1. Recommendations

- Competencies should have flexibility built in to allow for local

Table 7
Course education levels by informatics discipline.

Author	Date	Informatics type	Level					
			Foundation	Under graduate	Post graduate (masters/PGcert)	Post graduate (doctorate)	Fellowship	Other
Davies et al. [58]	2019	Bioinformatics	–	–	✓	–	–	–
Guerfali et al. [59]	2019	Bioinformatics	–	–	–	–	–	3 months advanced
Shaffer et al. [60]	2019	Bioinformatics and data science	–	–	✓	–	–	Various levels
Verma & Gupta [61]	2019	Nursing	–	✓	–	–	–	–
Vey et al. [62]	2019		–	–	–	–	✓	–
Ahonen et al. [63]	2018	Nursing, other health and social care, business	–	✓	–	–	–	–
Amro et al. [64]	2018	Health	–	✓	–	–	–	–
Feenstra et al. [65]	2018	Bioinformatics	–	–	✓	–	–	–
Madlung [66]	2018	Bioinformatics	–	✓	–	–	–	–
Mai et al. [67]	2018	Clinical	–	–	–	–	✓	–
Smaradottir & Gerdes [54]	2018	Health	–	–	✓	–	–	–
Torous et al. [68]	2018	Clinical	–	–	–	–	–	Residency
Valenta et al. [30]	2018	Health	–	–	✓	–	–	–
Vincent et al. [48]	2018	Bioinformatics	–	–	✓	–	–	–
Behrends, Steffens & Marschollek [69]	2017	Medical	–	✓	–	–	–	–
Clay & Fisher [34]	2017	Bioinformatics	✓	–	–	–	–	–
Custis, Hawkins & Thomason [70]	2017	Health	–	–	✓	–	–	–
Flynn et al. [71]	2017	Pharmacy	–	–	–	✓	–	–
Fossum et al. [72]	2017	Health	–	–	✓	–	–	–
Fox et al. [73]	2017	Pharmacy	–	–	–	✓	–	–
Hersh et al. [37]	2017	Clinical	–	✓	–	–	–	–
Khuri, VanHoven & Khuri [74]	2017	Bioinformatics	–	✓	–	–	–	–
Parker et al. [55]	2017	Health	–	✓	✓	–	–	–
Sapci & Sapci [40]	2017	Health	✓	–	–	–	–	–
Wei, Zhang & Yun-Feng [75]	2017	Medical	–	✓	–	–	–	–
Zainal et al. [76]	2017	Pharmacy	–	✓	✓	–	–	–
Ammerwerth et al. [77]	2016 2017	Health	–	–	✓	–	–	–
Breeden & Clauson [78]	2016	Pharmacy	–	–	✓	✓	–	–
Greene et al. [79]	2016	Bioinformatics	–	–	–	–	–	General course recommendations
Henricks et al. [80]	2016	Pathology	–	–	–	–	–	Residency
Macedo, Ruiz & Baranauskas [81]	2016	Bioinformatics	–	✓	–	–	–	–
Mendez et al. [82]	2016	Bioinformatics	–	–	–	–	–	Internship
Paliulis et al. [83]	2016	Bioinformatics	✓	–	–	–	–	–
Silverman, Lehmann & Munger [84]	2016	Clinical	–	–	–	–	✓	–
Wu, Raha & Zhang [56]	2016	Bioinformatics	–	–	✓	–	–	–
Fuji & Galt [85]	2015	Health	–	–	–	✓	–	–
Restrepo & Meraz [86]	2015	Nursing	–	–	✓	–	–	–
Sánchez-Mendiola et al. [87]	2015	Biomedical	–	✓	–	–	–	–
Wright et al. [52]	2015	Health	–	–	✓	–	–	–
Wu & Palani [88]	2015	Bioinformatics	–	–	✓	–	–	–

variations

- Course and curriculum designers should connect with industry contacts and former students to ascertain changes in industry that should be reflected in course/curriculum content
- Consideration should be given to how individuals working in a more specialised area of informatics can meet broader competency requirements
- Those publishing details of courses and curricula should use and report reproducible methods, linked to pedagogic theory and with some form of objective evaluation
- There is a need for informatics training and exposure at pre-degree level to promote the informatics professions and encourage student uptake

5. Conclusion

Cross-cutting informatics competencies are focused mainly around data, information management, human factors, project management, research skills/knowledge, leadership and management, systems development and evaluation, and health/healthcare. There is a need for standardised baseline competencies that are flexible enough to be adapted for local need. The disciplines with the most variation appear to be Bioinformatics and Pharmacy Informatics, with the former requiring knowledge of genetics, genomics and bioinformatics algorithms and tools, and the latter emphasising electronic prescribing and management systems. Most informatics education is delivered through postgraduate level courses. To prepare future informaticians to work in the field of informatics and close some of the skills deficits, informatics training is required at earlier educational stages.

Authors' contributions

AD wrote the manuscript and carried out the review and analysis/synthesis of literature. Both AD and JM screened the title and abstracts of all papers yielded by the literature search as well as the full text of the final included papers. GM supervised the project and JM and GM both reviewed the manuscript and made edits and suggested changes.

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Ethics committee approval

Ethical approval was not required for this systematic literature review

Declaration of Competing Interests

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Appendix A. Supplementary data

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