A curricula-based comparison of biomedical and health informatics programs in the USA

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ABSTRACT

Objective The field of Biomedical and Health Informatics (BMHI) continues to define itself, and there are many educational programs offering 'informatics' degrees with varied foci. The goal of this study was to develop a scheme for systematic comparison of programs across the entire BMHI spectrum and to identify commonalities among informatics curricula.

Design Guided by several published competency sets, a grounded theory approach was used to develop a program/curricula categorization scheme based on the descriptions of 636 courses offered by 73 public health, nursing, health, medical, and bioinformatics programs in the USA. The scheme was then used to compare the programs in the aforementioned five informatics disciplines.

Results The authors developed a Course-Based Informatics Program Categorization (CBIPC) scheme that can be used both to classify coursework for any BMHI educational program and to compare programs from the same or related disciplines. The application of CBIPC scheme to the analysis of public health, nursing, health, medical, and bioinformatics programs reveals distinct intradisciplinary curricular patterns and a common core of courses across the entire BMHI education domain.

Limitations The study is based on descriptions of courses from the university's webpages. Thus, it is limited to sampling courses at one moment in time, and classification for the coding scheme is based primarily on course titles and course descriptions.

Conclusion The CBIPC scheme combines empirical data about educational curricula from diverse informatics programs and several published competency sets. It also provides a foundation for discussion of BMHI education as a whole and can help define subdisciplinary competencies.

INTRODUCTION

For decades, biomedical and healthcare informaticians have debated the definition of their field.[1–8] Published opinions range from those of individuals to dedicated working groups of professional informatics associations (eg, Hersh,[3] Gardner *et al*[7]). Yet, substantial variations remain in understanding what biomedical and healthcare informatics comprise, and what the field should become. No consensus exists regarding required professional competencies in the domain, nor has key content of supporting educational curricula been established. In an attempt to better define the discipline, the present study analyzes curricula of existing US informatics educational programs. The authors present a holistic view of the domain from the perspective of current educational options.

BACKGROUND

Definitions

The first challenge is defining the term 'informatics' across the biomedical and healthcare domains. There are many published definitions of individual subdisciplines within the domain, such as Bioinformatics,[1–3] Medical,[4 5] Health,[6] Clinical,[7] and Nursing Informatics.[8] These subdisciplines differ culturally[9] as well as in scientific content and goals.[10] On the other hand, there are significant overlaps among the individual definitions,[9] and an increasing convergence in the methodologies of the subdisciplines can be seen in their shared techniques and approaches.[1 9 11] These parallels suggest the need to view the domain as a unified discipline with multiple areas of application.[12] The concept of a unified discipline has been discussed in the literature. Shortliffe and Blois proposed 'Biomedical Informatics' (BMI) as an umbrella term designating 'the scientific field that deals with biomedical information, data, and knowledge—their storage, retrieval, and optimal use for problem solving and decision-making.'[5] They propose BMI includes the entire domain ranging from the biological sciences to medical research, clinical care, and public health informatics.[5] The use of BMI as an all-inclusive term is also endorsed by the American College of Medical Informatics.[13]

Hersh[3] suggested 'Biomedical and Health Informatics' (BMHI) as the most comprehensive term for all fields concerned with the 'optimal use of information, often aided by the use of technology, to improve individual health, healthcare, public health, and biomedical research.' In his view BMHI includes bioinformatics, various subspecialties in medical (clinical) informatics, and public health informatics. Interestingly, the terms medical and clinical informatics are used interchangeably by Hersh in reference to the health of an individual, as distinct from public health informatics, which concerns population health. However, the recently published American Medical Informatics Association (AMIA) white paper on Clinical Informatics as a subspecialty defines the latter as encompassing both individual and population health.[7] It puts greater emphasis on the analysis, design, and evaluation of information and communication systems as fundamental elements of clinical informatics. Lastly, the terms medical and biomedical are frequently used to describe informatics programs with very similar curricula, so this study treats them as belonging to the same category of medical informatics.

The effort to define BMHI subspecialties is further complicated by the fact that some focused informatics concentration areas span several broader areas. For example, imaging informatics can be a component of both bioinformatics and medical/clinical subdomains. Likewise, the emerging subspecialty of clinical research informatics spans medical/clinical and public health domains.[3 14] In this study, the term BMHI is used to refer to the entire domain, which is viewed as a collection of related practice areas or subspecialties.

Informatics competencies

A number of competency sets have been proposed for the BMHI domain and its subdomains. These sets tend to overlap in content, but vary substantially in format and level of detail. Hersh[3] presents a broad schematic outline of BMHI competency areas as a list of disciplines originating from three categories of sciences: health and biological, management and social, and computational and mathematical. The International Medical Informatics Association (IMIA) recommendations issued in 2000 and revised in 2010 present a set of health and biomedical informatics competencies. Though similar in scope, these recommendations identify expectations at the level of specific knowledge and skills.[15 16]

Efforts have been made to define generic informatics skill sets applicable to multiple areas of BMHI, such as the skill set presented in the American College of Medical Informatics report[13] in the form of a concise list of informatics/computer science skills. There are also several extensive and granular subspecialty-specific competency sets proposed for bioinformatics,[17] public health,[18] clinical,[7] nursing,[19] and other informatics disciplines (see Mantas *et al*[16] for a comprehensive list of published competencies). These competency sets vary substantially in their organizing logic and structure as well as their scope (emphasis on generic informatics skills versus knowledge and skills related to a particular job or role). Despite these variations, some specific skills (eg, programming or project management) are common across most competency sets.

Educational curricula

BMHI educational curricula demonstrate even greater variation than do the existing competency guidelines. Additionally, curricula evolve over time, both because of the newness of the field and in response to the job market. Historically, biomedical education in the USA tended to be more theoretical and research-oriented with a narrow focus and higher levels of academic programs (doctoral and postdoctoral).[20] However, curricular frameworks have been proposed even for doctoral-level biomedical informatics education that would cover the 'entire scientific spectrum, from theory to application.'[21]

Some subfields of healthcare-related informatics (eg, nursing informatics) have always been more practice-oriented, offering degrees at the master's rather than the doctoral level. Technological advances, developments in genomics, and the move from curative to preventive patient care have broadened the scope of BMHI education, which now includes preparation for a wider range of informatician roles in health and biomedicine.[20] With a greater focus on practice settings such as hospitals, informatics has increasingly become an applied profession.[22] The latter trend is exemplified by AMIA's 10×10 program, created to train an informatics workforce for the US healthcare system.[23 24] Our own survey of informatics educational programs shows a move toward increased practice-oriented educational options across the BMHI domain, including professional, non-thesis master's, and certificate programs.[25]

To date, a number of case studies have been published describing individual informatics programs.[1 11 12 26–28] There have also been attempts to assess the needs of the practice community and the implication of those needs for BMHI education.[29] Additionally, analysis of current curricula has been undertaken periodically as part of the competency development process for a subspecialty, as was the case with the AMIA's working group on nursing informatics.[30] However, the authors were able to find only one survey study that compared curricula across the broader spectrum of BMHI programs.[31] That study concentrated on medical and health informatics programs only. Though the scope of the study was international, it overlooked some programs that existed in the USA at the time.[32] The authors are not aware of any current attempt to compare and analyze curricula across the entire spectrum of BMHI education.

In summary, BMHI education continues to evolve, driven by a combination of changes in the practice domain, theoretical developments, and workplace demands, while tempered by the historic and pragmatic realities of institutional educational practices. Though many theoretical frameworks and competency guidelines have been proposed for informatics education, less attention has been paid to informatics education as offered today. Also neglected is the question of correspondence between actual BMHI education and theory. In other words, the understanding of what informatics education in various areas of BMHI should be differs from what it in fact is.

The field of biomedical and health informatics struggles to define itself, and while there is some convergence in discipline definitions and understanding of informatics competencies, there is, as yet, no consensus. There are a growing number of 'informatics' programs, but they vary substantially by academic level and focus.[33] Thus, while the debate continues as to what informatics education should be, this education already exists in competing forms; many programs having produced informatics professionals for over a decade. This suggests studying existing educational programs and their curricula, and examining how such knowledge can contribute to defining the informatics professions. The main goals of this study were to:

1. Develop a course-level scheme for program comparison across all subspecialties in the BMHI domain
2. Compare this scheme to existing competency classification schemes
3. Use this scheme to analyze educational commonalities and differences across a broad and diverse set of informatics programs. For the analysis, two specific questions were addressed:
    - Which knowledge/skill sets currently define education for the BMHI domain and its subdisciplines?
    - What are the common informatics competencies across the entire BMHI domain or some of its subdisciplines?

In addition to contributing to the general discussion of BMHI education, answers to these questions might provide practical suggestions for curriculum design within specific areas of informatics. Answers might also assist in building a comprehensive informatics program based on existing focused educational offerings at a given institution.

METHODS

The study was carried out in three stages: (1) selection of programs/courses for analysis of curricula; (2) development of a course/competency classification scheme; (3) analysis of curricula based on the classification scheme developed in the previous stage.

Selection of programs/courses for analysis

In related work, we have conducted biannual web-based surveys of informatics programs in the USA since 2002, maintaining a comprehensive database of such programs.[32] This database is regularly updated based on web searches for new and modified programs, comparisons with other resources describing academic informatics programs, and feedback solicited from the informatics community (for the survey methodology, see Hemminger *et al*[34] and Kampov-Polevoi and Hemminger[25]). The scope of the survey has grown over the years from a focus on bioinformatics alone to the inclusion of all other areas of BMHI. In the most recent survey, the depth of information about each program was expanded, and now includes curriculum and course details.[25]

This database of informatics programs is the most comprehensive representation of the current state of BMHI education in the USA of which we are aware. Emerging informatics areas covered by the survey, such as dental and cheminformatics, were excluded from the present study. We concentrated on bioinformatics, medical/biomedical, nursing, and health (including public health) informatics survey data. However, in utilizing survey data for this study, we found that we needed to analyze health and public health informatics programs as separate categories due to substantial differences in curricular focus.

The comparative analysis of curricula was performed based on master's degree program options for the reasons outlined below. Seventy percent of the graduate programs in our survey offer master's degrees. Most of the required or expected coursework for doctoral students is drawn from the master's degree requirements. While many programs offer graduate certificates, those vary substantially in scope and academic rigor (from three courses to 39 courses). Master's programs tend to have fairly consistent academic requirements with well-defined courses of study across institutions. They differ in this respect from doctoral programs which, by their very nature, are designed to be readily customized to the needs and research interests of individual students.

After selecting from our survey data all programs with a master's degree, we collected course titles and catalog descriptions from the program/institution websites. We included required/core courses and specified electives (ie, explicitly listed courses from which a student is expected to select a subset for their study) resulting in a total of 636 course descriptions. Programs not listing curricular details were removed from consideration. Additionally, we excluded from the analysis several programs with curricular matrices so flexible as to make it impossible to conclusively identify a set of specific courses required of all students. Finally, several of the programs examined in our 2008 survey were excluded because they appeared to be in decline or discontinued. Thus, of the 107 programs offering master's degrees, 73 were analyzed as part of the current study, including four in public health, 15 in health, 12 in medical, 15 in nursing, and 27 in bioinformatics. The list of institutions covered in this review appears in online appendix 1 (available at www.jamia.org/).

Development of the course classification scheme

The course classification scheme was developed following a grounded theory[35] approach with input from published competency guidelines. Initially, we attempted to match course descriptions to several of published competency schemes (eg, Clinical Informatics Competencies,[7] IMIA's Recommendations on Education in Health and Medical Informatics,[15] AMIA's Health Informatics Categorized Competencies,[36] and several others), but found that this approach left too many courses unclassifiable. We see two reasons for this difficulty. First, is the subspecialty specificity of most competency schemes, whereas we were attempting to arrive at a classification that would scale across all of the areas of the BMHI domain and be applicable to all of the programs being analyzed. Second, use of a course and its description as the unit of classification is problematic. While an academic course is the most natural unit of comparison across educational programs, existing competency schemes tend to be structured in a way that does not readily map onto a typical academic curriculum structure.

In developing our own course classification, we followed the iterative card sort method (for a detailed description, see Lincoln and Guba[37]). Course titles and descriptions were placed on index cards. Cards with similar course descriptions were grouped together, and card groups were then organized into broad thematic clusters following the constant comparison principle. Several iterations were required before we arrived at a scheme that allowed categorization of all but a few unusual courses, independent of the program origin of the course. The labeling and clustering of the card groups that emerged from this process were derived from the course titles and descriptions of course content, and also informed by the aforementioned published competency sets. The resulting scheme is referred to as the Course-Based Informatics Program Categorization (CBIPC).

Application of the course classification scheme

The CBIPC scheme developed in the previous stage was then used to code individual courses for each program in each informatics subspecialty. The authors, both familiar with informatics fields, performed the coding independently, assigning one code per course based on the main course topic. Overall, there was good intercoder agreement as measured by a κ coefficient (0.849). Consensus was achieved on all coding disagreements by means of discussion and detailed examination of the course description in the context of the program to which that course belonged.

Based on this final set of codes, a comparative mapping of curricula by informatics discipline onto the CBIPC scheme was generated. For this purpose, we used simple counts of presence of a given course type in each program.

RESULTS AND DISCUSSION

Given the qualitative nature of the analysis, we are combining the result reporting and discussion for each of the study goals.

CBIPC scheme

One of the main goals of the study was to produce a course classification scheme that would allow the description and comparison of curricula within and among biomedical and healthcare-related informatics programs. The course classification scheme that emerged from the second stage of the study is presented in box 1. The grouping of course types was guided by two main considerations. First, we attempted to make a distinction between discipline-specific topics and skills (eg, computational biology courses) and more generic topics/skills applicable across all informatics disciplines (eg, database systems). Second, where appropriate, we distinguished between informatics-related topics (ie, originating from information or computer science) and topics originating in other domains, such as management or life sciences.

The proposed scheme is based on analysis of the content of existing academic programs and thus reflects the current state of BMHI informatics education in the USA. This grounding in empirical data distinguishes our scheme from theory-based curricular frameworks such as that presented by Johnson.[21] The CBIPC scheme complements existing competency guidelines that describe the desired knowledge and skills of informatics professionals, and adds value because it directly connects competencies with course-based academic curricula within given informatics subspecialties. Additionally, the scheme accounts for

Box 1 Course-Based Informatics Program Categorization scheme for Biomedical and Health Informatics curricula

1. Introduction to Informatics
    - 1.1. Generic Informatics
    - 1.2. Health Informatics
    - 1.3. Medical/Biomedical Informatics
    - 1.4. Bioinformatics
    - 1.5. Public Health Informatics
    - 1.6. Nursing Informatics
    - 1.7. Consumer Health Informatics
    - 1.8. Cheminformatics
2. Information/Computer Science Core
    - 2.1. IT foundations (computers, networks, etc)
    - 2.2. Programming (including Data Structures, Algorithms)
    - 2.3. Database Systems (analysis, design, use)
    - 2.4. System Analysis and Design
    - 2.5. Data and Knowledge Representation (including data standards)
    - 2.6. Data Mining, Knowledge Management and Discovery (tools, methods)
    - 2.7. Decision Support Tools/Methods and Evidence-based Practices
    - 2.8. Human Computer and Human Information Interaction
3. Statistics and Research Methods
    - 3.1. Statistics
    - 3.2. Research Methods
4. Domain-Specific Information Systems
    - 4.1. Healthcare Information Systems
    - 4.2. GIS
    - 4.3. Other Domain-Specific Systems (eg, laboratory, library, business)
5. Domain-Specific Knowledge and Competencies
    - 5.1. Healthcare System (operations, delivery, policy)
    - 5.2. Public Health Core (Epidemiology, Prevention, etc)
    - 5.3. Advanced Practice Nursing
    - 5.4. Clinical Sciences
    - 5.5. Life Sciences
    - 5.6. Biotechnology (including related wet lab courses)
    - 5.7. Computational Biology
    - 5.8. Medical Imaging
6. Management Core
    - 6.1. Organizational Behavior and Management
    - 6.2. Business Topics (finance, administration, quality control and assurance)
    - 6.3. Project Management
    - 6.4. Strategic Planning and IT Management
7. Interaction with Society
    - 7.1. Legal, Ethical, and Social Issues
    - 7.2. Communication (scientific, public education, etc)

the presence of specialized non-informatics courses in academic curricula, such as Public Health core courses in Public Health Informatics programs or Advanced Practice Nursing courses in Nursing Informatics Programs.

Comparison of CBIPC to published competency sets

As stated in the Methods section, the CBIPC was developed in response to the difficulty experienced matching program curricula with most of the published competency sets beyond very general categorization, such as that proposed by Hersh.[3] Figure 1 illustrates the relationship between CBIPC and several competency sets using top-level categories from each scheme. The number of main categories in each scheme varies, as does the organizing principle, but some clear parallels exist between the various competency sets and the course classification scheme that emerged from this study. These parallels are more pronounced in management, social sciences, and subdiscipline-specific coursework/competencies, while there is substantial divergence among schemes in the information/computer science core of the CBIPC.

Figure 2 presents the information/computer science core in greater detail to show how the proposed scheme maps elements of existing competency sets onto typical informatics course offerings. These mapping discrepancies can be attributed to differences between the structuring of academic programs and

CBIPC	Clinical Informatics Core[7]	Revised IMIA Recommendations on Education in BMHI[16]	AMIA HI Categorized Competencies[36]
1. Intro to Informatics	1. Fundamentals	1. BMHI Core Knowledge and Skills 4. Optional BMHI modules	A. Data, Inf., and Knowledge: Representation and Structure
2.Information/ Computer Science Core	2. Clinical Decision-Making and Care-Process Improvement 3. Health Information Systems	1. BMHI Core Knowledge and Skills 2. Medicine, Health, and Biosciences, Health System Organization 3. Informatics, CS, Mathematics, and Biometry	B. Data, Inf. And Knowledge: Analysis and Manipulation D. Information Technology G. User and Use of Health Information Systems
3. Statistics and Research Methods		3. Informatics, CS, Mathematics, and Biometry	
4. Domain-Specific Information Systems	3. Health Information Systems	1. BMHI Core Knowledge and Skills	C. Health Care Systems
5. Domain-Specific Competencies	1. Fundamentals	2. Medicine, Health, and Biosciences, Health System Org. 4. Optional Modules	J. Professional Skills
7. Management Core	4. Leading and Managing Change	2. Medicine, Health, and Biosciences, Health System Org. 3. Informatics, CS, Math, and Biometry	H. Management and Operations of Health Information Systems I. Design and Evaluation of Health Information Systems
8. Interaction with Society	1. Fundamentals 4. Leading and Managing Change	1. BMHI Core Knowledge and Skills	G. User and Use of Health Information Systems

Figure 1 Relationship between Course-Based Informatics Program Categorization scheme and select published Biomedical and Health Informatics (BMHI) competency guidelines.

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<table>
<tr><th>CBIPC</th><th>Clinical Informatics Core[7]</th><th>Revised IMIA Recommendations on Education in BMHI[16]</th><th>AMIA HI Categorized Competencies[36]</th></tr>
<tr><td>2.1 IT Systems (computers, networks, etc.)</td><td rowspan="3">3.1 Information Technology Systems</td><td>3.1 Basic Informatics Terminology
3.2 PC Use
3.3 Electronic Communications
3.6 Technical Informatics</td><td rowspan="4">D. Information Technology (system architecture, development)
2.1 and D should match (IT vs. spelled out)</td></tr>
<tr><td>2.2 Programming</td><td rowspan="2">3.4 Methods of Practical Informatics
3.5 Theoretical Informatics</td></tr>
<tr><td>2.3 Database Systems (analysis, design, use)</td></tr>
<tr><td>2.4 System Analysis and Design</td><td>3.5 Information System Lifecycle</td><td>3.8 Information System Lifecycle</td></tr>
<tr><td>2.5 Data and Knowledge Representation (including standards)</td><td>3.4 Clinical Data Standards</td><td>1.11 Health Data Management, Coding
1.12 Health records
1.14 Data Representation
1.7 Nomenclature, Vocabularies</td><td>A. Data, Information, and Knowledge: Representation and Structure</td></tr>
<tr><td>2.6 Data Mining, Knowledge Management, and Discovery</td><td>3.1 Information Technology Systems</td><td>1.14 Data Representation and Analysis; Data Mining and Knowledge Management</td><td rowspan="2">B. Data, Information, and Knowledge: Analysis and Manipulation</td></tr>
<tr><td>2.7 Decision Support Tools and Methods; Evidence-Based Practice</td><td>2.1 Clinical Decision Support
2.2 Evidence-Based Patient Care</td><td>2.3 Clinical/Medical Decision-Making
2.6 Principles of Evidence-Based Practice
3.12 Decision Support</td></tr>
<tr><td>2.8 Human-Computer and Human-Information Interactions</td><td>3.2 Human Factors Engineering</td><td>1.5 Information Literacy
3.14 Human-Computer Interaction</td><td>G. User and Use of Health Information Systems</td></tr>
</table>

Figure 2 Relationship between information/computer science core of Course-Based Informatics Program Categorization scheme and select published Biomedical and Health Informatics competency guidelines.

the way in which professional competency sets are defined. For example, the proposed competencies for clinical informatics[7] are more focused on healthcare information systems than on the general informatics principles an academic program might cover. Similarly, the IMIA recommendations[16] are oriented primarily toward daily practice tasks and, as a result, include lower-level information literacy such as PC use and electronic communications skills that students entering master's level informatics programs are assumed to possess. Conversely, academic coursework tends to be structured by established Information Science (IS)/Computer Science (CS) topical areas such as databases, systems analysis, etc. While a detailed analysis of differences between the various competency sets and program curricula is beyond the scope of this study, the CBIPC offers an opportunity to frame the discussion of how well the desired informatics competencies are reflected in existing educational programs.

Academic curricula within and across informatics disciplines

The third goal of the study was to compare curricula of the five disciplines within the BMHI domain. Figure 3 presents an overview of informatics programs by the subdomains studied: public health (PHI), nursing (NI), health (HI), medical (MI), and bioinformatics (BI). The numbers and intensity of shading in each cell indicate the percentage of programs (normalized by number of programs analyzed for that discipline) offering a course of each type. Examining the patterns of frequency of different courses and course categories allows us to describe the core curricula of existing academic programs for the five informatics disciplines in the BMHI domain, as well as relative similarities/differences between them.

The core of public health informatics combines general coursework in public health and statistics with introductory informatics concepts and knowledge of information systems relevant to public health, as well as relevant legal and organizational issues. Similarly, nursing informatics, at its core, combines training in advanced practical nursing and research methodology with select informatics-specific topics such as systems analysis and design, database systems, decision-support systems, project management, and business topics.

The medical informatics core includes a number of IS/CS courses, particularly in IT foundations, database systems, and decision-support systems, in combination with statistics and coursework addressing legal and ethical issues. The core of bioinformatics, in addition to introductory informatics, consists of programming, statistics, computational biology, and life sciences. Describing the core of health informatics is particularly challenging due to the diversity of program content. Most of these programs have a strong emphasis on healthcare information systems and offer a set of IS/CS courses dominated by systems analysis and design.

There is substantial variability in program content by informatics discipline. Public health and bioinformatics and, to a lesser degree, nursing informatics, are characterized by fewer different course types (18, 18, and 24, respectively), and by the uniform presence of certain course types (90–100% of the programs). Medical and health informatics programs offer greater curricular diversity (26 and 27 course types respectively) with no single course type present in more than two-thirds of the programs. Based on curricular variability, our research suggests that public health and bioinformatics are more precisely defined as academic disciplines than are health and medical informatics.

As can be seen in figure 3, introductory informatics courses in each discipline tend to be domain-specific, with some programs offering additional introductory courses in related disciplines. Unlike medical and health informatics programs, public health, nursing, and bioinformatics programs typically include a set of courses unique to those disciplines (Category 5 of CBIPC).

Programs that label themselves 'Bioinformatics' divide cleanly into two groups based on course requirements. The vast majority of these programs focus on computational biology (with many including 'Computational Biology' in the program name), while a few have a more 'informatics' focus. The latter tend to be very similar in structure to other types of BMHI programs and fit more logically with this set. Computational Biology programs, on the other hand, are distinguished by their particular emphasis on computational biology methods, programming, and a more extensive life sciences background. This suggests that Bioinformatics programs should be distinguished as either BMHI or Computational Biology programs, along the lines of the definitions proposed by the NIH.[2] Further, these facts invite discussion as to whether or not Computational Biology should be considered a part of BMHI or a separate area of informatics based on curricula.

Figure 3 Course offerings by informatics subdiscipline (numbers in cells represent percentages of programs offering the courses of each type).

	PHI (N=4)	NI (N=15)	HI (N=15)	MI (N=12)	BI (N=27)
1. Introduction to Informatics					
1.1 Generic Informatics	0	7	20	0	4
1.2 Health Informatics	0	13	67	0	0
1.3 Medical and Biomedical Informatics	25	0	20	100	0
1.4 Bioinformatics	0	0	7	17	67
1.5 Public Health Informatics	75	0	7	17	0
1.6 Nursing Informatics	0	67	0	0	0
1.7 Consumer Health Informatics	0	27	0	8	0
1.8 Cheminformatics	0	0	0	0	4
2. Information/Computer Science Core					
2.1 IT foundations	25	40	33	58	11
2.2 Programming	25	13	27	33	70
2.3 Database Systems	25	60	47	50	48
2.4 System Analysis and Design	0	73	60	25	4
2.5 Data and Knowledge Representation	25	20	40	17	0
2.6 Data Mining, Knowledge Management	50	33	27	17	11
2.7 Decision Support Tools and Methods	50	53	20	58	0
2.8 Human Computer and Human Information Interaction	0	13	20	42	7
3. Statistics and Research Methods					
3.1 Statistics	100	27	27	58	67
3.2 Research Methods	25	73	40	42	7
4. Domain Specific Information Systems					
4.1 Healthcare Information Systems	75	13	67	25	0
4.2 GIS	50	0	0	0	0
4.3 Other domain specific systems	0	7	13	0	0
5. Domain Specific Knowledge and Competencies					
5.1 US Healthcare System	50	47	27	17	0
5.2 Public Health Core	75	47	0	0	0
5.3 Advanced Practice Nursing	0	93	0	0	0
5.4 Clinical Sciences	0	0	13	17	0
5.5 Life Sciences	0	0	0	0	78
5.6 Biotechnology	0	0	7	8	33
5.7 Computational Biology	0	0	0	8	96
5.8 Medical Imaging	0	0	7	17	0
6. Management Core					
6.1 Organizational Behavior and Management	50	27	40	25	0
6.2 Business Topics	25	60	33	8	4
6.3 Project Management	0	53	47	25	11
6.4 Strategic Planning and IT Management	25	13	47	17	0
7. Interaction with Society					
7.1 Legal, Ethical and Social Issues	50	33	40	50	33
7.2 Communication	0	0	13	17	4

Despite these differences, there is evidence of curricular similarities among the five informatics disciplines, mainly in the IS/CS and management cores, as well as in statistics, research methods, and study of legal/ethical topics. There is a further level of similarity across BMHI programs in that a number of course topics, including IT foundations, programming, database systems, data-mining knowledge management/discovery, and statistics, as well as courses dealing with legal, ethical, and social issues are present in the majority of these programs, regardless of disciplinary focus (table 1).

Some clear patterns of interdisciplinary similarities and differences emerged. These patterns can be best described as course work related to what Shortliffe and Blois label as, respectively, 'biomedical informatics methods, techniques and theories,' and 'application domains.'[5] That is, while there are some clearly domain-specific courses in the educational programs of each discipline, there are also clear commonalities across all biomedical and health informatics curricula. This suggests that, on one hand, there is a certain BMHI informatics core set of courses that can potentially serve different curricular tracks within one program or several related programs within the same institution (table 1). In addition, the topics and skills addressed by this common core are well aligned with theoretically derived curricular suggestions, such as those presented by Bernstam *et al*.[38] On the other hand, there is a need for specialized coursework depending on the program/track focus. This observation has direct implications for BMHI program development, particularly for developing programs with different degree options or concentration areas.

LIMITATIONS

There are several significant limitations to this study. First, the methodology used relies on courses titles and descriptions to represent courses. This level of abstraction is necessary to create a unified view of the informatics educational domain because it contains a wide diversity of scientific content and goals.[10] However, coding courses at this high level may miss small-scale differences among the courses. For example, a database course included in the BMHI curriculum, but taught in a business or information science department, may differ in content from a database course developed specifically for a health-related informatics degree focused on clinical applications. A problem at

Table 1 Common courses across the Biomedical and Health Informatics domain

	Public Health Informatics	Nursing Informatics	Health Informatics	Medical Informatics	Bioinformatics
2. Information/Computer Science Core					
2.1 IT foundations	x	x	x	x	x
2.2 Programming	x	x	x	x	x
2.3 Database Systems		x	x	x	x
2.4 System Analysis and Design		x	x	x	x
2.5 Data and Knowledge Representation	x	x	x	x	
2.6 Data Mining, Knowledge Management	x	x	x	x	x
2.7 Decision Support and Evidence-Based Practice	x	x	x	x	
2.8 Human Computer and Human Information Interaction		x	x	x	x
3. Statistics and Research Methods					
3.1 Statistics	x	x	x	x	x
3.2 Research Methods	x	x	x	x	x
6. Management Core					
6.1 Organizational Behavior and Management	x	x	x	x	
6.2 Business Topics		x	x	x	x
6.3 Project Management		x	x	x	x
6.4 Strategic Planning and IT Management	x	x	x	x	
7. Interaction with Society					
7.1 Legal, Ethical, and Social Issues	x	x	x	x	x

the opposite end of the scale is grouping together courses which, though very different from other offerings, are only coarsely similar to one another. For example, the proposed course classification assigns all computational biology courses to one category, despite significant differences in individual course content. This limits the degree of meaningful comparison possible between bioinformatics/computational biology programs using the CBIPC scheme. To address this would require developing subclassification hierarchies. While the CBIPC classification scheme allowed for consistent coding of courses by the two authors, and mapped well onto other proposed schemes, it would be important to have additional independent confirmations deriving the coding scheme, and performing mappings with it.

A final limitation to the methodology was its sampling of the courses based on an institution's course descriptions on websites, at a single point in time. Several of the programs have been restructured since they were originally surveyed, while some have combined offerings as tracks within a larger program. To fully evaluate programs would require tracking them longitudinally, and to interview program directors, and course instructors. Without this information, one cannot evaluate factors such as program dynamics, underlying academic goals, how personnel or financial concerns affect the program offerings, or the correspondence of the curricula to workplace needs.

CONCLUSION

Based on a comprehensive survey of existing biomedical and health-related informatics education programs and their curricula at the course level, the CBIPC classification scheme is proposed for informatics programs and their courses. The proposed scheme derives its strength from a combination of empirical data and a number of authoritative informatics competency sets, and allows for the comparison of diverse biomedical and health-related informatics curricula within and across subdisciplines. In addition to providing a unified view of BMHI education, it offers a foundation for the discussion of educational similarities and differences between BMHI subdisciplines and the resulting impact on the professional competencies of the graduates. Moreover, the proposed classification can be easily extended with further subcategorization to allow for more nuanced analysis of programs and their curricula.

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