AMIA Board white paper: definition of biomedical informatics and specification of core competencies for graduate education in the discipline

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This paper was formally approved by the AMIA Board on April 17, 2012.

Received 20 April 2012
Accepted 3 May 2012

Published Online First
21 June 2012

ABSTRACT

The AMIA biomedical informatics (BMI) core competencies have been designed to support and guide graduate education in BMI, the core scientific discipline underlying the breadth of the field's research, practice, and education. The core definition of BMI adopted by AMIA specifies that BMI is 'the interdisciplinary field that studies and pursues the effective uses of biomedical data, information, and knowledge for scientific inquiry, problem solving and decision making, motivated by efforts to improve human health.' Application areas range from bioinformatics to clinical and public health informatics and span the spectrum from the molecular to population levels of health and biomedicine. The shared core informatics competencies of BMI draw on the practical experience of many specific informatics sub-disciplines. The AMIA BMI analysis highlights the central shared set of competencies that should guide curriculum design and that graduate students should be expected to master.

INTRODUCTION AND BACKGROUND

In 2005, the Board of the American Medical Informatics Association (AMIA), as the leading professional and academic organization in biomedical and health informatics, endorsed the AMIA Vision, Mission, and Goals as part of the AMIA Strategic Plan.[1] Goal III specifically called on AMIA to expand the size and to strengthen the competencies of the biomedical and health informatics workforce in the USA, while supporting the continued development of the informatics profession. These goals built on the prior work of the AMIA Education Committee which had already started defining biomedical informatics (BMI) roles and competencies in 2001–2002.[2] While there was also considerable earlier work on defining BMI competencies by many organizations such as IMIA, ACMI, ANA, PHI, MLA, and ACM (a more complete listing with references and an explanation of the acronyms is provided in table 1), none of these specifically covered competencies aimed at graduate education in BMI. The AMIA Academic Forum took up the task in 2009, and formed the committee that has generated this document.

The present articulation of BMI core competencies is intended to support AMIA and its members in promoting the discipline as a career choice, and to provide guidance to students and curriculum developers when choosing, designing (and implementing), or re-designing graduate-level academic BMI programs. We recognize that the core competencies for certificate programs, undergraduate training, or non-degree fellowships in BMI would likely include only a subset of the skills that we have addressed here. In addition, the competencies identified are intended to communicate to others what BMI professionals know and do, serving as a guide for career development, and will help human resource personnel and chief information officers to understand better the basic skills and knowledge that are expected of a BMI professional. Finally, the development of the competencies as defined here expresses the maturity of the profession and increases the understanding of its deep scientific foundations and contributions, while recognizing the broad professional diversity covered by the discipline.

Defining BMI as the scientific core of a discipline that has broad applications across health and biomedicine[3] highlights its foundational role and refutes the kind of reductionism that superficially explains BMI simply as the application of information technology (IT) to biomedical and health problems. The phrase 'biomedical and health informatics' is often used to describe the full range of application and research topics for which BMI is the pertinent underlying scientific discipline. A recent paper 'What is Biomedical Informatics,'[4] focusing on the effects of defining information as 'data+meaning,' led to much discussion in the Core Competencies Committee, and helped in the formulation of the definition of BMI used in the present paper, with important implications for the core competencies in the field. Also strongly influential were the AMIA program requirements for fellowship education in the subspecialty of clinical informatics[5 6] and an article describing the process of clinical informatics board certification.[7] These serve as useful context for understanding the clinical objectives and focus on health information that characterizes our field, where even basic bioinformatics work (translational bioinformatics) is motivated by developing insights and solutions for addressing issues in human health and disease.

Although we have identified, organized, and codified competencies in BMI as part of this work, we stress that these are intended neither to

Table 1 Informal inventory of competencies and curricula developed for specialties related to biomedical and health informatics

Origin	Year	Target	Title
ACM (Association for Computing Machinery)	1978	Computer science	Health Computing: Curriculum for an Emerging Profession—Report of the ACM Curriculum Committee on Health Computing Education. ACM '78: Proceedings of the 1978 Annual Conference. http://dl.acm.org
AAMC (Association of American Medical Colleges)	1998	Medical students	Medical School Objectives Project: Medical Informatics. http://www.aamc.org
IMIA (International Medical Informatics Association)	2000	General	Recommendations of IMIA on education in health and medical informatics. http://www.imia.org
ANA (American Nursing Association)	2001	Nursing	Results of a Delphi study to determine informatics competencies for nurses at four levels of practice. *J Nurs Educ* 2001;**40**:303–16.
Waterloo (Ontario, Canada)	2001	General	Pointing the Way: Competencies and Curricula in Health Informatics. http://www.nihi.ca/hi/
AMIA Education Committee	2003	General	Competencies in Informatics
Australia	2004	General	Australian Health Informatics Educational Framework. http://www.achi.org.au/
STFM (Society of Teachers of Family Medicine)	2004	Family medicine	Informatics Learning Goals and Objectives. http://fammed.musc.edu/fmc/data/Informatics.htm
ACMI (American College of Medical Informatics)	2004	Bioinformatics	Training the Next Generation of Informaticians: The Impact of 'BISTI' and Bioinformatics—A Report from the American College of Medical Informatics. *J Am Med Inform Assoc* 2004;**11**:167–72.
AMIA 10×10	2005 to present	General	10×10 Curriculum and Competencies. http://www.amia.org/education/10x10-courses
AMIA Dental Informatics Working Group	2006	Dentistry	Background material on informatics competencies. http://www.amia.org/programs/working-groups/dental-informatics
MLA (Medical Library Association)	2006	Medical librarians	Health Information Science Knowledge and Skills. http://www.mlanet.org/education/platform/skills.html
Public Health Informatics (PHI) Competencies Working Group (CDC funded)	2007	Public health	Public Health Informatics Competencies. http://www.cdc.gov/Informatics Competencies/
COACH (Canadian Health Informatics Association)	2007	Health informatics professionals	http://www.coachorg.com/
AMIA	2008	Clinical informatics	Core Content for the Subspecialty of Clinical Informatics. AMIA Board of Directors. *J Am Med Inform Assoc* 2009;**16**:153–7.
CAHIIM (Commission on Accreditation for Health Informatics and Information Management)	2009	Health informatics	http://www.cahiim.org/applyaccred_HI_grad.html
TIGER (Technology Informatics Guiding Education Reform)	2009	Nursing informatics	http://tigercompetencies.pbworks.com/f/TICC_Final.pdf

discourage diversity across training programs in the field, nor to establish a set of prescriptive guidelines for exclusion of topics or programs. On the contrary, identifying new competency areas on an ongoing basis is especially important for a field that is rapidly changing in both its informatics and its biomedical and health aspects. Only through consensus followed by iteration can we further facilitate the continuing development, and promote a greater understanding, of a discipline with an unusually wide scope. The process of defining BMI competencies affects all of those who are, aspire to be, or work with informatics professionals, including current and prospective students, faculty, employers, practitioners, researchers, clinicians, and managers. The definition of core competencies also serves those who do not have a degree or formal training in informatics but who can use these competencies to identity areas for additional study or experience.

There is a clear distinction between accrediting programs and certifying individuals. This document lays the foundation for AMIA's role in endorsing the development and subsequent use of competencies as a basis for program design, evaluation, and accreditation. In addition, the competencies could be used by educational programs to position their curricula and course offerings as they apply for funding, develop marketing materials, or evaluate the performance of their graduates. It is intended to supplement, and not to replace, related documents from related groups and disciplines, such as clinical or nursing informatics, which already have been developed, some under AMIA sponsorship such as the clinical informatics documents referred to above.[5 6] Thus this work is primarily intended to assist AMIA and informatics training programs as they track and guide the evolution of core BMI competencies for the field of BMI in general, especially at graduate levels of training (masters and doctoral levels).

DEFINITION OF BIOMEDICAL INFORMATICS

The term 'biomedical informatics' began to emerge in the 1990s as the Human Genome Project and the expanding investigation of issues in data analysis for basic biology led to a greater awareness that the methods and processes of what had been known as 'medical informatics' were broadly applicable across all of biomedicine. Over the last decade an increasing number of academic programs have embraced this broader range of application topics and have changed the names of their academic units to replace the term medical informatics in favor of biomedical informatics. This transition is not complete, and organizations such as AMIA and IMIA still have the former name of the discipline embedded in their own names (the American Medical Informatics Association and the International Medical Informatics Association), but the emphasis on biomedical informatics as the name of the field is now widely accepted. For the purposes of this paper, accordingly, we adopt a newer, more limited view of the term medical informatics, using it solely to refer to that component of research and practice in clinical informatics that focuses on disease, and predominantly involves the role of physicians. Thus AMIA now uses *medical informatics* primarily as a parallel notion to other subfields of clinical informatics, such as nursing informatics or dental informatics.

The committee's first task was to develop a definition of BMI that could be adopted for ongoing use by AMIA and would capture the field's scope and focus without inappropriately overemphasizing the role of computers and IT. After extensive deliberations, we developed the following brief consensus definition, which is complemented by four corollaries that refine the explanation of the field's characteristics:

Definition: Biomedical informatics (BMI) is the interdisciplinary field that studies and pursues the effective uses of biomedical data, information, and knowledge for scientific inquiry, problem solving, and decision making, driven by efforts to improve human health.

- **Scope and breadth of discipline:** BMI investigates and supports reasoning, modeling, simulation, experimentation, and translation across the spectrum from molecules to individuals and to populations, from biological to social systems, bridging basic and clinical research and practice and the healthcare enterprise.
- **Theory and methodology:** BMI develops, studies, and applies theories, methods, and processes for the generation, storage, retrieval, use, management, and sharing of biomedical data, information, and knowledge.
- **Technological approach:** BMI builds on and contributes to computer, telecommunication, and information sciences and technologies, emphasizing their application in biomedicine.
- **Human and social context:** BMI, recognizing that people are the ultimate users of biomedical information, draws upon the social and behavioral sciences to inform the design and evaluation of technical solutions, policies, and the evolution of economic, ethical, social, educational, and organizational systems.

BMI is the core scientific discipline that supports applied research and practice in several biomedical disciplines, including *health informatics*, which is composed of *clinical informatics* (including subfields such as medical, nursing, and dental informatics) and *public health informatics* (sometimes referred to more broadly as *population informatics* to capture its inclusion of *global health informatics*). There are related notions, such as *consumer health informatics*, which involves elements of both clinical and public health informatics. BMI in turn draws on the practical experience of the applied subspecialties, and works in the context of clinical and public health systems and organizations to develop experiments, interventions, and approaches that will have scalable impact in solving health informatics problems. However, it is the *depth of informatics methods, shared across the spectrum from the molecular to the population levels*[3 8 9] that defines the core discipline of BMI and provides its coherence and its professional foundation for defining a common set of core competencies. Figure 1 illustrates the relationship among BMI and its major areas of applied research and practice, addressing individuals and populations through *health informatics* (defined as spanning *clinical informatics* and *public health informatics*), and molecular, cellular, and organ systems through *bioinformatics* and *structural* (or *imaging*) *informatics*. As noted above, clinical informatics covers the practice of informatics in healthcare through medical, nursing, dental, and other forms of informatics that are applied to patients or to healthy individuals. Figure 1 illustrates how basic research in informatics applied to biomedicine is the natural purview of BMI, since it provides the methods, techniques, processes, and theories that are used across all the subspecialty areas. The different BMI application areas, meanwhile, provide the research motivations and the practice goals that interact with the core of BMI and provide feedback for the generalization of methods and theories as the discipline evolves. An example of this is the recently emerging subfield of *translational bioinformatics*,[10–12] which bridges bioinformatics, structural informatics, and clinical informatics in seeking genomic and cellular mechanisms to explain and predict clinical phenomena. It then overlaps with the recently defined field of *clinical research informatics*, which addresses data and information management and analysis in support of clinical trials and population studies.[13]

In defining the core competencies for professionals in BMI, one must place the above definition of the field into the context

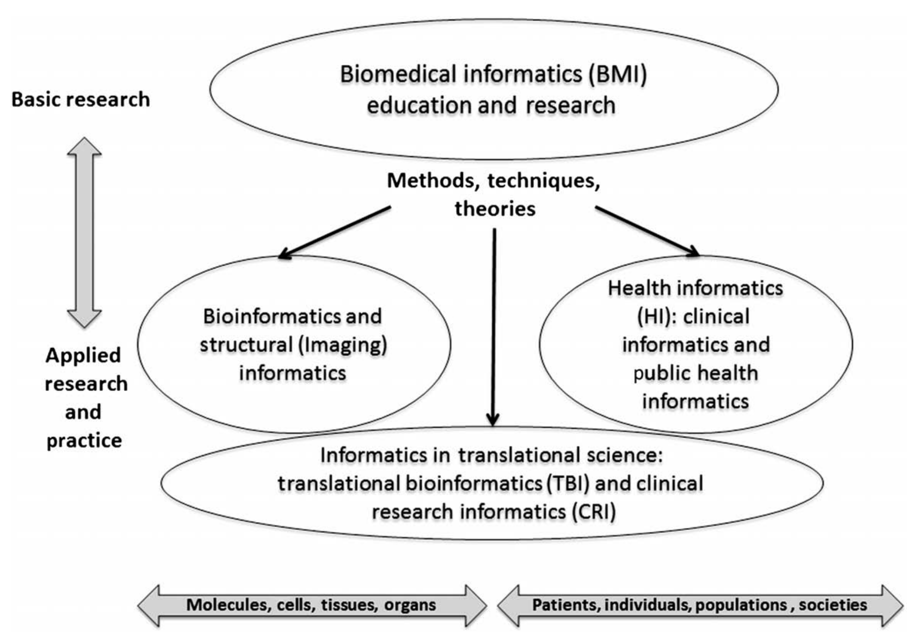


Figure 1 Biomedical informatics and its areas of application and practice, spanning the range from molecules to populations and society (adapted from Shortliffe and Blois[3]).

within which scientific, technological, and healthcare practices are developing. Figure 2 illustrates how BMI and health informatics (HI) interact synergistically. Basic research in BMI is carried out largely in academic institutions, research institutes, and corporate research labs that typically work with academic centers on specific HI projects within hospitals, clinics, and practices, often in collaboration with the corporate healthcare industry. The clinical systems provide the test-beds for experimentation with BMI methods, techniques, and theories through the exchange of people, ideas, and software that makes for a 'virtuous circle' of feedback between BMI and HI. A similar diagram could be drawn for the interaction of BMI and translational bioinformatics in the burgeoning applied world of drug discovery and biotechnology.

In defining the core competencies needed by BMI practitioners, one must focus primarily on this feedback, and the practical experience with which it supports education in BMI, so that theory informs practice, while practice and experience influence the evolution of theory. As a result of this feedback, BMI research not only advances knowledge in BMI but also advances knowledge in contributing foundational fields such as computer science and information science as well as advancing knowledge in the application domains such as biomedical research, clinical care, and population health.

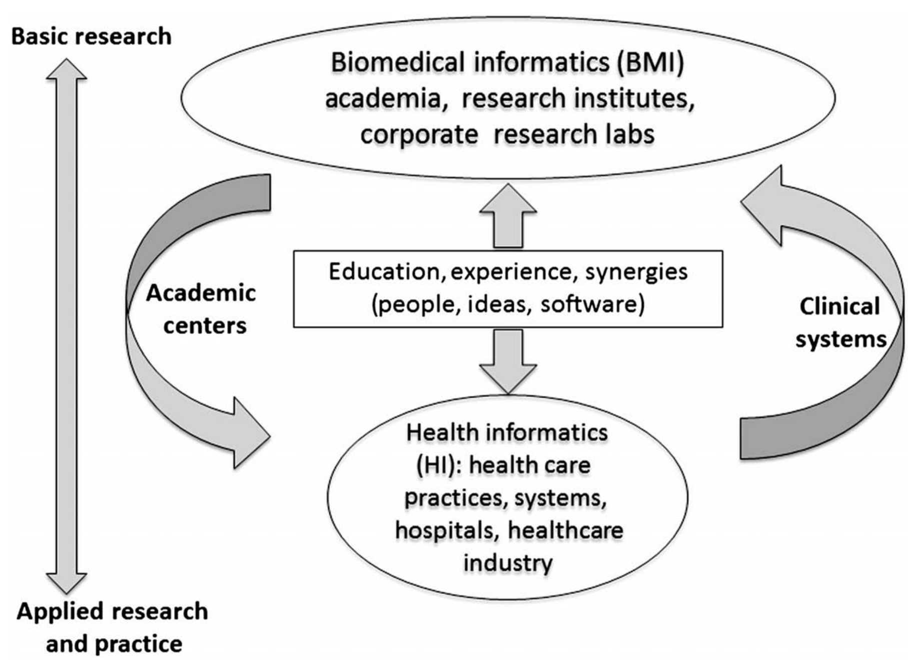
CORE COMPETENCIES IN BMI

Most of the recommendations for BMI core competencies have been structured according to Bloom's cognitive process dimension terms[14] into categories of (a) Prerequisite Knowledge and Skills; (b) Fundamental Knowledge; and (c) Procedural Knowledge and Skills. The process dimension terms are: *remember*, *understand*, *apply*, *analyze*, *evaluate*, and *create*. Because BMI is a scientific as well as a technological field, individual core competencies always assume that practitioners will show creativity in asking the right questions, demonstrate scientific skepticism in questioning past approaches, and apply methods with rigor for experimental design, data analysis, and theory formulation. And, it will be up to each BMI academic program to convert the terms into objectively measurable outcomes based on the program level and goals (eg, applied MS, research MS, PhD).

What follows is taken directly from the document presented to the AMIA Academic Forum and approved by the Forum members at their meeting of June 17, 2010.[15]

- **Fundamental scientific skills:** Faculty should design BMI graduate programs so that every student attains the following competencies, expected of practitioners in any scientific discipline:
  - ***Acquire professional perspective:*** *Understand and analyze the history and values of the discipline and its relationship to other fields while demonstrating an ability to read, interpret, and critique the core literature.*
  - ***Analyze problems:*** *Analyze, understand, abstract, and model a specific biomedical problem in terms of data, information, and knowledge components.*
  - ***Produce solutions:*** *Use the problem analysis to identify and understand the space of possible solutions and generate designs that capture essential aspects of solutions and their components.*
  - ***Articulate the rationale****: Defend the specific solution and its advantage over competing options.*
  - ***Implement, evaluate, and refine****: Carry out the solution (including obtaining necessary resources and managing projects), evaluate it, and iteratively improve it.*
  - ***Innovate:*** *Create new theories, typologies, frameworks, representations, methods, and processes to address biomedical informatics problems.*
  - ***Work collaboratively:*** *Team effectively with partners within and across disciplines.*
  - ***Educate, disseminate, and discuss:*** *Communicate effectively to students and to other audiences in multiple disciplines in persuasive written and oral form.*
- **Scope and breadth of the discipline**: BMI investigates and supports reasoning, modeling, simulation, experimentation, and translation across the spectrum from molecules to individuals to populations, from biological to social systems, bridging basic and clinical research and practice, and the healthcare enterprise.

Figure 2 Interrelation of biomedical informatics and health informatics in creating a 'virtuous circle' of feedback for education and practice that connects basic and applied research (adapted from Shortliffe and Blois[3]).



- *Prerequisite knowledge and skills: Students must be familiar with biological, biomedical, and population health concepts and problems including common research problems.*
- ***Fundamental knowledge:*** *Understand the fundamentals of the field in the context of the effective use of biomedical data, information, and knowledge. For example:*
  - *Biology: molecule, sequence, protein, structure, function, cell, tissue, organ, organism, phenotype, populations.*
  - *Translational and clinical research: genotype, phenotype, pathways, mechanisms, sample, protocol, study, subject, evidence, evaluation.*
  - *Healthcare: screening, diagnosis (diagnoses, test results), prognosis, treatment (medications, procedures), prevention, billing, healthcare teams, quality assurance, safety, error reduction, comparative effectiveness, medical records, personalized medicine, health economics, information security and privacy.*
  - *Personal health: patient, consumer, provider, families, health promotion, personal health records.*
  - *Population health: detection, prevention, screening, education, stratification, spatio-temporal patterns, ecologies of health, wellness.*
- ***Procedural knowledge and skills:*** *For substantive problems related to scientific inquiry, problem solving, and decision making, apply, analyze, evaluate, and create solutions based on biomedical informatics approaches.*
  - *Understand and analyze complex biomedical informatics problems in terms of data, information, and knowledge.*
  - *Apply, analyze, evaluate, and create biomedical informatics methods that solve substantive problems within and across biomedical domains.*
  - *Relate such knowledge and methods to other problems within and across levels of the biomedical spectrum.*

▸ **Theory and methodology**: BMI develops, studies, and applies theories, methods, and processes for the generation, storage, retrieval, use, management, and sharing of biomedical data, information, and knowledge. All involve the ability to reason and relate to biomedical information, concepts, and models spanning molecules to individuals to populations:
- ***Theories:*** *Understand and apply syntactic, semantic, cognitive, social, and pragmatic theories as they are used in biomedical informatics.*
- ***Typology:*** *Understand, and analyze the types and nature of biomedical data, information, and knowledge.*
- ***Frameworks:*** *Understand, and apply the common conceptual frameworks that are used in biomedical informatics.*
  - *A framework is a modeling approach (eg, belief networks), programming approach (eg, object-oriented programming), representational scheme (eg, problem space models), or an architectural design (eg, web services).*
- ***Knowledge representation:*** *Understand and apply representations and models that are applicable to biomedical data, information, and knowledge.*
  - *A knowledge representation is a method of encoding concepts and relationships in a domain using definitions that are computable (eg, first order logics).*
- ***Methods and processes:*** *Understand and apply existing methods (eg, simulated annealing) and processes (eg, goal-oriented reasoning) used in different contexts of biomedical informatics.*

▸ **Technological approach**: BMI builds on and contributes to computer, telecommunication, and information sciences and technologies, emphasizing their application in biomedicine.
- ***Prerequisite knowledge and skills:*** *Assumes familiarity with data structures, algorithms, programming, mathematics, statistics.*
- ***Fundamental knowledge:*** *Understand and apply technological approaches in the context of biomedical problems. For example:*
  - *Imaging and signal analysis.*
  - *Information documentation, storage, and retrieval.*
  - *Machine learning, including data mining.*
  - *Networking, security, databases.*
  - *Natural language processing, semantic technologies.*
  - *Representation of logical and probabilistic knowledge and reasoning.*
  - *Simulation and modeling.*
  - *Software engineering.*
- ***Procedural knowledge and skills:*** *For substantive problems, understand and apply methods of inquiry and criteria for selecting and utilizing algorithms, techniques, and methods.*
  - *Describe what is known about the application of the fundamentals within biomedicine.*
  - *Identify the relevant existing approaches for a specific biomedical problem.*
  - *Apply, adapt, and validate an existing approach to a specific biomedical problem.*

▸ **Human and social context**: BMI, recognizing that people are the ultimate users of biomedical information, draws upon the social and behavioral sciences to inform the design and evaluation of technical solutions, policies, and the evolution of economic, ethical, social, educational, and organizational systems.
- ***Prerequisite knowledge and skills:*** *Familiarity with fundamentals of social, organizational, cognitive, and decision sciences.*
- ***Fundamental knowledge:*** *Understand and apply knowledge in the following areas:*
  - *Design: for example, human-centered design, usability, human factors, cognitive and ergonomic sciences and engineering.*
  - *Evaluation: for example, study design, controlled trials, observational studies, hypothesis testing, ethnographic methods, field observational methods, qualitative methods, mixed methods.*
  - *Social, behavioral, communication, and organizational sciences: for example, computer supported cooperative work, social networks, change management, human factors engineering, cognitive task analysis, project management.*
  - *Ethical, legal, social issues: for example, human subjects, HIPAA, informed consent, secondary use of data, confidentiality, privacy.*
  - *Economic, social and organizational context of biomedical research, pharmaceutical and biotechnology industries, medical instrumentation, healthcare, and public health.*
- ***Procedural knowledge and skills:*** *Apply, analyze, evaluate, and create systems approaches to the solution of substantive problems in biomedical informatics.*
  - *Analyze complex biomedical informatics problems in terms of people, organizations, and socio-technical systems.*
  - *Understand the challenges and limitations of technological solutions.*
  - *Design and implement systems approaches to biomedical informatics applications and interventions.*
  - *Evaluate the impact of biomedical informatics applications and interventions in terms of people, organizations, and socio-technical systems.*
  - *Relate solutions to other problems within and across levels of the biomedical spectrum.*

THEORY AND METHODOLOGY ISSUES: RELATIONSHIP OF BMI CORE COMPETENCIES TO BACKGROUND EDUCATION IN THE UNDERLYING SCIENCES AND TECHNOLOGIES

The preceding discussion illustrates that BMI uses and develops a wide range of mathematical, scientific, technological, heuristic, and cognitive methods for modeling and solving its complex and heterogeneous problems. Defining BMI core competencies is accordingly complex. Graduate education in BMI draws—and is likely to continue to draw—students with correspondingly diverse prior specializations. As illustrated in figure 3, most current MS or PhD candidates in BMI will come from either (a) clinical, public health, or biological backgrounds, (b) mathematical, computational, physical sciences, information sciences, or engineering backgrounds, or (c) cognitive or social science backgrounds. The core competencies that can be considered as *prerequisites* will vary accordingly, but regardless of this, the fundamental and procedural competencies with which graduate students *leave* a program should be sufficient for them to carry out advanced work (either basic or applied research) in BMI successfully.

The relationship of BMI to its component sciences and technological disciplines (computer science, information science, decision science, statistics, cognitive science, organizational theory, etc) varies from institution to institution, usually reflecting the way in which a BMI program has developed and the strengths or expertise of its faculty.[4 10] A critical function of a good graduate program is to identify foundational components that are essential for a student with one major type of background so that the core competencies can best be personalized to their needs and career goals. Based on the BMI core competencies listed above, one can select a subset that best complements an individual's prior experience and future directions.

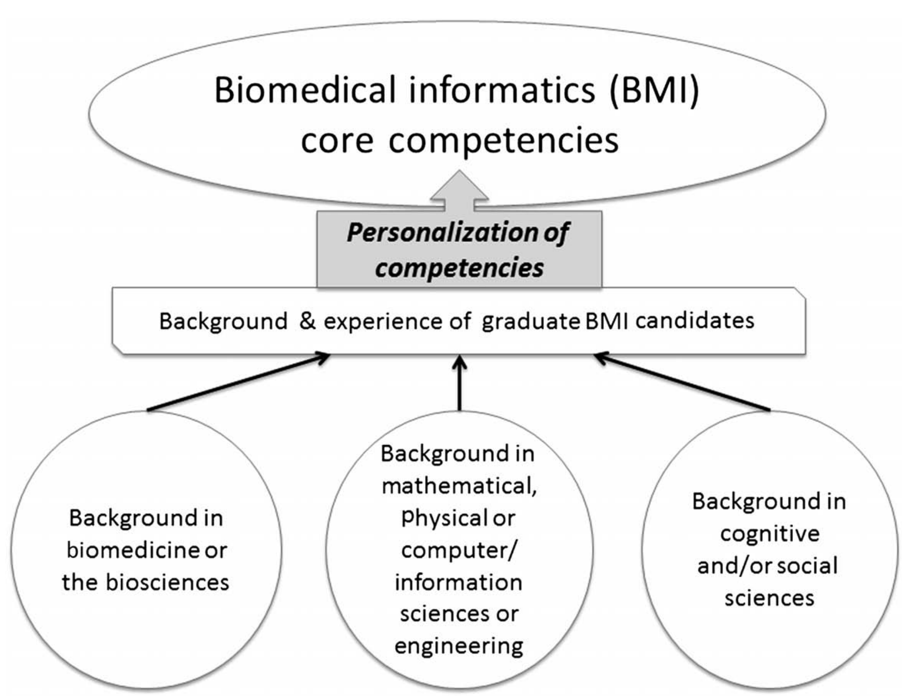
For example, a graduate student with a primary background in the biological sciences and a medical, dental, or nursing degree will need to be taught about the distinctions between syntactic and semantic representations and about cognitive, social, and pragmatic theories as they are used in BMI—much more so than would be the case for a student with a primary background in the mathematical and computational sciences (who is more likely already to know about these concepts and distinctions). Similarly, an incoming student with technical computing skills will instead have to learn much more about typologies of biomedical data, information, and knowledge, with which the biomedical student will already be familiar. Students of both backgrounds will need to learn about knowledge representations and frameworks for modeling in the context of practical problems, such as the analysis of genomic or clinical datasets, or the integration of signal and imaging data with patient electronic health record (EHR) data. The identification of substantive problems where different representations, algorithms, and methods are possible assumes that BMI graduates will acquire a degree of sophistication in identifying the most relevant existing approaches, adapting them to a specific test problem, and validating the results using the best methods (eg, cross-validation for machine learning prediction problems). As students proceed through a BMI program, they should mature in their understanding of the ways in which information (ie, meaningful data) is converted into knowledge (ie, a justified, true belief) and how they both contribute to posing hypotheses, developing theories, and proposing experimental tests of new questions suggested by the theories (that is, the kind of understanding that is usually seen as 'wisdom', as in Ackoff's hierarchy[16]).

SCIENTIFIC AND TECHNOLOGICAL ISSUES: RELATIONSHIPS TO INFORMATION AND COMPUTER SCIENCE

As indicated in the BMI core competencies, the discipline both builds upon and contributes to computer science, communications, and the information sciences and technologies.

Historically, biological modeling of neural networks inspired cybernetics approaches to decision-making,[17] and later, BMI pioneered new representations of knowledge within fields such as artificial intelligence (eg, rule-based systems[18]), where the first generation of expert systems were predominantly for clinical application.[19] Likewise, medical imaging has been the catalyst for many multi-resolution representations of visual objects and robust methods for estimation and segmentation that have been widely adopted in computer vision.[20]

Figure 3 The need to adapt biomedical informatics core competencies to the backgrounds of individual graduate program candidates.



 J Am Med Inform Assoc 2012;19:931–938. doi:10.1136/amiajnl-2012-001053

However, it is fair to say that the most influential application of BMI methods has been in the library or information sciences, where the MEDLINE (and PubMed) systems for biomedical literature indexing and retrieval have revolutionized the science of biomedicine, made the Genome Project possible, and enabled countless discoveries in both basic biosciences and medicine.[21] The Unified Medical Language System and subsequent ontologies on the web are now making it possible to scale-up discoveries through efficient social networking among those in biomedical computing.[22] Telecommunication in medicine has also been notable in bringing the latest diagnostic and treatment skills to the care of patients in remote locations, while the use of informatics methods for the monitoring and rehabilitation of patients with multiple, chronic conditions is becoming increasingly important for the aging societies of developed countries.[23] All these factors make it important to include among the BMI core competencies the underlying technologies of networking, security, and databases upon which information documentation, storage, and retrieval now depend. In addition to the established methods of machine learning, imaging, and signal analysis, the challenging areas of natural language processing and the semantics of information provide windows into a future that will be transformative for healthcare as well as biomedical research, and to which BMI graduates have the opportunity to make valuable contributions.[24] Figure 4 illustrates some of the relationships of BMI to the underlying disciplines that enable the science and technology that it builds upon, and to which it contributes.

HUMAN FACTORS AND SOCIAL ISSUES IN BMI CORE COMPETENCIES

Since the ultimate goal of all BMI research and education is to produce methods for supporting biomedical research and improving healthcare, both of which depend critically on human and social context issues, it is important for BMI practitioners to include in their core competencies a familiarity with the fundamentals of social, organizational, cognitive, and decision science insights (as is indicated in figure 4). The rapid development of computer-supported cooperative work, social networks, and cognitive task analysis is added to the more traditional methods from human factors engineering as well as change and project management.

Large-scale systems increasingly require team-based approaches to software engineering, design, and implementation. BMI practitioners should become familiar with the current approaches to collaborative design and the challenges of coordination and system testing and validation that these entail. Cognitive modeling of tasks and human–machine interaction methodologies (increasingly related to neuroscience and economics insights) are also important aspects that can benefit developers of these socio-technical BMI systems. Cognitive studies of decision making, usability evaluations, team performance and communication, plus system failures and challenges to patient safety are also crucial components in the training of BMI graduate students.

The ethical, legal, and social issues involved in complex healthcare systems design, implementation, testing, and evaluation require that BMI graduates be knowledgeable about the boundaries of individual and group responsibility and how the interaction with a wide range of stakeholders in biomedical information systems means that they must be sensitive to ethical and legal considerations. The implications of introducing informatics methods and systems in large-scale public health settings add to these challenges. With recent discoveries of the critical role of the microbiome, and its relationship to other biological ecosystems affecting human health, the scope and depth of what a responsible practitioner in BMI must appreciate across the biomedical spectrum has grown substantially; BMI graduates must know how to place such new information into context when solving difficult informatics problems.

OTHER RELATED HEALTH INFORMATICS COMPETENCY REPORTS

The International Medical Informatics Association (IMIA) has recently published a summary of recommendations on competencies for education in medical informatics[25] that focuses, in light of its international emphasis, on a much wider range of competencies than the present report, which concentrates on the foundations of BMI as a scientific discipline for graduate study. Several other studies and proposals for informatics curricula have been developed by a variety of organizations, as is summarized in table 1, but none has focused solely on graduate study and the core science issues in the same way as this current effort. Note, as previously discussed, that the current work does not propose a curriculum per se, but rather focuses on competencies that can be acquired through a variety of different courses or teaching methods. Our focus on core competencies and graduate education distinguishes this paper from the other efforts that are listed in table 1.

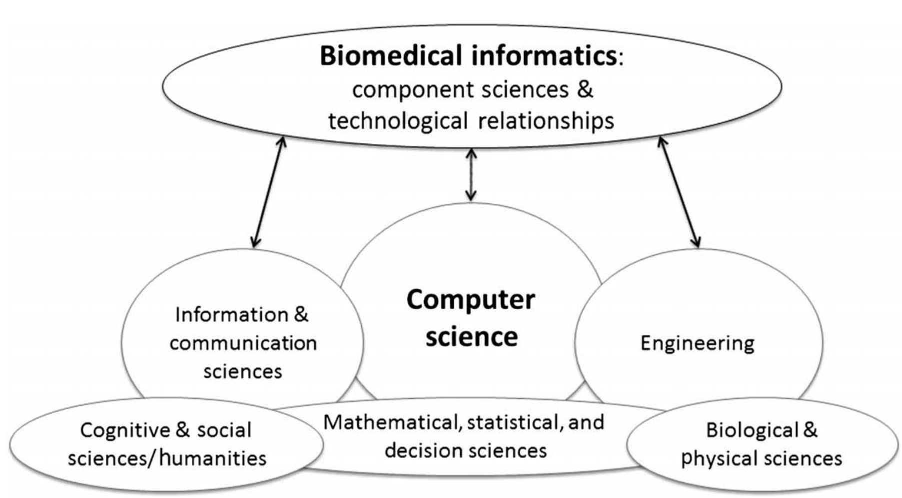


Figure 4 Component sciences and disciplines upon which biomedical informatics depends and to which it contributes.

CONCLUSIONS

The AMIA BMI core competencies described in this paper are designed as a broad and dynamic set of recommendations or guidelines for graduate education in BMI. AMIA and its Academic Forum invite comments from the community. We fully recognize that the guidelines here will evolve with time and will need to be improved and refined to keep them current with the rapidly changing science and technology of the field.

Contributors The authors of this report are members of an Academic Forum committee charged with addressing the definition and core competencies for graduate education in biomedical informatics. JS chaired the committee. CK took the lead in writing the paper with ES contributing extensively as well. All authors reviewed, commented, and approved the content.

Competing interests None.

Provenance and peer review Not commissioned; internally peer reviewed.

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