INFORMATICS PROFESSIONALS. LEADING THE WAY.

1A – History and Current State of Informatics

William Hersh, MD, FACMI, FAMIA

Oregon Health & Science University

Clinical Informatics Board Review Course

Clinical Informatics Subspecialty Delineation of Practice (CIS DoP)

Domain 1: Fundamental Knowledge and Skills (no Tasks are associated with this Domain which is focused on fundamental knowledge and skills)

Clinical Informatics

K001. The discipline of informatics (e.g., definitions, history, careers, professional organizations)

K002. Fundamental informatics concepts, models, and theories

K003. Core clinical informatics literature (e.g., foundational literature, principle journals, critical analysis of literature, use of evidence to inform practice)

K004. Descriptive and inferential statistics

K005. Health Information Technology (HIT) principles and science

K006. Computer programming fundamentals and computational thinking

K007. Basic systems and network architectures

K008. Basic database structure, data retrieval and analytics techniques and tools

K009. Development and use of interoperability/exchange standards (e.g., Fast Health Interoperability Resources [FHIR], Digital Imaging and Communications in Medicine [DICOM])

K010. Development and use of transaction standards (e.g., American National Standards Institute X12)

K011. Development and use of messaging standards (e.g., Health Level Seven [HL7] v2)

K012. Development and use of ancillary data standards (e.g., imaging and Laboratory Information System[LIS])

K013. Development and use of data model standards

K014. Vocabularies, terminologies, and nomenclatures (e.g., Logical Observation Identifiers Names and Codes [LOINC], Systematized Nomenclature of Medicine --Clinical Terms [SNOMED-CT], RxNorm, International Classification Of Diseases[ICD], Current Procedural Terminology [CPT])

K015. Data taxonomies and ontologies

K016. Security, privacy, and confidentiality requirements and practices

K017. Legal and regulatory issues related to clinical data and information sharing

K018. Technical and non-technical approaches and barriers to interoperability

K019. Ethics and professionalism

The Health System

K020. Primary domains of health, organizational structures, cultures, and processes (e.g., health care delivery, public health, personal health, population health, education of health professionals, clinical research)

K021. Determinants of individual and population health

K022. Forces shaping health care delivery and considerations regarding health care access

K023. Health economics and financing

K024. Policy and regulatory frameworks related to the healthcare system

K025. The flow of data, information, and knowledge within the health system

Domain 2: Improving Care Delivery and Outcomes

K026. Decision science (e.g., Bayes theorem, decision analysis, probability theory, utility and preference assessment, test characteristics)

K027. Clinical decision support standards and processes for development, implementation, evaluation, and maintenance

K028. Five Rights of clinical decision support (i.e., information, person, intervention formats, channel, and point/time in workflow)

K029. Legal, regulatory, and ethical issues regarding clinical decision support

K030. Methods of workflow analysis

K031. Principles of workflow re-engineering

K032. Quality improvement principles and practices (e.g., Six Sigma, Lean, Plan-Do-Study-Act [PDSA] cycle, root cause analysis)

K033. User-centered design principles (e.g., iterative design process)

K034. Usability testing

K035. Definitions of measures (e.g., quality performance, regulatory, pay for performance, public health surveillance)

K036. Measure development and evaluation processes and criteria

K037. Key performance indicators (KPIs)

K038. Claims analytics and benchmarks

K039. Predictive analytic techniques, indications, and limitations

K040. Clinical and financial benchmarking sources (e.g., Gartner, Healthcare Information and Management Systems Society [HIMSS] Analytics, Centers for Medicare and Medicaid Services [CMS], Leapfrog)

K041. Quality standards and measures promulgated by quality organizations (e.g., National Quality Forum [NQF], Centers for Medicare and Medicaid Services [CMS], National Committee for Quality Assurance [NCQA])

K042. Facility accreditation quality and safety standards (e.g., The Joint Commission, Clinical Laboratory Improvement Amendments [CLIA])

K043. Clinical quality standards (e.g., Physician Quality Reporting System [PQRS], Agency for Healthcare Research and Quality [AHRQ], National Surgical Quality Improvement Program [NSQIP], Quality Reporting Document Architecture [QRDA], Health Quality Measure Format [HQMF], Council on Quality and Leadership [CQL], Fast Health Interoperability Resources [FHIR] Clinical Reasoning)

K044. Reporting requirements

K045. Methods to measure and report organizational performance

K046. Adoption metrics (e.g., Electronic Medical Records Adoption Model [EMRAM], Adoption Model for Analytics Maturity [AMAM])

K047. Social determinants of health

K048. Use of patient-generated data

K049. Prediction models

K050. Risk stratification and adjustment

K051. Concepts and tools for care coordination

K052. Care delivery and payment models

Domain 3: Enterprise Information Systems

K053. Health information technology landscape (e.g., innovation strategies, emerging technologies)

K054. Institutional governance of clinical information systems

K055. Information system maintenance requirements

K056. Information needs analysis and information system selection

K057. Information system implementation procedures

K058. Information system evaluation techniques and methods

K059. Information system and integration testing techniques and methodologies

K060. Enterprise architecture (databases, storage, application, interface engine)

K061. Methods of communication between various software components

K062. Network communications infrastructure and protocols between information systems (e.g., Transmission Control Protocol/Internet Protocol [TCP/IP], switches, routers)

K063. Types of settings (e.g., labs, ambulatory, radiology, home) where various systems are used

K064. Clinical system functional requirements

K065. Models and theories of human-computer (machine) interaction (HCI)

K066. HCI evaluation, usability engineering and testing, study design and methods

K067. HCI design standards and design principles

K068. Functionalities of clinical information systems (e.g., Electronic Health Records [EHR], Laboratory Information System [LIS], Picture Archiving and Communication System [PACS], Radiology Information System [RIS] vendor-neutral archive, pharmacy, revenue cycle)

K069. Consumer-facing health informatics applications (e.g., patient portals, mobile health apps and devices, disease management, patient education, behavior modification)

K070. User types and roles, institutional policy and access control

K071. Clinical communication channels and best practices for use (e.g., secure messaging, closed loop communication)

K072. Security threat assessment methods and mitigation strategies

K073. Security standards and safeguards

K074. Clinical impact of scheduled and unscheduled system downtimes

K075. Information system failure modes and downtime mitigation strategies (e.g., replicated data centers, log shipping)

K076. Approaches to knowledge repositories and their implementation and maintenance

K077. Data storage options and their implications

K078. Clinical registries

K079. Health information exchanges

K080. Patient matching strategies

K081. Master patient index

K082. Data reconciliation

K083. Regulated medical devices (e.g., pumps, telemetry monitors) that may be integrated into information systems

K084. Non-regulated medical devices (e.g., consumer devices)

K085. Telehealth workflows and resources (e.g., software, hardware, staff)

Domain 4: Data Governance and Data Analytics

K086. Stewardship of data

K087. Regulations, organizations, and best practice related to data access and sharing agreements, data use, privacy, security, and portability

K088. Metadata and data dictionaries

K089. Data life cycle

K090. Transactional and reporting/research databases

K091. Techniques for the storage of disparate data types

K092. Techniques to extract, transform, and load data

K093. Data associated with workflow processes and clinical context

K094. Data management and validation techniques

K095. Standards related to storage and retrieval from specialized and emerging data sources

K096. Types and uses of specialized and emerging data sources (e.g., imaging, bioinformatics, internet of things (IoT), patient-generated, social determinants)

K097. Issues related to integrating emerging data sources into business and clinical decision making

K098. Information architecture

K099. Query tools and techniques

K100. Flat files, relational and non-relational/NoSQL database structures, distributed file systems

K101. Definitions and appropriate use of descriptive, diagnostic, predictive, and prescriptive analytics

K102. Analytic tools and techniques (e.g., Boolean, Bayesian, statistical/mathematical modeling)

K103. Advanced modeling and algorithms

K104. Artificial intelligence

K105. Machine learning (e.g., neural networks, support vector machines, Bayesian network)

K106. Data visualization (e.g., graphical, geospatial, 3D modeling, dashboards, heat maps)

K107. Natural language processing

K108. Precision medicine (customized treatment plans based on patient-specific data)

K109. Knowledge management and archiving science

K110. Methods for knowledge persistence and sharing

K111. Methods and standards for data sharing across systems (e.g., health information exchanges, public health reporting)

Domain 5: Leadership and Professionalism

K112. Environmental scanning and assessment methods and techniques

K113. Consensus building, collaboration, and conflict management

K114. Business plan development for informatics projects and activities (e.g., return on investment, business case analysis, pro forma projections)

K115. Basic revenue cycle

K116. Basic managerial/cost accounting principles and concepts

K117. Capital and operating budgeting

K118. Strategy formulation and evaluation

K119. Approaches to establishing Health Information Technology (HIT) mission and objectives

K120. Communication strategies, including one-on-one, presentation to groups, and asynchronous communication

K121. Effective communication programs to support and sustain systems implementation

K122. Writing effectively for various audiences and goals

K123. Negotiation strategies, methods, and techniques

K124. Conflict management strategies, methods, and techniques

K125. Change management principles, models, and methods

K126. Assessment of organizational culture and behavior change theories

K127. Theory and methods for promoting the adoption and effective use of clinical information systems

K128. Motivational strategies, methods, and techniques

K129. Basic principles and practices of project management

K130. Project management tools and techniques

K131. Leadership principles, models, and methods

K132. Intergenerational communication techniques

K133. Coaching, mentoring, championing and cheerleading methods

K134. Adult learning theories, methods, and techniques

K135. Teaching modalities for individuals and groups

K136. Methods to assess the effectiveness of training and competency development

K137. Principles, models, and methods for building and managing effective interdisciplinary teams

K138. Team productivity and effectiveness (e.g., articulating team goals, defining rules of operation, clarifying individual roles, team management, identifying and addressing challenges)

K139. Group management processes (e.g., nominal group, consensus mapping, Delphi method)

Knowledge Statements from the DoP

K001. The discipline of informatics (e.g., definitions, history, careers, professional organizations)

K002. Fundamental informatics concepts, models, and theories

1A – History and Current State of Informatics

Definitions of informatics

History of informatics (e.g., evolution of health records)

Domains/subspecialties of informatics

Careers in informatics

Professional organizations

Current and future challenges for informatics

Key informatics concepts, models, and theories

Definitions of Informatics

AMIA (Kulikowski, 2012)

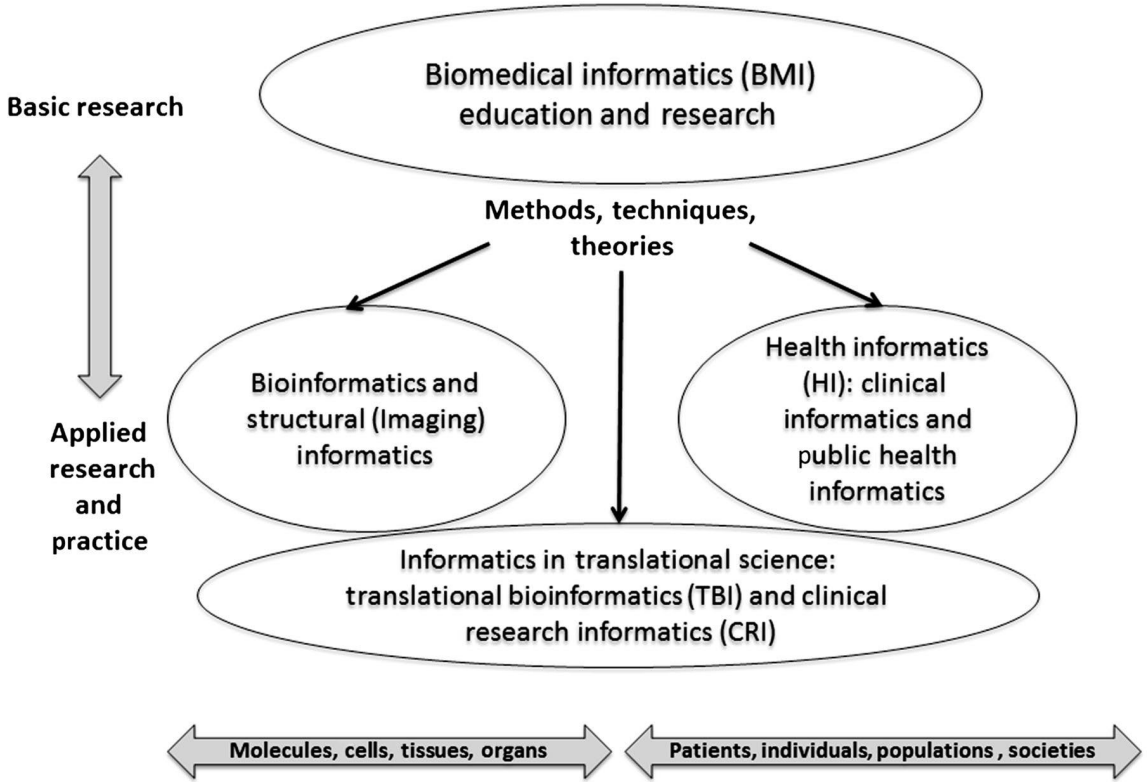
(Hersh, 2009)

(Bernstam, 2010)

AMIA View (Kulikowski, 2012)

- 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, decision making, motivated by efforts to improve human health.”
- “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.”

AMIA View (Kulikowski, 2012)



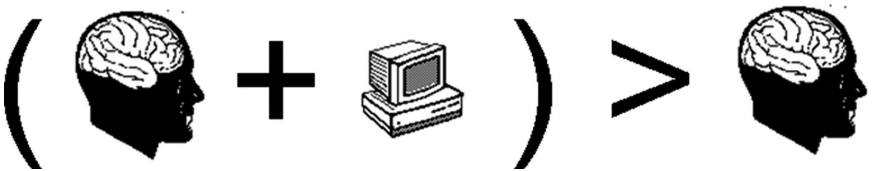
More Definitions

"The science of information applied to biomedicine … data plus meaning." (Bernstam, 2010)

European and global perspectives (Haux, 2010; Hasman, 2011; Geissbuhler, 2011)

Early definition: "storage, acquisition, and use of information" (Greenes, 1990)

"Fundamental theorem" (Friedman, 2009)



What Informatics “is and isn’t” (Friedman, 2012)

Is

- Cross-training where basic informational science meets a biomedical application domain
- Relentless pursuit of assisting people
- Tower of achievement
  - Model formulation
  - System development
  - System implementation
  - Study of effects

Isn’t

- Scientists or clinicians tinkering with computers
- Analysis of large data sets per se
- Circumscribed roles related to deployment of electronic health records (*point of disagreement)
- Profession of health information management
- Anything done using a computer

History of Informatics (Collen, 1994)

Origin of term attributed to Dreyfus in 1962 (Fourman, 2002)

Achieved widespread use in France (*informatique*), Russia, and later rest of Europe in 1960s to denote computing issues related to information use

"Medical informatics" first used in 1974 (Collen, 1994)

- More European history from Moehr (2004)
- History of field documented by Collen (2015)

At present, most significant use is in biomedical arena, but it is used by other domains, such as law, chemistry, social sciences, etc.

Some Early Systems in Informatics

EHR

- COSTAR – Massachusetts General Hospital (Barnett, 1979)
- HELP – Utah (Kuperman, 1991)
- TMR – Duke (Stead, 1988)
- Regenstrief – Indiana (McDonald, 1999)
- El Camino – California (Carter, 1987)
- VistA – Veteran's Administration (Brown, 2003)

Other

- MYCIN (Shortliffe, 1975; Clancy, 1984)
- Internist-1/QMR (Miller, 1982)
- ELHILL (Lindberg, 1986)
- Problem-knowledge coupler (Weed, 1969)

Careers in Informatics (Hersh, 2010)

Traditional groupings of information professionals in health care

- Information technology (IT) – usually with computer science or information systems background
- Health information management (HIM) – historical focus on medical records
- Clinical informatics (CI) – often from healthcare backgrounds, performing analysis, training, etc.
- Others – librarians, managers, etc.

Careers in Informatics (Hersh, 2006)

Category	Jobs
Academic	Informatics researcher or teacher
Professional	Chief Information Officer, Chief Medical/Nursing Informatics Officer, Developer, Trainer
Liaison	Represent clinical or research community in IT initiatives, e.g., clinical champion

Careers of Informatics Leaders

Who are the leaders in IT and informatics?

- Chief Information Officer (CIO)
- Chief Clinical Informatics Officer (CCIO) (Kannry, 2016), including
  - Chief Medical/Health Informatics Officer (CMIO)
  - Chief Nursing Informatics Officer (CHIO)
- Other Chief X Officer (CXO) – security, quality, data, etc.
- Many other titles, no standards

Hospitals and healthcare organizations increasingly creating operational "clinical informatics" departments

- Often separate from IT (and CIO)
- Usually with clinical leadership, often CMIO
- Increasingly incorporate HIM

What Do Clinical Informatics Subspecialists *Do*?

Table 2. Practice analysis survey rating scales

Survey Element	Rating Scales
Domains of practice	1. *Percentage of* clinical informatics *Work Time* spent in each domain of practice 2. *Importance* of domain to effective clinical informatics practice.
Tasks	1. *Frequency* of performance 2. *Importance* of the task to effective clinical informatics practice
Knowledge and skills	Version A *and* Version B included: • *Frequency* of use In addition to the above, Version A: • *Level of Mastery* Version B: • *Importance* for inclusion in ACGME Clinical Informatics Fellowship Training

Table 3. CIS domains of practice

Domain 1: Fundamental Knowledge and Skills
Fundamental knowledge and skills which provide clinical informaticians with a common vocabulary, basic knowledge across all Clinical Informatics domains, and understanding of the environment in which they function.

Domain 2: Improving Care Delivery and Outcomes
Develop, implement, evaluate, monitor, and maintain clinical decision support; analyze existing health processes and identify ways that health data and health information systems can enable improved outcomes; support innovation in the health system through informatics tools and processes.

Domain 3: Enterprise Information Systems
Develop and deploy health information systems that are integrated with existing information technology systems across the continuum of care, including clinical, consumer, and public health domains. Develop, curate, and maintain institutional knowledge repositories while addressing security, privacy, and safety considerations.

Domain 4: Data Governance and Data Analytics
Establish and maintain data governance structures, policies, and processes. Incorporate information from emerging data sources; acquire, manage, and analyze health-related data; ensure data quality and meaning across settings; and derive insights to optimize clinical and business decision making.

Domain 5: Leadership and Professionalism
Build support and create alignment for informatics best practices; lead health informatics initiatives and innovation through collaboration and stakeholder engagement across organizations and systems.

- (Silverman, 2019)
- Comparable analysis for health informatics (Gadd, 2020)
- Inform board exam, MOC, etc.

Current and Future Challenges – Start of a List

- Healthcare spending continues to rise; most see need to stabilize or reduce
- Implementation is difficult
- Return on investment is difficult to measure (and conceptualize)
- How much is too much? Is it all hype?
- Complexity creates risk; simplicity seems unsatisfying

Key Informatics Concepts, Models, and Theories – Start of a List

Bayes' Theorem

Moore's Law

Metcalfe's Law – but not really: n(n-1)/2

Greek Oracle problem (Miller, 1990)

"Curly braces" problem (Samwald, 2012)

Homer Warner's summarization of informatics: "10% medicine, 10% technology, 80% sociology" and its implications for the field

Metrics used in diagnostic decision-making and information retrieval – recall/sensitivity, precision, and specificity calculated in 2x2 tables

Clinical Informatics Literature

Journals

- Journal of the American Medical Informatics Association (JAMIA)
  - JAMIA Open
- Applied Clinical Informatics (ACI)
- Journal of Medical Internet Research (JMIR)
  - Specialty journals, e.g., JMIR Medical Informatics
- International Journal of Medical Informatics (IJMI)
- Methods of Information in Medicine (MIM)
- Journal of Biomedical Informatics (JBI)
- BMC family (Medical Informatics & Decision-Making)
- Clinical (specialty-specific)
- Information/computer science and others

Conference proceedings

- AMIA
  - Annual Symposium
  - Clinical Informatics Conference
  - Summit
- MEDINFO – formerly triennial, now biennial

Key Readings

Key

- Hersh, W (2009). A stimulus to define informatics and health information technology. BMC Medical Informatics & Decision Making. 9: 24. https://bmcmedinformdecismak.biomedcentral.com/articles/10.1186/1472-6947-9-24
- Kulikowski, CA, Shortliffe, EH, et al. (2012). AMIA Board white paper: definition of biomedical informatics and specification of core competencies for graduate education in the discipline. Journal of the American Medical Informatics Association. 19: 931-938. [Article]

Supplemental

- Finnell, JT and Dixon, BE, Eds. (2016). Clinical Informatics Study Guide: Text and Review. New York, NY, Springer. (new edition forthcoming)
- Hoyt, RE, Hersh W, Eds. (2018). Health Informatics: Practical Guide, Seventh Edition. Pensacola, FL, Lulu.com.
- Shortliffe, EH and Cimino, JJ, Eds. (2021). Biomedical Informatics: Computer Applications in Health Care and Biomedicine, 5th Edition. New York, NY, Springer.
- Silverman, H., Steen, E., Carpenito, J., Ondrula, C., Williamson, J., & Fridsma, D. (2019). Domains, tasks, and knowledge for clinical informatics subspecialty practice: results of a practice analysis. Journal of the American Medical Informatics Association. [Article]

Appendix

Another Definition (Hersh, 2009)

Biomedical and health informatics (BMHI) is the field concerned with the optimal use of information, often aided by technology, to improve individual health, healthcare, public health, and biomedical research

- Informatics applied in a more focused domain is {X} informatics, e.g., nursing, dental, pathology, primary care, etc.
- Can be classified by "level" of domain but also has some overarching areas, e.g., imaging and research

Practitioners of BMHI are usually called *informaticians* (sometimes *informaticists*)

Chief Medical Informatics Officer (CMIO)

Position now an important part of healthcare organizations, serving as (Kilbridge, 2012)

- Liaison between clinicians and IT
- Executive informatician
- Director of clinical IT systems – leading the path forward

Analysis of five CMIOs (Leviss, 2006)

- Leadership, communication, and consensus-building among most important skills
- Desired to be part of senior physician executive team
- Did not want to be seen as just “techie” doctors

Gartner-AMDIS CMIO Annual Surveys (Shaffer, 2015-2018)

Respondents mostly from integrated delivery systems, followed by hospitals and group practices

Priorities now include EHR optimization, data analytics, and population health

Key challenges are competing priorities, organizational culture, clinician disconnect as systems expand, and shortages of resources and talent

87% have additional master's degree, PhD, and/or training such as AMIA 10x10

Many pursued/pursuing clinical informatics subspecialty

- 48% have received
- 20% pursuing

Gartner-AMDIS CMIO Survey (cont.)

68% still practice medicine – slowly declining over years

Reporting relationships

- 33% to Chief Medical Officer (CMO)
- 32% to CIO
- 17% to Chief Executive Officer (CEO) or Chief Operating Officer (COO)
- 9% dual to CMO and CIO
- Most would prefer to report to CMO or dual CMO/CIO

64% have people reporting to them, with most of rest having small staffs

- Responsibility without authority?

Average salary $353K

Professional Organizations

AMIA (formerly American Medical Informatics Association)

- https://www.amia.org/

Mission

- AMIA advances the informatics professions relating to health and disease. To this end it advances the use of health information and communications technology in clinical care and clinical research, personal health management, public health/population, and translational science with the ultimate objective of improving health.

Other Professional Organizations

Healthcare Information and Management Systems Society (HIMSS) – www.himss.org

Association of Medical Directors of Information Systems (AMDIS) – www.amdis.org

American Health Information Management Association (AHIMA) – www.ahima.org

Alliance for Nursing Informatics (ANI) – www.allianceni.org

Public Health Informatics Institute (PHII) – https://www.phii.org/

Society for Imaging Informatics in Medicine (SIIM) – www.siim.org

International Society for Computational Biology (ISCB) – www.iscb.org

Association for Computing Machinery (ACM) – www.acm.org

Medical Library Association (MLA) – www.mlanet.org

Medical and Nursing Specialty Societies (non-exhaustive)

American Medical Association (AMA) – www.ama-assn.org

American Nurses Association (ANA) – www.nursingworld.org

Association of American Medical Colleges (AAMC) – www.aamc.org

American College of Physicians (ACP) – www.acponline.org

American Academy of Family Physicians (AAFP) – www.aafp.org

International Clinical Informatics Practices

Until recently, US was a laggard behind other developed countries, e.g.,

- Widespread adoption in European countries although even they have much less use of advanced systems (Osborn, 2015)
- National exemplars: Denmark (Protti, 2010), UK (Payne, 2011)
- Even efforts in developing countries (e.g., Quiros, 2009; Tierney, 2010)
- But US now has mostly caught up due to HITECH Act (DesRoches, 2015)

Critical Analysis of Informatics Literature

General approaches covered in 1F and 3B

Some unique challenges in “evidence-based informatics” (Friedman, 2006)

- Appropriate outcomes measures may be indirect from system intervention
- Unit of analysis – may be beyond person and include clinic, hospital unit, etc.

Barnett, G.O., Justice, N.S., Somand, M.E., Adams, J.B., Waxman, B.D., Beaman, P.D., Parent, M.S., Deusen, F.R.V., Greenlie, J.K., 1979. COSTAR—A computer-based medical information system for ambulatory care. Proceedings of the IEEE 67, 1226–1237. https://doi.org/10.1109/PROC.1979.11438

Bernstam, E.V., Hersh, W.R., Johnson, S.B., Chute, C.G., Nguyen, H., Sim, I., Nahm, M., Weiner, M.G., Miller, P., DiLaura, R.P., Overcash, M., Lehmann, H.P., Eichmann, D., Athey, B.D., Scheuermann, R.H., Anderson, N., Starren, J., Harris, P.A., Smith, J.W., Barbour, E., Silverstein, J.C., Krusch, D.A., Nagarajan, R., Becich, M.J., CTSA Biomedical Informatics Key Function Committee, 2009. Synergies and distinctions between computational disciplines in biomedical research: perspective from the Clinical andTranslational Science Award programs. Acad Med 84, 964–970. https://doi.org/10.1097/ACM.0b013e3181a8144d

Brown, S.H., Lincoln, M.J., Groen, P.J., Kolodner, R.M., 2003. VistA--U.S. Department of Veterans Affairs national-scale HIS. Int J Med Inform 69, 135–156. https://doi.org/10.1016/s1386-5056(02)00131-4

Clancey, W.J., Shortliffe, E.H., 1984. Readings in medical artificial intelligence: the first decade. Addison-Wesley Longman Publishing Co., Inc., USA.

Collen, M.F., 1994. The origins of informatics. J Am Med Inform Assoc 1, 91–107. https://doi.org/10.1136/jamia.1994.95236152

Collen, M.F., Ball, M.J. (Eds.), 2015. The History of Medical Informatics in the United States, 2 edition. ed. Springer.

Fourman, M., 2002. Informatics, in: Feather, J., Sturges, P. (Eds.), International Encyclopedia of Information and Library Science (Second Edition). Routledge, pp. 237–244.

Friedman, C.P., 2013. What informatics is and isn't. J Am Med Inform Assoc 20, 224–226. https://doi.org/10.1136/amiajnl-2012-001206

Friedman, C.P., 2009. A "fundamental theorem" of biomedical informatics. J Am Med Inform Assoc 16, 169–170. https://doi.org/10.1197/jamia.M3092

Gadd, C.S., Steen, E.B., Caro, C.M., Greenberg, S., Williamson, J.J., Fridsma, D.B., 2020. Domains, tasks, and knowledge for health informatics practice: results of a practice analysis. J Am Med Inform Assoc 27, 845–852. https://doi.org/10.1093/jamia/ocaa018

Greenes, R.A., Shortliffe, E.H., 1990. Medical informatics. An emerging academic discipline and institutional priority. JAMA 263, 1114–1120. https://doi.org/10.1001/jama.263.8.1114

Hasman, A., Ammenwerth, E., Dickhaus, H., Knaup, P., Lovis, C., Mantas, J., Maojo, V., Martin-Sanchez, F.J., Musen, M., Patel, V.L., Surjan, G., Talmon, J.L., Sarkar, I.N.,

2011. Biomedical informatics--a confluence of disciplines? Methods Inf Med 50, 508–524. https://doi.org/10.3414/ME11-06-0003

Haux, R., 2010. Medical informatics: past, present, future. Int J Med Inform 79, 599–610. https://doi.org/10.1016/j.ijmedinf.2010.06.003

Hersh, W., 2010. The health informatics workforce: unanswered questions, needed answers. Stud Health Technol Inform 151, 492–503.

Hersh, W., 2009. A stimulus to define informatics and health information technology. BMC Med Inform Decis Mak 9, 24. https://doi.org/10.1186/1472-6947-9-24

Hersh, W., 2006. Who are the informaticians? What we know and should know. J Am Med Inform Assoc 13, 166–170. https://doi.org/10.1197/jamia.M1912

Kulikowski, C.A., Shortliffe, E.H., Currie, L.M., Elkin, P.L., Hunter, L.E., Johnson, T.R., Kalet, I.J., Lenert, L.A., Musen, M.A., Ozbolt, J.G., Smith, J.W., Tarczy-Hornoch, P.Z., Williamson, J.J., 2012. AMIA Board white paper: definition of biomedical informatics and specification of core competencies for graduate education in the discipline. J Am Med Inform Assoc 19, 931–938. https://doi.org/10.1136/amiajnl-2012-001053

Kuperman, G.J., Gardner, R.M., Pryor, T.A., 1991. HELP: A Dynamic Hospital Information System, Computers and Medicine. Springer-Verlag, New York. https://doi.org/10.1007/978-1-4612-3070-0

Lindberg, D.A., Schoolman, H.M., 1986. The National Library of Medicine and medical informatics. West J Med 145, 786–790.

McDonald, C.J., Overhage, J.M., Tierney, W.M., Dexter, P.R., Martin, D.K., Suico, J.G., Zafar, A., Schadow, G., Blevins, L., Glazener, T., Meeks-Johnson, J., Lemmon, L., Warvel, J., Porterfield, B., Warvel, J., Cassidy, P., Lindbergh, D., Belsito, A., Tucker, M., Williams, B., Wodniak, C., 1999. The Regenstrief Medical Record System: a quarter century experience. Int J Med Inform 54, 225–253. https://doi.org/10.1016/s1386-5056(99)00009-x

Miller, R.A., Masarie, F.E., 1990. The demise of the “Greek Oracle” model for medical diagnostic systems. Methods Inf Med 29, 1–2.

Miller, R.A., Pople, H.E., Myers, J.D., 1982. Internist-1, an experimental computer-based diagnostic consultant for general internal medicine. N Engl J Med 307, 468–476. https://doi.org/10.1056/NEJM198208193070803

Moehr, J.R., 2004. The Quest for Identity of Health Informatics and for Guidance to Education in it - The German Reisensburg Conference of 1973 Revisited. Yearb Med Inform 201–210.

Samwald, M., Fehre, K., de Bruin, J., Adlassnig, K.-P., 2012. The Arden Syntax standard for clinical decision support: experiences and directions. J Biomed Inform 45, 711–718. https://doi.org/10.1016/j.jbi.2012.02.001

Shortliffe, E.H., Davis, R., Axline, S.G., Buchanan, B.G., Green, C.C., Cohen, S.N., 1975. Computer-based consultations in clinical therapeutics: explanation and rule acquisition capabilities of the MYCIN system. Comput Biomed Res 8, 303–320. https://doi.org/10.1016/0010-4809(75)90009-9

Silverman, H.D., Steen, E.B., Carpenito, J.N., Ondrula, C.J., Williamson, J.J., Fridsma, D.B., 2019. Domains, tasks, and knowledge for clinical informatics subspecialty practice: results of a practice analysis. J Am Med Inform Assoc 26, 586–593. https://doi.org/10.1093/jamia/ocz051

Stead, W.W., Hammond, W.E., 1988. Computer-based medical records: the centerpiece of TMR. MD Comput 5, 48–62.

Weed, L.L., 1969. Medical records, medical education, and patient care;: The problem-oriented record as a basic tool. Press of Case Western Reserve University, Distributed by Year Book Medical Publishers, Chicago, Cleveland.