Dental informatics: An emerging biomedical informatics discipline

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Abstract

Biomedical informatics is a maturing discipline. During the last 40 years, it has developed into a research discipline of significant scale and scope. One of its subdisciplines, dental informatics, is beginning to emerge as its own entity. While there is a growing cadre of trained dental informaticians, dental faculty and administrators in general are not very familiar with dental informatics as an area of scientific inquiry. Many confuse informatics with information technology (IT), are unaware of its scientific methods and principles, and cannot relate dental informatics to biomedical informatics as a whole. This paper delineates informatics from information technology, and explains the types of scientific questions that dental and other informaticians typically engage in. Scientific investigation in informatics centers primarily on model formulation, system development, system implementation and the study of effects. Informatics draws its scientific methods mainly from information science, computer science, cognitive science and telecommunications. Dental informatics shares many types of research questions and methods with its parent discipline, biomedical informatics. However, there are indications that certain research questions in dental informatics require novel solutions that have not yet been developed in other informatics fields.

Keywords

Dental informatics, biomedical informatics, research methods, computers, information technology, dentistry

INTRODUCTION

The use of digital computers in biomedicine traces its origins closely to the seminal events that mark the beginning of the computer revolution. The world's first electromechanical digital computer developed by Konrad Zuse in 1941, Mauchly's and Eckert's Electronic Numerical Integrator and Calculator (ENIAC) of 1946, the invention of the transistor at Bell Labs in 1948, and the development of electronic core memory by An Wang in 1949 laid many of the foundations of digital computing as we know it today (1). Concurrent with the development of computer hardware, information science, computer science and telecommunications evolved as the core research fields contributing to the computer revolution.

From those early beginnings, medical problems and applications provided significant impetus and stimulus to the development of new principles in computer science and information science. For instance, early artificial intelligence systems were pioneered in attempts to solve medical problems (2;3). In the 1960s, "informatics" emerged as a distinct concept. A. Mikhailov at the Moscow State University first defined the term as the discipline that "studies the structure and general properties of scientific information and the laws of all processes of scientific communication" (1). The term "medical informatics" first appeared in France at the same time, and made its entry into the English literature in 1974. Twelve years later, "dental informatics" was first used in a MEDLINE-indexed publication (4).

Today, dental informatics is a small but growing discipline (5;6). Two NIDCR/NLM-funded training programs have existed since 1997 (7;8), and the number of formally trained dental informaticians is slowly increasing. Several graduates of those training programs hold positions at dental schools and the NIH. Some dental journals have established sections for informatics, and, at this time, one journal dedicated exclusively to dental informatics (the Journal of Computerized Dentistry published by Quintessence Publishing Co., Inc.) exists. Dental informatics is represented by working groups and sections in several professional societies, such as the American Medical Informatics Association and the American Dental Education Association.

Despite these developments, dental faculty and administrators in general are not very familiar with dental informatics as an area of scientific inquiry. Many confuse informatics with information technology (IT), are unaware of its scientific methods and principles, and cannot relate dental informatics to biomedical informatics as a whole. The purpose of this paper is to differentiate informatics from IT, explain the types of scientific questions that dental informaticians typically engage in, and discuss the research methods they use. A deeper understanding of dental informatics will help faculty and administrators understand how dental informatics can most effectively help their efforts, and how its methods can be exploited to elevate the state-of-the-art in education, research and patient care. The paper also presents a global view of biomedical informatics and its subdisciplines in order to allow readers to appreciate the context in which dental informatics functions.

DENTAL INFORMATICS: A RESEARCH DISCIPLINE

Despite the continuing debate about what exactly constitutes research in biomedical informatics (9-12), several authors (11;13) have proposed frameworks for defining such research. Friedman has described the tower of science in biomedical informatics (see Fig. 1), which is somewhat paralleled by a more recent categorization into theory, abstraction and design by Maojo (11).

Model formulation, at the lowest level of the tower, is primarily concerned with developing theories and abstractions in the biomedical domain. Such models are representations of the real world, and can describe objects, concepts or methods. For instance, the Medical Subject Headings (MeSH), a key part of the MEDLINE database, represent objects and concepts, such as diseases and anatomical structures, that professionals in biomedicine deal with on a daily basis. Structured collections of terms and concepts such as MeSH are often referred to as taxonomies or ontologies. Problem-solving methods and strategies operate on such terms and concepts. For instance, to diagnose diseases in dentistry, we first collect a large number of data, such as pocket depths, bleeding indices, restorations, carious lesions, and gingival and mucosal status. Then, we combine those signs and symptoms with our knowledge of dental disease in a complex problem-solving process to arrive at a diagnosis (2). Various methods to model such processes on the computer are available. Bayesian belief networks (14), for instance, statistically correlate the presence or absence of findings with the most likely corresponding diagnosis or diagnoses. Many other methods, such as neural networks and rule-based expert systems, for modeling problem-solving strategies exist. Musen (10) considers defining ontologies and problem-solving methods as core research activities in biomedical informatics.

Once a model has been formulated, the next step is to develop a computing system that implements the model, and allows end users can interact with it. Conceiving and programming such systems is a complex task. For instance, translating all information in a dental patient record into a format usable on a computer screen has proven to be a daunting problem. Designing computer systems that integrate with the workflow and needs of clinicians is a challenge that has been attempted but not mastered. One may justifiably ask why almost every office worker in the U.S. uses Microsoft Word in their daily activities, but why only five percent of physicians use of computer-based patient records routinely (15). While the number of dentists using computers in their office is currently above 85% (16), the number of dentists using computer-based patient records (or paperless charts) is believed to be quite low. Maojo et al. (11) and others (9) offer some suggestions on why developing computer systems in biomedicine may be less tractable than in other domains. The complexity of the information, the fact that the human body is largely uncontrollable by humans, environmental issues, and cognitive, ethical and emotional aspects are factors that contribute to the difficulty of "computerizing" biomedicine.

Once a system has been programmed, it must be installed. While most people would regard this step as a minor endeavor, reality tells a different story. The literature is full of single descriptions of elegant and innovative systems that never made it beyond the pilot testing or initial evaluation stage. For instance, none of the expert systems for endodontics, oral radiology, oral pathology and removable prosthodontics that White described in a comprehensive review in 1996 (17) are in general use in practice today. In order to implement computer systems is successfully, it is essential to understand the psychology and cultural traits of individuals, groups and organizations; the workflow; the organizational and systems infrastructure; and the available resources. A supporting research agenda in informatics focuses on people, organizational, and social issues (18), which are becoming more complex as both health care institutions and information technologies evolve. Many research methods and approaches in this area are borrowed from psychology, social science and anthropology.

Evaluation occupies the top level of Friedman's tower. At this level, informaticians conduct formal studies to study the effects of implemented systems. Considering the potential outcomes of such systems on the health of individuals, groups and populations, evaluation is critical. A rich literature and set of methods (19;20) has developed in this area. Research methods in evaluation are often borrowed from those of randomized clinical trials. As such, evaluation studies often are most readily understood by scientists from other biomedical fields.

This description of biomedical informatics as a research discipline highlights both differences as well as areas of overlap with information technology (6). While informatics is a research discipline aimed at uncovering fundamental principles and methods relating to information and computers, information technology (IT) is primarily focused on the implementation, application and support of computer technology and telecommunications. IT support staff and informaticians are sometimes seen doing the same things, such as programming, installing software and providing assistance to users. However, the underlying motivation is fundamentally different. The activities of informaticians are typically framed by one or more research questions, while IT personnel are primarily interested in getting users productive with information technology in a specific situation. A lack of understanding of these subtle but fundamental distinctions often leads individuals to equate informatics with information technology (21). These differences, however, do not preclude close integration and cooperation between informatics and information technology. Many commentators see such a union as highly beneficial (22), because it allows researchers to test some of their theories in practice.

Research questions in informatics tend to be complex and interdisciplinary. It is therefore natural that informatics borrows its research methods from a large number of scientific fields. In the next section, we discuss the sciences that underpin research in informatics, and provide examples of practical applications.

SCIENTIFIC METHODS IN INFORMATICS

The scientific methods in informatics come primarily from four research areas: computer science, information science, cognitive science and telecommunications. However, many other fields, such as social sciences, psychology, anthropology, linguistics, engineering, and mathematics also contribute to the scientific basis of informatics. Figure 2 illustrates how a domain area (such as dentistry) combines with one or more component sciences of informatics to develop solutions in dental practice, research and education.

Information science (23) is the collection, classification, storage, retrieval, and dissemination of recorded knowledge treated both as a pure and as an applied science. Information science deals with information, regardless of the medium. While the origins of information science predate the advent of computers by almost 100 years, much of what is practiced as information science today would cease if not for the computer (24). Examples of how advances in information science assist us in our professional activities abound. Large literature databases, such as MEDLINE could not function without controlled vocabularies, efficient databases and query interfaces. Information design principles (25-27) make complex information more easily understood and analyzed (28). Text data mining methods transcend the capabilities of human searchers, and allow us to formulate novel hypotheses (29).

Computer science (30) is a discipline that involves the understanding and design of computers and computational processes. Here, the emphasis is not on information, but how it is represented, processed, manipulated and managed in computing systems. Computer science studies and develops data representations, algorithms, programming languages, operating systems and computational approaches (such as symbolic reasoning). One may assume that advances in computer science occur primarily outside of the biomedical informatics domain. While this is largely true, the attempt to solve medical problems has resulted in some unique innovations in computer science. For instance, biomedical informatics research has produced rule-based expert systems (3) and domain-specific programming languages (31).

Cognitive science (32) is a research area that draws on several fields (such as psychology, artificial intelligence, linguistics, and philosophy) to develop theories of perception, thinking and learning. The central hypothesis of cognitive science is that thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on those structures. Cognitive science relates to information science inasmuch we try to understand how information is represented in the human mind. It also relates to computer science, inasmuch we try to simulate our mental processes in computing environments. Biomedicine is replete with complex cognitive processes (such as diagnosis, treatment planning and evaluation). It is therefore no surprise that cognitive science represents a significant component of biomedical informatics research (33).

Finally, telecommunications (34) is the science that deals with communication at a distance. Key research issues in telecommunications include how computers communicate with each other, how communication traffic is routed, how bandwidth is used most efficiently and how communication can be kept secure. Advances in telecommunications tend to occur primarily outside of biomedicine. However, sometimes biomedical problems provide important stimuli for telecommunications research. For instance, the need to transmit digital images efficiently resulted in new approaches to image compression and transmission (35). Another example is aggregating information from many different sources, such as information about the same patient from different healthcare providers. This (in this country) still hypothetical example requires innovative approaches in cataloging, labeling and transmitting patient-related information.

The foundations of biomedical informatics do not rest exclusively on the four scientific areas we described. The social sciences and psychology help elucidate the human factor in designing and implementing systems, and can provide important clues for why some implementations succeed and others fail. Anthropology facilitates the understanding of the personal, cultural and contextual environment in health care settings. Linguistics helps to codify and interpret the language of biomedicine, and makes important contributions in representation and analysis of the free text commonly used in research, education and patient care. Engineering provides global underpinnings for the design of systems and devices, regardless of whether they are hardware or software (36).

Biomedical informatics borrows and/or derives its methods, techniques and theories from the sciences we have discussed, and vice versa. This methodological foundation is largely generic. For instance, ontologies are as useful in medicine as they are in geography, botany and philosophy. Neural networks may assist in diagnosing pathologies in radiographs, filtering malicious traffic on computer networks or detecting enemy targets for military strikes. Datamining techniques can help biomedical researchers find patient records with particular clinical events as well as sift historical texts for geographic and temporal information.

Yet, the methods come alive for the practitioner, be it a researcher, clinician or educator, only in their practical application. As Fig. 3 illustrates, many methods are applicable across the continuum of applied informatics disciplines. At the most granular level, bioinformatics is concerned with elucidating molecular and cellular processes. Imaging informatics is primarily focused on the study of tissues and organs. For the broad domain of clinical informatics, the individual patient is at the center of interest. Lastly, public health informatics is focused on populations and society. It is important to note that the interaction between basic and applied research in informatics is a two-way street. Specific problems in the applied area often result in the development of new methods, and new methods may offer alternative approaches to solving existing practical problems.

Figure 3 makes also clear that informatics is not equal to bioinformatics. Bioinformatics is simply informatics applied to the most granular level of science in biomedicine. While bioinformatics has received a tremendous boost through the ongoing decoding of the human genome, new insights into structure-function relationships, and the potential to prevent or combat diseases beginning at the molecular level, it should be acknowledged that neither the subject matter nor the scientific methods used are entirely novel. Bioinformatics applies well established informatics approaches, such as datamining, machine learning, statistics and artificial intelligence, to achieve its aims. New and/or refined methods can emerge from these applications.

Over the years, many subspecializations of biomedical informatics have developed. Dental informatics, nursing informatics, pharmacology informatics, pathology informatics and oncology informatics are only a few of them. In the next section, we explore how dental informatics relates to its parent discipline.

DENTAL INFORMATICS AND ITS RELATIONSHIP TO BIOMEDICAL INFORMATICS

How exactly nursing informatics, dental informatics, pathology informatics and other disciplines are related to biomedical informatics is subject to an ongoing debate (37). On one hand, it is understandable that established professions such as dentistry and nursing would like to claim informatics as part of their domain. On the other hand, an excessive number of boundaries has the danger of balkanizing biomedical informatics as a whole.

It is obvious that the spectrum of research questions ranging from the cellular and molecular level to public health is similar in most clinical disciplines. It is also intuitive that most informatics methods are more or less broadly applicable across this range of research questions. The differences seem to cluster in the applied domain, where discipline-specific solutions are most needed. To give a practical example, much energy, thought and effort has been expended on the development of computer-based patient records (38). Many innovations in computerizing medical records, however, have had little or no utility for dentistry. For instance, representational schemes and standards for clinical data, such as the SNOMED, the Reed Codes, the ICD and HL-7, typically don't represent dental concepts and data very well. Since the representations are not the same, computer systems for inputting, storing, managing and analyzing information must necessarily differ. Differences at the systems level, such as the practice setting (which in dentistry is heavily weighted towards the solo practitioner model), the distribution of generalists and specialists, and reimbursement schemes also tend to limit the transferability of theories, methods and applications from one setting to another.

However, despite the fact that many practical problems require discipline-specific solutions, broad and interdisciplinary collaboration within the biomedical informatics community seems to one of the best ways to develop these solutions. As inclusive and broad communities of researchers, such as the American Medical Informatics Association, continue to illustrate, enormous opportunities for cross-fertilization and collaboration across health disciplines exist. This spirit is also embodied in the philosophies of most biomedical informatics training programs (39-41) that train physicians, dentists, nurses, pharmacologists, computer scientists and individuals from many other disciplines with curricula that share a common core, but are adapted to the needs of specific disciplines.

CONCLUSION

The purpose of informatics is to solve practical problems for researchers, practitioners and educators. Before informatics can be helpful, however, its "customers" must understand exactly what informatics is and what it is not. Unfortunately, the confusion about the nature, differences and commonalities of informatics and IT has resulted in many misconceptions and false starts. To be truly useful, informatics must be understood as what it is: a research discipline aimed at uncovering generalizable principles. With a better understanding of its goals and methods, individuals in applied areas will be able to identify more easily how informatics could potentially help them in their own work. Conversely, informaticians must learn as much as possible about the research issues and problems in the applied areas, so they can target their work at the resolution of real, fundamental problems.

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Fig. 1: Tower of science in medical informatics formulated by Friedman (13)(reprinted with permission from Hanley&Belfus, Philadelphia, PA)

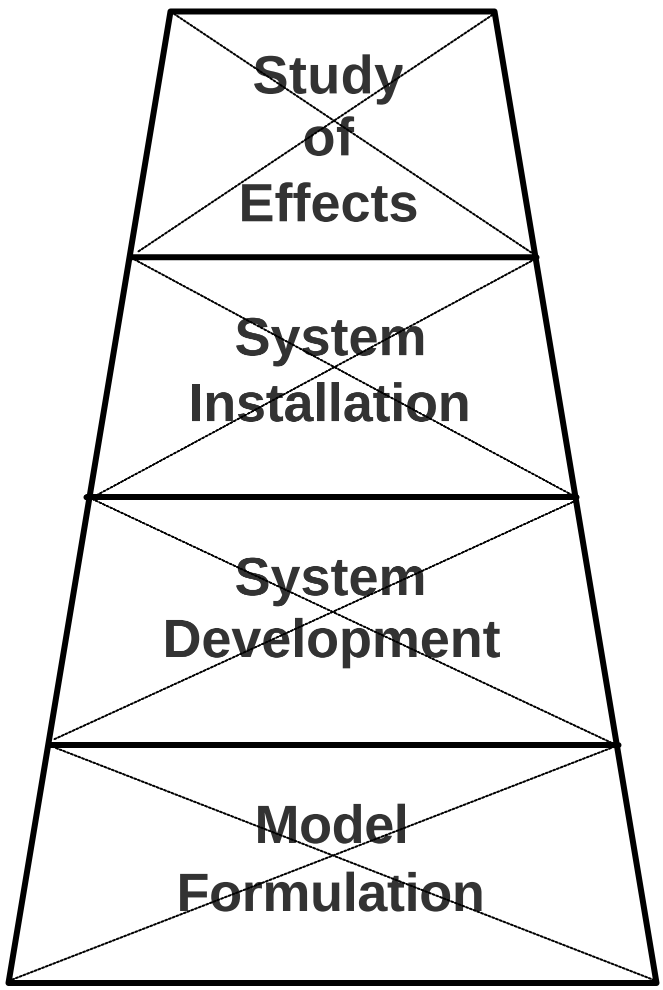

Fig. 2: Dental informatics combines two or more of its methodological foundations to address problems in practice, research and education.

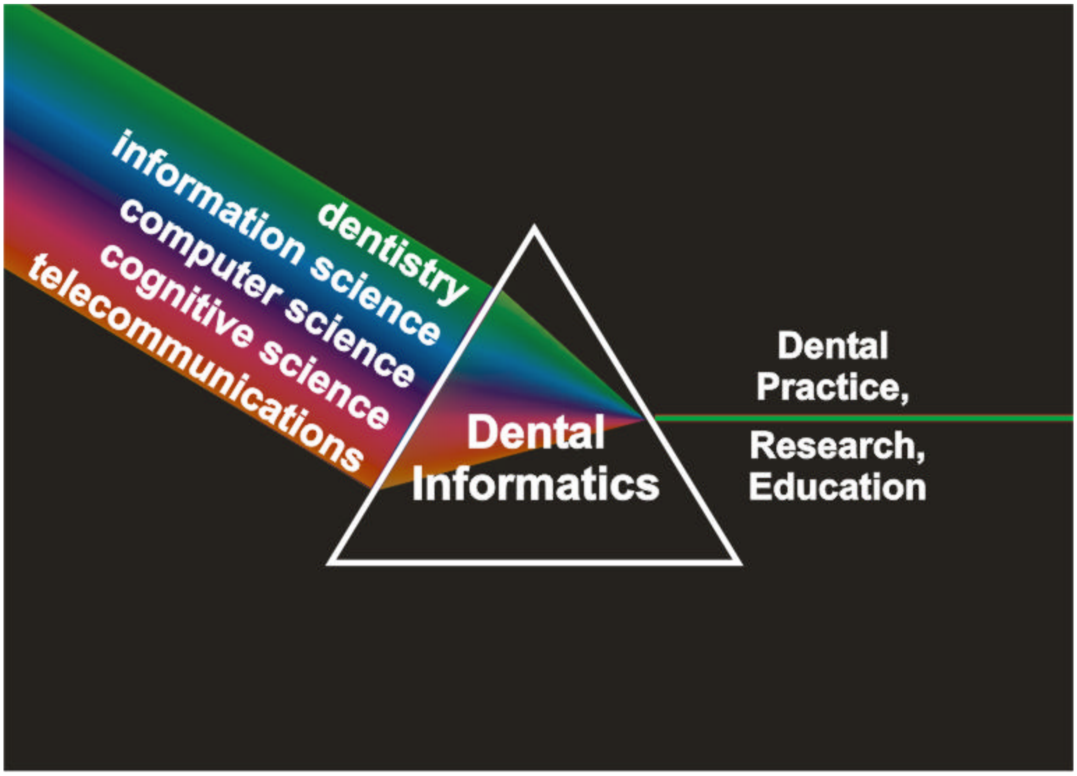

Fig. 3: Relationship of basic research in biomedical informatics to the spectrum of applications in biomedicine (39) (reprinted with permission from Schattauer Verlag, Stuttgart, Germany)