Cognitive Informatics in Biomedicine and Healthcare

Kai Zheng
Johanna Westbrook
Vimla L. Patel *Editors*

Reengineering Clinical Workflow in the Digital and AI Era

Toward Safer and More Efficient Care

Second Edition

Springer

Cognitive Informatics in Biomedicine and Healthcare

Series Editor

Vimla L. Patel, Center for Cognitive Studies in Medicine and Public Health,
New York Academy of Medicine, New York, USA

Enormous advances in information technology have permeated essentially all facets of life. Although these technologies are transforming the workplace as well as leisure time, formidable challenges remain in fostering tools that enhance productivity, are sensitive to work practices, and are intuitive to learn and to use effectively. Informatics is a discipline concerned with the applied and basic science of information, the practices involved in information processing, and the engineering of information systems.

Cognitive Informatics (CI) is the multidisciplinary study of cognition, information and computational sciences. It has been adopted and applied particularly in the fields of biomedicine and health care. The field investigates cognitive aspects of human problem solving and is accordingly closely linked to artificial intelligence (AI) and decision-support systems. It includes all facets of computer applications in biomedicine and health care, including system design and computer-mediated intelligent action. The discipline of CI is strongly grounded in methods and theories derived from cognitive science. It provides a framework for the analysis, modeling and evaluation of complex human performance in technology-mediated settings, thereby contributing to the design, development and safe improvement of information systems for biomedicine and health care.

Despite the significant growth of the field, there have been few systematic reference books or instructional volumes intended for working professionals, scientists or graduate students in both human cognition and biomedical informatics. This series was introduced to meet those needs. Although information technologies are now in widespread use for promoting increased self-reliance in patients, there is often a disparity between the scientific and technological knowledge underlying healthcare practices and the lay beliefs, mental models and cognitive representations of illness and disease. The topics covered in this series also address the key research gaps in biomedical informatics related to the applicability of theories, models and evaluation frameworks of human-computer interaction, human factors and human-centered AI as they apply to health professionals as well as to the lay public.

Kai Zheng · Johanna Westbrook · Vimla L. Patel
Editors

Reengineering Clinical Workflow in the Digital and AI Era

Toward Safer and More Efficient Care

Second Edition

Springer

Editors
Kai Zheng
Department of Informatics
University of California
Irvine, CA, USA

Johanna Westbrook
Australian Institute of Health Innovation
Macquarie University
North Ryde, NSW, Australia

Vimla L. Patel
Center for Cognitive Studies in Medicine
and Public Health
The New York Academy of Medicine
New York, NY, USA

ISSN 2662-7280 ISSN 2662-7299 (electronic)
Cognitive Informatics in Biomedicine and Healthcare
ISBN 978-3-031-82970-3 ISBN 978-3-031-82971-0 (eBook)
https://doi.org/10.1007/978-3-031-82971-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Edward H. (Ted) Shortliffe

We would like to express our gratitude to him for his lifelong dedication to enhancing clinical practice through the contribution of decades of work on biomedical computing and artificial intelligence. His recognition of the importance of cognitive, social scientific, and educational research has been invaluable in advancing the field of biomedical informatics.

Foreword

Clinical care problems today—inefficiency, errors, applying best evidence.

There is universal recognition that healthcare today is expensive, inefficient and plagued by failure to deliver high quality. Nowhere is this truer than the United States, with its fragmented system of providers and payers and it its singularly huge health expenditures per capita as a proportion of gross domestic product. It is hardly controversial to propose that part of the solution is to improve efficiency through communication and coordination among all the stakeholders.

Current communication and coordination are largely related to financial matters, especially payment to healthcare providers. Where "workflow" is addressed, it is largely administrative in nature (admission, discharge, transfer, referral for clinical procedures, and documentation for billing purposes). Yet the real workflow—moving the patient through the healthcare system to transform the sick patients to healthy ones and keep them that way—what the administrative processes were created for in the first place—often garners less study for process improvement. As a result, clinical workflows take a back seat to administrative ones. By way of illustration, I once worked at a hospital where transfer of a patient from a medical or surgical service to the rehabilitation service required formally discharging the patient, with attendant discharge summary and orders, and then readmitting them, with attendant intake and admission orders—even though the patient might not physically move from one bed to another. The opportunity for degraded continuity of care, such as order transcription errors, was only one of the problems that this process imposed.

In the United States, the Affordable Care Act has led to rapid adoption of electronic health record (EHR) systems, largely commercial products, many of which with serious flaws that had previously impeded their adoption. The unintended consequences of this experience can inform similar efforts in other countries. Nevertheless, EHR adoption has been held out as a way to improve healthcare effectiveness and efficiency through automation of, in part, the communication and coordination related to workflow processes.

It is fair to say that the clinical (previously "medical") informatics research community has been poised to help with information-technology-based workflow for decades, at least since the inception of the Symposium on Computer Applications in Medical Care in 1977 (now renamed as the Annual Symposium of the American Medical Informatics Association). The work presented at that conference alone, over it 40-plus years, comprises many thousands of informatics projects, the majority of which failed to find long-term adoption.

While early evaluation of informatics solutions consisted of demonstrating that programs could run to completion without errors, and could do so faster and more accurately than previous attempts, current evaluations examine issues such as usability and usefulness. Yet even systems that fair well in such assessments find that enthusiasm for their use is underwhelming.

To a large extent, the lack of success of most of these projects has been related to failure to integrate them into healthcare systems and, even where integrated, failure to support workflow processes in natural, intuitive ways. For example, nurses and physicians find work-arounds in using electronic clinician order entry systems to the detriment of patients, while alerts and reminders are overridden more often than not as being inappropriate and bothersome. In my own experience, a tool I developed called the Medline Button, the first version of a class of applications called infobuttons that attempt to anticipate and assist with clinician information needs. The Medline Button executed medical literature searches based on a patient's ICD9 codes in the pre-PubMed era. It was a technical success, making the retrieval of relevant information possible with the touch of a button. However, it was a practical failure because it used data generated at the time of hospital discharge that were no longer relevant during a subsequent hospital admission.

What has largely been missing from efforts to health information technology-based efforts to improve clinical workflow, as evidenced by the Medline Button experience, are studies of cognitive processes of patient care providers and their impact on health care team communication and coordination. In subsequent infobutton research, for example, successful adoption did not occur until I partnered with Vimla Patel, one of this book's editors, and her team of cognitive scientists at McGill University to study clinicians' information needs through formal observational think-aloud studies in actual clinical settings.

Which brings me to the purpose and place of this book. Its reviews, essays, and case studies will collectively raise the reader's awareness of the myriad issues that relate health information technology to clinical workflow, not from the perspective of administrative processes, but based on cognitive processes that such systems are intended to support. Once enlightened with that perspective, the reader should consider the systems present (or needed) in his or her own institution and how they should be studied. Hopefully, some of these readers will be decision-makers at their institutions, who will be able to include cognitive researchers in the task of putting the findings of their research into practice. This book will then be at the right place at the right time to provide insight into the types of tools and evaluation expertise that will be needed to better match workflow systems to intended, rather than unintended, consequences.

Birmingham, AL, USA James J. Cimino, MD

Contents

Contributors

Joanna Abraham Department of Anesthesiology and Institute for Informatics, School of Medicine, Washington University in St. Louis, St. Louis, MO, USA

Nate Apathy University of Maryland, College Park, MD, USA

Ann M. Bisantz University at Buffalo, Buffalo, NY, USA

Guy André Boy CentraleSupélec (Paris Saclay University), ESTIA Institute of Technology, Bidart, France

Timothy Buchman Emory University, Atlanta, USA

Kenrick Cato School of Nursing, University of Pennsylvania, Philadelphia, PA, USA

Yunan Chen University of California, Irvine, USA

Elizabeth L. Ciemins AMGA, Alexandria, VA, USA

Joanna Clive Centre for Health Systems and Safety Research, Australian Institute of Health Innovation, Faculty of Medicine, Health and Human Sciences, Macquarie University, Sydney, Australia

Enrico Coiera Macquarie University, North Ryde, Australia

William T. M. Dunsmuir Department of Statistics, School of Mathematics and Statistics, University of New South Wales, Sydney, Australia

Patricia C. Dykes Department of Medicine, Division of General Internal Medicine and Primary Care, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA

Elizabeth V. Eikey University of California, San Diego, USA

Rollin J. Fairbanks MedStar Health Research Institute, Columbia, MD, USA; Georgetown University School of Medicine, Washington, DC, USA

Penelope Fu City of Hope, Duarte, USA

Aaron Zachary Hettinger MedStar Health Research Institute, Columbia, MD, USA;
Georgetown University School of Medicine, Washington, DC, USA

Cheryl Hiddleson Emory University, Atlanta, USA

Jan Horsky Parexel International, Newton, USA

R. Stanley Hum McGill University, Montreal, Canada

A. Jay Holmgren UC San Francisco, San Francisco, CA, USA

Eugene Y. Kim Department of Emergency Medicine, Columbia University Irving Medical Center, New York, NY, USA

Craig E. Kuziemsky Office of Research Services, MacEwan University, Edmonton, AB, Canada

Holly J. Lanham University of Texas Health Science Center, San Antonio, TX, USA

Ling Li Centre for Health Systems and Safety Research, Australian Institute of Health Innovation, Faculty of Medicine and Health Sciences, Macquarie University, Sydney, Australia

Curt Lindberg Partners in Complexity, Waitsfield, VT, USA

Marcelo Lopetegui HICAPPS SpA, La Reina, Santiago, Chile

Sunny Lou Washington University, St. Louis, MO, USA

Keertana Nambiar Department of Informatics, School of Informatics and Computer Science, University of California, Irvine, CA, USA

Laurie Novak Vanderbilt University Medical Center, Nashville, USA

Mustafa Ozkaynak College of Nursing, University of Colorado-Denver, Denver, USA;
College of Nursing, University of Colorado | Anschutz Medical Campus, Aurora, CO, USA

Vimla L. Patel Cognitive Studies in Medicine and Public Health, The New York Academy of Medicine, New York, NY, USA;
The New York Academy of Medicine, New York, USA

Philip Payne Institute for Informatics, Data Science, and Biostatistics, Washington University in St. Louis, St. Louis, MO, USA

Siddarth Ponnala Saama Technologies, Chennai, India

Magdalena Z. Raban Centre for Health Systems and Safety Research, Australian Institute of Health Innovation, Faculty of Medicine, Health and Human Sciences, Macquarie University, Sydney, Australia

Madhu C. Reddy Department of Informatics, School of Informatics and Computer Science, University of California, Irvine, CA, USA

Sarah Rossetti Department of Biomedical Informatics, School of Nursing, Columbia University, New York City, NY, USA

Emilie M. Roth Roth Cognitive Engineering, Stanford, CA, USA

Kumiko Schnock Department of Medicine, Division of General Internal Medicine and Primary Care, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA

Zhe Shan Farmer School of Business, Miami University, Oxford, OH, USA

Bryan Steitz Vanderbilt University, Nashville, TN, USA

Edward H. Suh Department of Emergency Medicine, Columbia University Irving Medical Center, New York, NY, USA

Jennifer Thate Siena College, Albany, NY, USA

Akshay Vankipuram Tempe, Arizona, USA

Jonathan Wald SmarterDx, New York City, USA

Scott R. Walter National Institute for Health and Care Research, Applied Research Collaboration West (NIHR ARC West), University Hospitals Bristol and Weston NHS Foundation Trust, Bristol, UK;
Population Health Sciences, Bristol Medical School, University of Bristol, Bristol, UK;
Centre for Health Systems and Safety Research, Australian Institute of Health Innovation, Faculty of Medicine and Health Sciences, Macquarie University, Sydney, Australia

Nicole E. Werner Departments of Anesthesiology and Biomedical Informatics, School of Medicine, Vanderbilt University, Nashville, USA

Johanna Westbrook Centre for Health Systems and Safety Research, Australian Institute of Health Innovation, Faculty of Medicine, Health and Human Sciences, Macquarie University, Sydney, Australia;
Macquarie University, North Ryde, Australia

Novia Wong Department of Informatics, School of Informatics and Computer Science, University of California, Irvine, CA, USA

Danny T. Y. Wu Department of Biostatistics, Health Informatics, and Data Sciences, University of Cincinnati College of Medicine, Cincinnati, OH, USA

Po-Yin Yen Institute for Informatics, Data Science, and Biostatistics, Washington University School of Medicine in St. Louis, St. Louis, MO, USA;
Goldfarb School of Nursing, Barnes-Jewish College, BJC HealthCare, St. Louis, MO, USA

Sean Yu Regeneron Pharmaceuticals Inc, Tarrytown, NY, USA

Kai Zheng University of California, Irvine, CA, USA

Chapter 1
Clinical Workflow in the Digital and Artificial Intelligence Era

Kai Zheng, Johanna Westbrook, and Vimla L. Patel

1.1 Introduction

Health information technology (IT) in general, electronic health records (EHR) in particular, hold great promise to cross the quality chasm of the healthcare system and to bend the curve of ever-rising costs (). However, health IT implementation projects globally have experienced a wide range of issues, from rollout delays to budget overruns (Kaplan and Harris-Salamone 2009). Successfully deployed systems often fail to generate anticipated results (Black et al. 2011; Kellermann and Jones 2013); some are even associated with unintended adverse consequences (Ash et al. 2007; Campbell et al. 2006; Koppel et al. 2005; Zheng et al. 2016).

In the U.S., for example, over $30 billion were invested in accelerating EHR adoption and promoting its "meaningful use" through the appropriation from the Health Information Technology for Economic and Clinical Health (HITECH) Act 2009 (Blumenthal 2010; Blumenthal and Tavenner 2010). While the program was successful in boosting EHR penetration rates across U.S. hospitals and clinics (ONC 2016), research on the effectiveness of the systems implemented has showed mixed results (Jones et al. 2010; Romano and Stafford 2011). In their Health Affair article entitled "*What it will take to achieve the as-yet-unfulfilled promises of health information technology*," Kellermann and Jones concluded that despite the widespread adoption of health IT, the quality and efficiency of patient care in the U.S. were only

K. Zheng (✉)
University of California, Irvine, USA
e-mail: kai.zheng@uci.edu

J. Westbrook
Macquarie University, North Ryde, Australia

V. L. Patel
The New York Academy of Medicine, New York, USA

K. Zheng et al. (eds.), *Reengineering Clinical Workflow in the Digital and AI Era*,
Cognitive Informatics in Biomedicine and Healthcare,
https://doi.org/10.1007/978-3-031-82971-0_1

marginally better; and the annual aggregate expenditures on healthcare continue to soar (Kellermann and Jones 2013).

Disruption to clinical workflow as a result of health IT implementation has been repeatedly shown as a major cause for the under-realized value of health IT. A key issue is that today's health IT systems are often designed to simply mimic existing paper-based forms, and thus provide little support for the cognitive tasks of clinicians or the workflow of the people who must actually use the system (National Research Council 2009). In a systematic review of the health IT evaluation literature, Buntin and colleagues found that a considerable number of studies reported negative or mixed findings, and that "most negative findings within these articles relate to the work-flow implications of implementing health IT, such as order entry, staff interaction, and provider-to-patient communication (Buntin et al. 2011, p. 467)."

"More/New Work" and "Unfavorable Workflow Change" are two workflow disruptions that have been most often discussed in the literature; both are directly attributable to the radical changes to established clinical workflow associated with introduction of health IT (Ash et al. 2007; Campbell et al. 2006; National Research Council 2009; Niazkhani et al. 2009). While some changes are purposefully planned—to reengineer existing processes to take full advantage of new capabilities offered by health IT—some are manifestations of a wide range of problems such as poor software usability, misaligned end-user incentives, rushed implementation processes, and the lack of sociotechnical considerations to effectively integrate software systems into their complex behavioral, organizational, and societal contexts (Ash et al. 2007; Campbell et al. 2006; National Research Council 2009; Niazkhani et al. 2009).

It is therefore critical to develop a comprehensive understanding of the impact of health IT on clinical workflow, in addition to their root causes, mechanisms, and consequences. Unfortunately, studies of these phenomena are still relatively scarce, and available findings are often inconclusive or conflicting (Unertl et al. 2010; Zheng et al. 2010; Carayon and Karsh 2010). Further, a consensus on the research definition of "clinical workflow" remains elusive, especially in the context of assessing workflow changes introduced by health IT (Unertl et al. 2010).

While conceptual models are available, e.g., (Unertl et al. 2010) many challenges remain in the development and application of robust measures of changes to clinical workflow (Zheng et al. 2010). Methods used in existing workflow studies vary to a great extent (Unertl et al. 2010; Zheng et al. 2010, 2011; Carayon and Karsh 2010; Lopetegui et al. 2014). Even among studies using the same method, a considerable degree of discrepancies exists in application of the method and interpretation of study results (Zheng et al. 2011; Lopetegui et al. 2014) For example, time and motion is considered to be the "gold standard" approach for obtaining quantitative assessments of clinical workflow; yet among the time and motion studies published, there has been a large degree of methodological inconsistencies in the design, execution, and results reporting of those studies, such as how inter-observer reliability is assessed and how multitasking is handled (Zheng et al. 2011; Lopetegui et al. 2014). This issue has significant implications for the rigor and generalizability of time and motion studies, diminishing our ability to accumulate knowledge as a field. As commented by

Carayon and Karsh in a comprehensive literature survey report commissioned by the U.S. Agency for Healthcare Research and Quality (AHRQ), the empirical evidence of health IT's impact on clinical workflow has been "anecdotal, insufficiently supported, or otherwise deficient in terms of scientific rigor (Carayon and Karsh 2010, p. 7)."

This book intends to address some of these knowledge gaps by assembling a team of experienced researchers and practitioners who have dedicated their career to studying and improving clinical workflow. Several chapters included in this book are results of a series of research or quality improvement efforts spanning multiple decades; some are syntheses of the research literature since early 1900s, bringing together what we know about clinical workflow, where gaps remain, and how these gaps can be addressed in future research. In this second edition, most chapters have been updated to reflect new developments of the field since the first edition of the book was published in 2019. This second edition also includes several new chapters that provide in-depth discussions on emerging methods for studying clinical workflow and workflow implications when introducing new, artificial intelligence (AI)-enabled health IT applications.

This book is organized into four Sections and 23 Chapters. The first Section, *Clinical Workflow, Health IT, and Artificial Intelligence*, orientates readers to the problem domain, basic concepts (e.g., cognitive behavior, workflow modeling, healthcare AI), and consequences of disrupted workflow due to health IT implementation. Chapter 3 is a new addition in the second edition that specifically looks into the promises and challenges originating from implementing AI-based tools.

The second Section, *the State of the Art of Workflow Research*, summarizes workflow studies conducted in healthcare in the past few decades. Chapter 6 is a new addition in this second edition of the book that reviews the most recent research developments since 2019. We purposefully include in this section workflow research from a non-healthcare domain, aviation, to draw a comparison between how clinical workflow differs from workflows in other industries and how they are conceptualized and studied differently. Section 2 also includes a chapter specifically on multitasking and interruptions, which are two defining characteristics of clinical workflow that have significant efficiency, care quality, and patient safety implications; in addition to chapters that address nursing and patient perspectives, and workflow-related issues during patient handoff and when patients transition from one healthcare setting to another, i.e., workflow at the edges.

Section 3, *Research Methods for Studying Clinical Workflow*, introduces research methodologies that have been commonly used in clinical workflow studies, including work sampling, time and motion, human factors engineering, and emerging methods that leverage sensor technology for automated data collection and real-time workflow assessment. Section 3 also includes a chapter that discusses the unique characteristics of quantitative workflow data and consequently unique challenges to statistically analyzing such data.

Section 4, *Applications and Case Studies*, first presents three large clinical workflow studies supported by the U.S. Agency for Healthcare Research and Quality (AHRQ) that looked into how health IT systems, introduced as part of ambulatory care practice redesign, impact clinical workflow. Section 4 then presents three case studies each focusing on a distinct perspective. These include effort in reengineering clinical workflow to enable a cross-continental collaboration on creating continuously monitored intensive care units, and efforts in enhancing clinical pathways, clinical rounding, and patient handoff communications.

By compiling a collection of high-quality scholarly works that seeks to provide clarity, consistency, and reproducibility in workflow research, we hope to create a repository of knowledge to inform future studies on health IT design, implementation, and evaluation. In addition to a research reader, this book offers pragmatic insights for practitioners in assessing workflow changes in the context of health IT adoption, and in implementing remedial interventions when such strategies are warranted. The book is also designed to present the state of the art on clinical workflow research, providing an excellent reader for graduate students in all clinical disciplines as well as in biomedical and health informatics.

References

The Office of the National Coordinator for Health Information Technology (ONC); Office of the Secretary, United States Department of Health and Human Services (HHS). 2016 Report to Congress on Health IT Progress: Examining the HITECH Era and the Future of Health IT; accessed August 20, 2018, https://dashboard.healthit.gov/report-to-congress/2016-report-congress-examining-hitech-era-future-health-information-technology.php.

Ash JS, Sittig DF, Poon EG, Guappone K, Campbell E, Dykstra RH. The extent and importance of unintended consequences related to computerized provider order entry. J Am Med Inform Assoc. 2007;14(4):415–23.

Black AD, Car J, Pagliari C, Anandan C, Cresswell K, Bokun T, McKinstry B, Procter R, Majeed A, Sheikh A. The impact of eHealth on the quality and safety of health care: A systematic overview. PLoS Med. 2011;8(1): e1000387.

Blumenthal D. Launching HITECH. N Engl J Med. 2010;362(5):382–5.

Blumenthal D, Tavenner M. The, "meaningful use" regulation for electronic health records. N Engl J Med. 2010;363(6):501–4.

Buntin MB, Burke MF, Hoaglin MC, Blumenthal D. The benefits of health information technology: A review of the recent literature shows predominantly positive results. Health Aff (Millwood). 2011;30(3):464–71.

Campbell EM, Sittig DF, Ash JS, Guappone KP, Dykstra RH. Types of unintended consequences related to computerized provider order entry. J Am Med Inform Assoc. 2006;13(5):547–56.

Carayon P, Karsh B-T. Incorporating health information technology into workflow redesign—summary report. AHRQ Publication No. 10–0098-EF. Rockville, MD: Agency for Healthcare Research and Quality. 2010.

Girosi F, Meili R, Scoville R. Extrapolating evidence of health information technology savings and costs. Santa Monica, CA: RAND Corp.; 2005.

Jones SS, Adams JL, Schneider EC, Ringel JS, McGlynn EA. Electronic health record adoption and quality improvement in US hospitals. Am J Manag Care. 2010;16(12 Suppl HIT):SP64–71.

Kaplan B, Harris-Salamone KD. Health IT success and failure: recommendations from literature and an AMIA workshop. J Am Med Inform Assoc. 2009;16(3):291–9.

Kellermann AL, Jones SS. What it will take to achieve the as-yet-unfulfilled promises of health information technology. Health Aff (Millwood). 2013;32(1):63–8.

Koppel R, Metlay JP, Cohen A, Abaluck B, Localio AR, Kimmel SE, Strom BL. Role of computerized physician order entry systems in facilitating medication errors. JAMA. 2005;293(10):1197–203.

Lopetegui M, Yen PY, Lai A, Jeffries J, Embi P, Payne P. Time motion studies in healthcare: What are we talking about? J Biomed Inform. 2014;49:292–9.

Institute of Medicine (U.S.). Crossing the quality chasm: A new health system for the 21st century. Washington D.C.: National Academy Press; 2001.

National Research Council. Computational technology for effective health care: Immediate steps and strategic directions. Washington D.C.: National Academies Press; 2009.

Niazkhani Z, Pirnejad H, Berg M, Aarts J. The impact of computerized provider order entry systems on inpatient clinical workflow: A literature review. J Am Med Inform Assoc. 2009;16(4):539–49.

Romano MJ, Stafford RS. Electronic health records and clinical decision support systems: Impact on national ambulatory care quality. Arch Intern Med. 2011;171(10):897–903.

Unertl KM, Novak LL, Johnson KB, Lorenzi NM. Traversing the many paths of workflow research: Developing a conceptual framework of workflow terminology through a systematic literature review. J Am Med Inform Assoc. 2010;17(3):265–73.

Zheng K, Haftel HM, Hirschl RB, O'Reilly M, Hanauer DA. Quantifying the impact of health IT implementations on clinical workflow: A new methodological perspective. J Am Med Inform Assoc. 2010;17(4):454–61.

Zheng K, Guo MH, Hanauer DA. Using the time and motion method to study clinical work processes and workflow: Methodological inconsistencies and a call for standardized research. J Am Med Inform Assoc. 2011;18(5):704–10.

Zheng K, Abraham J, Novak LL, Reynolds TL, Gettinger A. A survey of the literature on unintended consequences associated with health information technology: 2014–2015. Yearb Med Inform. 2016;1:13–29.

Part I
Clinical Workflow, Health IT, and Artificial Intelligence

Chapter 2
Cognitive Support for Decisions in the Context of Clinical Workflows

Jan Horsky

Abstract Modern medical care has one of the most complex organizational structures in society, with many non-linear work processes and intricate networks of professional relationships of people who often have interdependent individual and collective responsibilities. Healthcare organizations share many attributes with those in other safety–critical domains that are science-based and information-intensive, and therefore the initiative to improve the quality and safety of care has often been informed by interventions that proved to be effective in those industries. At the same time, many important features of care delivery do not have corresponding examples elsewhere. Researchers analyzing clinical workflows must often do so without the benefit of models that can be readily adapted from other fields, as standard models can describe such extensive and complex work environments only to a limited degree. The ability to reliably assess and model work processes is crucial for developing safe and effective health information technology that needs to be tightly integrated into workflows without adding extraneous complexity and cognitive effort. However, studies have historically investigated primarily the business process of care, and today many workflow analyses show conflicting results and may lack sufficient rigor. Work organization and processes in a socio-natural system that has many non-linear and non-additive functions that characterize healthcare are difficult to model and predict because complex systems are non-reducible to their constituent parts. This chapter discusses several analytic and explanatory frameworks that can guide studies that model workflows and cognitive processes associated with decision making that is often done with incomplete or unreliable information and where goals and priorities often need to be rearranged in response to dynamically changing circumstances. The application of artificial intelligence to the areas of care where they can have a sizeable effect is also reviewed. Patient care can be greatly advanced by the careful harnessing of powerful new forms of information technology into a collaborative environment where complex reasoning and ethics are the exclusive responsibilities of clinicians.

J. Horsky (✉)
Parexel International, Newton, USA
e-mail: horsky@live.com

K. Zheng et al. (eds.), *Reengineering Clinical Workflow in the Digital and AI Era*, Cognitive Informatics in Biomedicine and Healthcare,
https://doi.org/10.1007/978-3-031-82971-0_2

Keywords Clinical workflow · Complex systems · Socio-technical systems · Decision making · Medical cognition · Distributed cognition · Workflow modeling · Cognitive workload · Medical error · Patient safety · Cognitive engineering · Health Information Technology · Artificial Intelligence

2.1 Complex Work Environments

The healthcare industry comprises, at the highest level, a wide array of organizational entities, from small private practices and independent clinics to hospitals and large healthcare delivery networks. Many often work together to provide different or specialized types of care to patients, and each institution also interacts with a multitude of ancillary and support service businesses, insurance and payer companies, public, administrative and regulatory bodies, research centers and academic institutions that jointly form one of the most complex organizational structures in society today (Begun et al. 2003; McDaniel et al. 2013). Modern healthcare has primarily evidence-based character that routinely uses many kinds of medical and information technology that, in turn, shape the work environments where care is delivered. Individuals engaged directly or indirectly in patient care and its administration typically collaborate across professional and institutional boundaries. The quality of their work, level of performance and patient safety are highly dependent on health information technology (HIT) to collect, store, and share information in the complex settings of clinical care.

Decision-making and reasoning of clinicians is as often autonomous as it is contingent on the expertise and decisions made by others at different times and locations. This intricate combination of individual and collective responsibilities, actions and judgements tends to generate many non-linear work processes that account for much of the dynamism and elasticity of both personal and collaborative workflows (Fig. 2.1). Standard workflow models intended to reliably predict outcomes with precision have therefore only limited utility in describing extensive, interconnected processes, especially where dependencies are not always clearly apparent and may change over time.

Many salient characteristics of healthcare work are unique to the domain and do not have good corresponding examples in other industries. Researchers analyzing clinical workflows must often do so without the benefit of models that can be readily adapted from other fields. The primary responsibility of all clinicians is to ensure that patients receive timely, appropriate, and effective care whenever and wherever needed. It means that, in practice, goals, their sequence of completion and plans—the constituent parts of workflow analysis—are quickly reorganized and modified to accommodate emergent events. Interventions that conflict with prior or existing objectives or are outside of normative pathways are sometimes carried out to prevent the exacerbation of minor issues into greater problems. Decisions and actions may be deferred, substituted, or finalized only to a sufficient degree when time or resources are limited, so that tasks with higher priority get completed in full. For example,

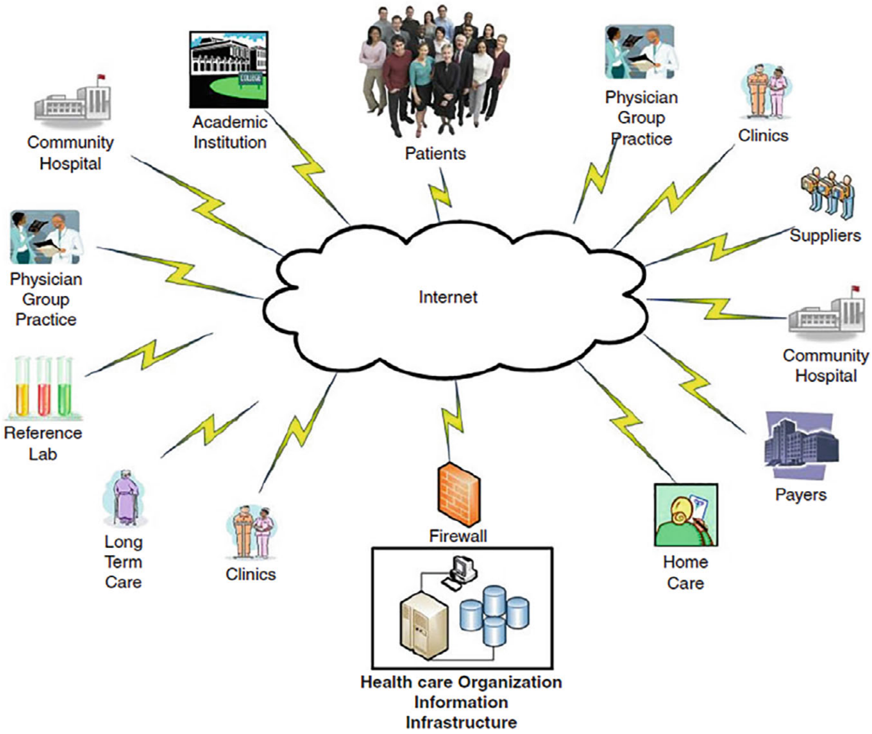

Fig. 2.1 Major organizational components of an integrated. Reprinted from Vogel (2014). Management of information in health care Organizations. Biomedical informatics: Computer applications in health care and biomedicine. E. H. Shortliffe and J. J. Cimino. London, Heidelberg, New York, Dordrecht, Springer: 443–474

planned procedures or evaluations may be postponed or replaced when updated laboratory test results become available, or when new findings require immediate attention. Patients may get treated without delay for acute problems while care for their long-term conditions may be temporarily limited to stabilization or postponed to more opportune time. An important part of improving care quality by making clinical work primarily evidence-based is the reduction of unwarranted variation (Wennberg 2002). At the same time, seeming aberrations and deviations from plans and norms can frequently be considered as necessary corrections to counter evolving risks.

Many public and private organizations have complicated internal structures and employ a large workforce where scientists, researchers, lawyers, professionals and administrative and support personnel collaborate across the boundaries of different expertise and responsibilities. The National Aeronautics and Space Agency (NASA), many national airlines, technology corporations and power-generating companies conduct their work and research in an environment that is science-based, safety–critical and where considerable risks need to be well understood and controlled.

Healthcare organizations share many of these critical attributes and many have therefore informed their effort to increase safety, quality, and effectiveness by considering initiatives successfully implemented in other industries, such as long-term investment in information technology.

There are considerable differences, to be sure, between an engineered system on one hand (the aircraft, engineering), and biological, natural systems (the patient, medical science) on the other. The provision of healthcare has in fact many characteristics that are not typically found in engineered systems and therefore accelerating the uneven pace of progress towards greater effectiveness and safety requires new insights into the specifics and idiosyncrasies of this knowledge and information-intensive domain and its work organization (Durso and Drews 2010). Understanding how health information technology can be best used to advance these goals remains a challenge.

Biomedicine is, in many respects, quite unlike other applied and natural scientific disciplines. One defining but elusive feature of physiologic systems is their remarkable complexity arising from the interaction of a myriad of structural units and regulatory feedback loops that operate over a wide range of temporal and spatial scales, enabling an organism to adapt to environmental stresses (Glass 2001). Medical care and research encompass the properties and behavior of human beings—organisms whose complexity have no counterpart in other sciences. Many properties of natural systems are opaque; for example, important interactions can often be only deduced and in fact may not be fully understood. Individual elements of biological systems occurred without intentional design and are the result of reorganization and evolution in order to adapt to changing environment (Durso and Drews 2010). Medical investigations and discourse therefore includes an aspect of uncertainty that inevitably creates variability among individuals and makes clinical information systematically different from information used in physics, engineering, or even clinical chemistry (Shortliffe and Barnett 2014).

Much of decision making in healthcare involves reasoning with inherently probabilistic information. The level of uncertainty in diagnostic hypotheses or treatment options that clinicians seek to reduce by testing and by gathering data is further affected by information that is often incomplete, dated, or unreliable. For example, observations, laboratory results and narrative reports may not have been completed in time or cannot be obtained when needed, their interpretation could be erroneous and be in apparent conflict (Weber et al. 2017; Smithson 1999). When the history of respiratory problems is not found in the patient record, its lack could be interpreted as an indication of the absence of prior problems by a clinician hypothesizing about the possibility of acute lung disease, even if such assessment occurred but simply was not documented. The value of any patient information rises in the eyes of clinicians when the record is comprehensive: typically, completeness needs to reach 85% or above for the content to be truly useful to clinicians (Yasnoff 2014).

Gathering and reviewing the information that is available adds yet another obstacle that HIT needs to successfully navigate. Somewhat ironically, paucity and excess of information may coincide even in the record of a single patient. Clinicians routinely write assessments, case summaries and test reports and collect laboratory data but

Chapter 22
Clinical Workflow: The Past, Present, and Future

Kai Zheng, Johanna Westbrook, and Vimla L. Patel

As evident from the discussions throughout this book, workflow plays a central role in ensuring smooth functioning of all clinical activities—from patient encounter to medication administration to population health management. Any disruption to workflow can result in severe, adverse consequences such as decreased time efficiency and greater patient safety risks. In the past few decades, the most systemic disruption to clinical workflow is associated with the widespread implementation of health IT systems, electronic health records (EHR) in particular, and more recently due to the adoption of artificial intelligence (AI)-based applications.

In the digital and AI era, coordination of clinical workflow increasingly relies on the use computerized systems with sophisticated decision-making capabilities embedded. However, it has been well recognized that current generation health IT systems "appear designed largely to automate tasks or business processes," providing limited support for clinical workflow and the cognitive tasks of clinicians (National Research Council 2009). Disruption to workflow as a result of health IT implementation is thus common, which is a manifestation of a wide range of design and implementation problems including poor software usability, complex intersystem dependencies, and the lack of sociotechnical integration of software systems into their complex use environments.

Understanding the impact of health IT on clinical workflow has been a key focus of the research on health IT-related unintended consequences (Bloomrosen et al. 2011; Zheng et al. 2016). In this body of the literature, there has been a general consensus

K. Zheng (✉)
University of California, Irvine, USA
e-mail: kai.zheng@uci.edu

J. Westbrook
Macquarie University, North Ryde, Australia

V. L. Patel
The New York Academy of Medicine, New York, USA

K. Zheng et al. (eds.), *Reengineering Clinical Workflow in the Digital and AI Era*, Cognitive Informatics in Biomedicine and Healthcare,
https://doi.org/10.1007/978-3-031-82971-0_22

that the top-down approach in the prevalent health IT design, which predominantly emphasizes administrative efficiency, is responsible for many of the adverse effects observed (National Research Council 2009). Because newly introduced health IT systems often fail to adequately support clinical workflow, clinicians are forced to develop or maintain their own workflow processes deviating from the 'recommended' practice, which as a result could increase workload and introduce new threats to patient safety.

There have been some efforts to address this issue. For example, the U.S. Agency for Healthcare Research and Quality (AHRQ) funded a project to develop a toolkit to help small and medium-sized outpatient practices more effectively manage their workflow (Carayon and Karsh 2010); and subsequently launched a funding program, "Using Health IT in Practice Redesign: Impact of Health IT on Workflow," to specifically support research that studies the causal relationship between health IT and workflow processes (Zheng et al. 2015a; Wald et al. 2015; Carayon et al. 2015). Further, the U.S. National Institute of Standards and Technology (NIST) issued a guideline in 2014 recommending the use of human factors modeling methods to better align EHR design with ambulatory care clinical workflow; and to move away from a billing-centered design to a patient-centered design in order to support better workload management and more flexible flow of patients and tasks (Lowry et al. 2014).

However, as several chapters in this book point out, there remain significant knowledge and methodological gaps in clinical workflow research. Even though disruption to workflow is a topic frequently discussed in the literature, very few studies actually measure workflow changes directly. Instead, most studies speculated that workflow might have been modified because of differences observed in outcomes-oriented measures (e.g., improved guideline adherence and reduced patient safety events) (Carayon and Karsh 2010). Even among studies that have attempted to directly quantify health IT's impact on workflow, many focused on changes in time utilization (e.g., average total time spent in direct patient care activities vs. using the computer), rather than 'flow' of the work (Zheng et al. 2010). This distinction is important because the spirit of workflow lies in the chronological organization of clinical tasks and the temporal (inter)dependencies among them.

In the literature that directly measures workflow, the most commonly used approaches are qualitative methods, such as ethnographic observations, interviews, and focus groups, and quantitative analysis of data collected from self-reported questionnaire surveys. While such approaches provide an important means for studying workflow and understanding the disruptive effects of health IT, they often fall short of measuring the magnitude of the impact; and their results are susceptible to prejudices (e.g., clinicians' negative emotions due to reluctance to change rather than shortcomings of health IT) and biases (e.g., cognitive heuristics, recall errors).

Quantitative studies on workflow that do not rely on self-reported data usually employ a pre-post observational design to assess changes in workflow. Time and motion is the most commonly used approach, which collects workflow data by having human observers observe clinicians for a continuous period of time to record how they perform their clinical tasks (what, when, for how long) (Zheng et al. 2011).

Compared to alternative methods (e.g., work sampling and self-reported questionnaires), the time and motion method is considered the most accurate way to quantify workflow. However, conducting time and motion studies is resource demanding, and their results are subject to many limitations, such as small sample size, observer bias, and the Hawthorne effect (when being observed, clinicians may demonstrate different behavior from their usual practice) (Zheng et al. 2011).

In recent years, several new methods have emerged for studying workflow using data automatically collected through software tools (e.g., screen capture software) or sensor technology such as eye tracking devices, 3D infrared laser projectors (e.g., Microsoft Kinect), and radio-frequency identification (RFID) (Furniss et al. 2017; Calvitti et al. 2017; Kannampallil et al. 2011). These methods, collectively referred to as "computational ethnography," present an automated and less obtrusive means for collecting in situ data reflecting real end users' actual, unaltered behaviors in real-world settings (Zheng et al. 2015b). These methods have the potential to substantially reduce the resource requirement for conducting workflow studies while producing more granular data than what could not be captured by human observers.

Log analysis of security audits, in particular, can be a valuable solution to enabling large-scale workflow studies at a very low cost. In the U.S., mandated by Health Insurance Portability and Accountability Act (HIPAA) and the Meaningful Use criteria, all computerized systems in healthcare must implement security auditing mechanisms for detecting malicious access to, or alteration of, protected health information. These security logs record each and every clinical activity and the associated metadata (when, by whom, the nature of the action, and the IP address or geocode of the device used), providing very rich information on how medical work is conducted. Such data are also highly structured, and can be readily analyzed to reveal insights into workflow through reconstruction of the spatiotemporal distribution of clinical activities. While still limited, workflow researchers have started to tap into this rich data resource. Chapter 16, entitled "Using Electronic Health Record Metadata to Understand Clinician Work and Behavior," is a new chapter included in this second edition of the book that describes recent efforts in using security log data captured in EHR systems to study clinical workflow.

In conclusion, understanding and reducing disruption to clinical workflow as a result of health IT implementation is of vital importance, because of its critical patient safety consequences and the broader concerns about inefficiency and clinician burnout that may result from suboptimal workflow. To develop a systematic solution, it requires a collective effort from multiple stakeholders and an evidence-based approach. This includes regulatory oversight, continued effort by the industry to improve the design of their products, and development of new, patient- and clinician-centered implementation models to better incorporate software systems into clinical workflow. It should also be recognized that there does not exist a *one-size-fits-all* solution, especially considering the complexity of medical work and the variability across specialties and settings. More adaptable software designs are therefore desired, to better respond to the dynamic nature of clinical workflow to allow changes and deviations both during and after system adoption. In addition, clinicians' knowledge of and expectation for health IT also need to be updated to accommodate technological interventions, such as emerging AI-based technologies. Clinicians need to develop a more informed understanding of the new methods of medical work enabled by computerized systems, and the limitations thereof, to better leverage technology in their clinical practice. Through this book, we hope to establish a solid foundation toward these goals by compiling a collection of high-quality scholarly works that seek to provide clarity, consistency, and reproducibility, with a shared view of clinical workflow and its relevance to health IT design, implementation, and evaluation. We also hope that the discussions presented in this book will lead to actionable, pragmatic insights for informatics practitioners in designing, implementing, and evaluating workflow changes to better accommodate the adoption and use of health IT.

References

Bloomrosen M, Starren J, Lorenzi NM, Ash JS, Patel VL, Shortliffe EH. Anticipating and addressing the unintended consequences of health IT and policy: a report from the AMIA 2009 health policy meeting. J Am Med Inform Assoc. 2011;18(1):82–90.

Calvitti A, Hochheiser H, Ashfaq S, Bell K, Chen Y, El Kareh R, Gabuzda MT, Liu L, Mortensen S, Pandey B, Rick S, Street RL Jr, Weibel N, Weir C, Agha Z. Physician activity during outpatient visits and subjective workload. J Biomed Inform. 2017;69:135–49.

Carayon P, Karsh B-T. Incorporating health information technology into workflow redesign—summary report. AHRQ Publication No. 10–0098-EF. Rockville, MD: Agency for Healthcare Research and Quality; 2010.

Carayon P, Hoonakker P, Cartmill R, Hassol A. Patient-reported health information technology and workflow. AHRQ Publication No. 15–0043-EF. Rockville, MD: Agency for Healthcare Research and Quality; 2015.

Furniss SK, Burton MM, Grando A, Larson DW, Kaufman DR. Integrating process mining and cognitive analysis to study EHR workflow. AMIA Annu Symp Proc. 2017;2016:580–9.

Kannampallil T, Li Z, Zhang M, Cohen T, Robinson DJ, Franklin A, Zhang J, Patel VL. Making sense: sensor-based investigation of clinician activities in complex critical care environments. J Biomed Inform. 2011;44(3):441–54.

Lowry SZ, Ramaiah M, Patterson ES, Brick D, Gurses AP, Ozok A, Simmons D, Gibbons MC. Integrating electronic health records into clinical workflow: an application of human factors modeling methods to ambulatory care. NISTIR 7988. Gaithersburg, MD: National Institute of Standards and Technology; 2014.

National Research Council. Computational technology for effective health care: immediate steps and strategic directions. Washington D.C.: National Academies Press; 2009.

Wald JS, Novak LL, Simpson CL, et al. Health IT-enabled care coordination and redesign in Tennessee. AHRQ Publication No. 15–0048-EF. Rockville, MD: Agency for Healthcare Research and Quality; 2015.

Zheng K, Haftel HM, Hirschl RB, O'Reilly M, Hanauer DA. Quantifying the impact of health IT implementations on clinical workflow: a new methodological perspective. J Am Med Inform Assoc. 2010;17(4):454–61.

Zheng K, Guo MH, Hanauer DA. Using the time and motion method to study clinical work processes and workflow: methodological inconsistencies and a call for standardized research. J Am Med Inform Assoc. 2011;18(5):704–10.