Guest Editorial

Biomedical Complexity and Error

In assessing progress towards patient safety since the release of the seminal Institute of Medicine (IOM) report “To Err Is Human” [1], observers have noted that while the report raised awareness of medical error, little evidence exists to indicate that there have been subsequent systematic improvements in healthcare safety. One of the recognized barriers to meeting this grand challenge has been the complexity of the healthcare decision-making environment [2]. This observation highlights the need for approaches to error that address the complex nature of healthcare work. The framework of individual accountability is poorly suited to the problem of medical errors, as it isolates erroneous action from its larger context. In addition, and in keeping with contemporary human error research, investigators have begun to acknowledge that currently prevalent approaches seeking to eradicate error fail to recognize that error recovery (rather than absolute error prevention) is integral to any cognitive work and is thereby crucial in enhancing patient safety. In response, a new approach to medical error that focuses on the emergence, detection, and management of error within a complex cognitive system has been gaining momentum.

The study of complex systems offers insights that are applicable to the study of distributed cognitive systems, which are systems composed of networks of heterogeneous human and machine agents. A complex cognitive system underlies the decision-making process in cooperative workplaces, as exemplified by the critical care environment. At a theoretical level, these approaches consider technology, as well as other artifacts, as an integral part of the distributed cognitive system of the environment. Such an integrated perspective to errors and complexity has been approached in a multidisciplinary and transdisciplinary manner by researchers. Methodologies that capitalize on advances in technology to facilitate data collection and analysis and to develop intervention studies are being developed in a variety of domains such as aviation, the military, health care, and interventions by first-response teams.

Understanding human limitations and failures of their decision-making is important if we are to build robust decision-support systems. We must explore lessons learned from both natural and human-made systems that display a high degree of robustness in the face of component failures. One of the purposes of this special issue has been to reexamine error research within the context of complexity and to have people from different disciplines provide insights into new scientific theories and methods that will help us to understand and resolve some of the outstanding challenges of errors in the biomedical domain [3]. This issue is timely in that there has been a rapid increase in research efforts addressing the application of methods and tools from complexity science and resilience engineering to the study of natural biological environments and social networks. Such work has been inspired in part by a “think tank” symposium organized at Arizona State University and sponsored by James S McDonnell Foundation in October 2008 and followed by a second event at Sedona, Arizona in October 2009. This special issue provides a focused venue for outlining the relevant research topics in the area of complex systems and their application to the biomedical domain, including critical care. Investigators from a number of domains, including complexity science, authored or coauthored the articles submitted and we believe that the resulting selected papers will serve as seminal texts for the study of complexity and error in biomedicine and clinical computing.

The papers are organized in three categories: managing errors and complexity, capturing complexity in clinical workflow, and decision making in complex environments. There are five papers in the first category, beginning with Amalberti et al.’s discussion of the relationship between complexity and errors [4]. The authors argue that a purely systems-based approach to understanding complexity (i.e., the conventional method) is limited in its scope for fully modeling and avoiding adverse events. They accordingly stress the need for a patient-centered and outcomes-driven approach for modeling complexity and errors. As governments across the world struggle with reducing costs associated with health care and increasing patient safety, it is important to explore patient-centered approaches and to understand their implications.

Holtman discusses the relationship between errors and professionalism in complex healthcare environments [5]. Professionalism is identified as a major competency metric for healthcare personnel, but the interaction of professionalism and the emergence of errors has not been a subject of significant research. Conventional wisdom would suggest that increased professionalism would lead to fewer errors, more error reporting, and better overall system performance. Holtman found, however, that this may not be the case and provides a theoretical framework to support his claim. The article also goes onto suggest a relationship between professionalism and better error management.

Lawson et al. discuss how inference and reasoning mechanisms influence decision making in a complex healthcare environment [6]. Using theoretical foundations derived from cognitive science, the authors present a framework for the evolution of errors and describe mechanisms for how they can be avoided. The paper describes the virtues of consciously processing

information and the use of metacognitive knowledge by clinicians to avoid errors.

Patel et al. discuss the relationship between errors and expertise in complex environment such as an intensive care unit [7]. They show that in an “in vitro” situation, both experts and non-experts commit, detect, and recover from errors, but the nature of these errors (knowledge-based and procedural) and time to recovery differ with expertise. They found that the detection of and recovery from errors is complex and not easy for either experts or novices. This is an intriguing insight into how errors occur in complex situations.

Kahol et al. then analyze activities in a trauma center and classify deviations from a protocol as either errors or innovations [8]. The authors take the position that errors and innovation lie on a continuum and it is important to consider cognitive variables underlying both errors and innovations in a clinical environment to understand fully the theoretical basis of medical proficiency. The work analyzes experts and novices and aims to identify the relationship among expertise, errors, and innovations.

The next series of papers develop methods for capturing the complexity of clinical workflow. Vankipuram et al. present a system to model workflow in complex critical care environment [9]. By employing sensor technology and developing algorithms to detect high-level activities in the trauma center, the authors present a system that allows clinicians to play back an entire trauma event in a virtual reality environment. This paper lays the foundation for automated analysis of workflow in complex environments and suggests the potential for educational interventions to promote efficient team practices.

In a similar vein, Kannampillai et al. describe a sensor-based system for modeling ER workflow [10]. The authors found that sensors enhance the capabilities of observers to record and analyze clinical team behavior and, indeed, may capture details that are hard to capture from traditional data-gathering approaches. This validation work makes a case for enhanced research in employing real-time location systems and asset-tracking systems for cognitive complexity research.

In the next paper, Bouarfa et al. explore surgical complexity by investigating surgical workflow using sensor technologies [11]. The authors discuss the implementation and development of such technology for monitoring surgical workflow and preventing errors.

Turchin et al. provide an argument for including alerts in Health Information Technology (HIT) systems [12]. As HIT systems evolve, functionalities tend to be added on a frequent basis. However users often stick to a few well-known workflows and ways of inputting data and do not utilize the innovative functionalities, many of which are developed in response to perceived user needs. The authors present a framework for alerts that monitor user goals and provide contextual alerts for using new functionalities. Testing of the system suggests potential benefits of this approach.

Decision making in a complex environment is the theme for the final three research papers. Franklin et al. studied clinical practice in the emergency room from a cognitive perspective by employing a theoretical framework of naturalistic decision making to identify the nature of time-sensitive decisions [13]. They found that several decisions were emergent in nature and were influenced by interruptions and distractions. This study provides evidence for how unplanned decisions affect the quality, safety, and efficiency of care in complex emergency room environments.

Parush et al. discuss the complexity associated with team situation awareness and development of augmented displays to encourage good team practices [14]. Situation awareness has long been recognized as a hallmark of good performance in complex environments. However, there is very little work in the development of devices, protocols and systems for encouraging good situation awareness in the clinical arena. This paper presents a requirements analysis for one such system by leveraging a theory of situation awareness and suggesting the operational characteristics for a system that can potentially help in increasing such awareness.

Pugh et al. discuss intra-operative decision making using a cognitive task analysis [15]. Surgeons often combine decision making with psychomotor proficiency in the OR to achieve high efficiency and patient safety. This type of multitasking with divided attention environment poses a major cognitive load on surgeons’ performance. Pugh’s work begins to unravel the issues related to decision making while performing surgery and is one of the first studies of this kind in the surgical domain.

Finally, in a methodological review paper, Bartos and colleagues present an intriguing perspective on technology adoption [16]. The development of sustained technology adoption models is a burgeoning research area. Given the current focus on informatics and related tools, it is important to study how such technologies need to be presented to clinicians and healthcare professionals so as to ensure maximum and optimally efficient adoption. The authors use established theories on power, influence tactics, and resistance to suggest a model for administrators and policy makers regarding how to use these parameters when rolling out technologies. It intricately captures the complexity of technology adoption in clinical environments.

The papers in this special issue present a snapshot of the current empirical and theoretical work in biomedical complexity and error. Our intent is that the readers will find it illuminating and will have as much fun reading the articles as we had in putting the issue together. The authors thank all the reviewers and authors who helped us and would also especially like to thank the JBI staff for their help. Finally we would like to acknowledge the gracious support of the James S. McDonnell Foundation, which supported the initial workshops that served as the launching pad for this work and were the source of some of the ideas that were converted to papers and published in this special issue.

References


