Basic Principles for Integrating Next-Generation Technologies into Surgical Workflows

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Abstract—Emerging technologies for the operating room are subject to evaluation against the Quadruple Aim, which describes healthcare performance as a union of: patient satisfaction, clinical outcomes, provider satisfaction, and operational efficiency. Consequently, new developments will be expected to fulfill multiple aims simultaneously. This paper outlines basic principles for increasing the usability of prospective surgical innovations. As technologies become more sophisticated, system designers can incorporate these concepts to ensure intuitive operation and efficient workflows. Such investments address the experience of clinical professionals, who are already subject to physically, cognitively, and emotionally taxing responsibilities. As the dimensions of the Quadruple Aim are coupled, improved user experience has the potential to impact patient satisfaction, outcomes, and efficiency as well.

I. INTRODUCTION

In 2008, Berwick et al. [1] proposed a measure of healthcare performance around improving population health, supported by the contributing aims of patient satisfaction and operational efficiency. Documentation requirements increased, patient expectations grew, and healthcare systems faced increasing cost pressures. The burden of improving performance was ultimately placed on clinicians, whose needs were overlooked leading to the deterioration of provider experience and subsequent declines in all three performance criteria. The fundamental role of personnel in the delivery of healthcare was acknowledged as an added dimension in the Quadruple Aim [2], upon which emerging technologies will be increasingly evaluated against.

Healthcare technologies have grown in complexity alongside broader innovation, as evident in history of bronchoscopy [3]. With its 1964 invention, the 1992 introduction of endobronchial ultrasound, the 2006 integration of electromagnetic (EM) tracking, and the 2018 regulatory approval of endobronchial ultrasound, the 2006 integration of electro-}

II. BASIC PRINCIPLES, BY EXAMPLE

A. Cognitive Friction

Cognitive friction includes the intermediate steps that ostensibly lead to a goal, yet detract from it at the same time; this property can nudge one to avoid the task or its tools. For critical tasks of surgery, cognitive friction can increase cognitive load, impairing both judgment and motor skills [7]. One example is the registration of navigated devices, which is widely regarded as cumbersome [8]. Canonically, the user touches a tracked device to multiple ordered fiducials. They then hope that the sequence was performed satisfactorily, lest they have to repeat the seemingly arbitrary ritual. In [9], the generic registration task is streamlined to a single swipe in an effort to reduce cognitive load; it can furthermore make re-registration a less burdensome process, affording clinicians more freedom in setup and workflow.

Beyond efficiency and convenience, reducing friction offers immediacy as a cognitive benefit. A natural user tendency is to correlate the activation of a task with its eventual outcome in a bid to improve future results. Reducing the latency of task execution allows one to infer cause-effect relationships more precisely, leading to improved performance and problem identification.

B. Natural Vision

Medical images can be rendered in naturally interpretable ways. Fig. 1 (left) shows a B-mode ultrasound image of a mitral valve. Standard 3D imaging (Fig. 1, center) helps reduce the cognitive load needed for mental 3D reconstruction. Then thanks to natural lighting and shadows, a photorealistic rendering (Fig. 1, right) improves depth perception and visualization of 3D spatial relationships, thereby reducing the cognitive effort of interpreting the arbitrary color shading commonly applied in 3D ultrasound today. Natural
A user can gainfully teleoperate a robot with low absolute accuracy provided the relationship between control input and actuation output is proportional and predictable. People excel at estimating linear trends [11], which opens the possibility of relaxing technical requirements.

III. DISCUSSION

The experience of clinical practitioners is vital to improving care delivery, especially as the demands on healthcare systems continue to grow. The usability of supporting technologies will thus become a key characteristic in the next generation of surgery. This paper lists illustrative examples on how complex systems may use intuitive interfaces to ease technological burdens on clinicians. While described independently, these concepts are often related; for example, augmented reality headsets may improve both data representation and ergonomics simultaneously. An intimate understanding of users and workflows is a prerequisite to applying suitable usability enhancements, and more generalized approaches may emerge through experience.

REFERENCES