Operationalizing Sensemaking in Learning Health Systems: A Sociotechnical Case Study in Anesthesiology

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Abstract*—Learning health systems require sociotechnical frameworks that align human cognition, technology, and organizational practice to support continuous improvement in care delivery. Anesthesiology presents a compelling context for examining how clinicians make sense of monitoring data under uncertainty, time, and resource constraints. This study applies and evaluates an adapted sensemaking framework, grounded in Weick's organizational sensemaking theory and Klein et al.'s data-frame theory of sensemaking, to characterize how an expert anesthesiology clinician engages with neuromuscular monitoring data intraoperatively. A think-aloud protocol and semi-structured interview were conducted with a board-certified anesthesiologist in a high-fidelity operating room simulation. Transcript data were analyzed using hybrid deductive and inductive thematic analysis. Deductive analysis yielded five themes operationalized from the adapted framework: *Familiarization, Cue Extraction, Plausibility, Trust Calibration, and Collaborative Sensemaking,* each populated with empirically grounded subthemes. Inductive analysis identified an emergent theme, *Consequence Awareness,* capturing the clinician's reasoning about downstream patient safety implications when monitoring is absent, proposed as an additional construct for subsequent theoretical refinement. Barriers to neuromuscular monitoring spanned individual, workflow, and institutional levels, encompassing knowledge gaps, distrust of monitoring technology, device unavailability, and inadequate integration with electronic health records. Corresponding opportunities were identified in clinical decision support and technology interoperability. The study provides initial evidence for the construct validity, feasibility, and translational utility of the adapted framework in a high-acuity clinical setting. It further demonstrates the viability of a researcher-practitioner partnership model. The findings offer a theoretically grounded foundation for developing low-burden, practice-oriented tools to support clinicians and implementation teams in mapping, reflecting on, and redesigning intraoperative work systems.

Keywords—sensemaking, neuromuscular monitoring, anesthesiology, learning health systems

I. Background & Introduction

Learning health systems aim to continuously improve care by integrating data generation, knowledge production, and practice within routine healthcare delivery. However, realizing this promise requires novel sociotechnical frameworks that align technologies, organizations, and human behaviors to sustain innovation, adaptation, and continuous improvement across the healthcare ecosystem. Anesthesiology is a cognitively demanding clinical setting in which clinicians must continuously interpret evolving patient data rapidly, coordinate across the care team, and act under time and resource constraints [1], [2]. An ongoing challenge in anesthesiology is the distribution and fragmentation of clinical information across multiple sources, including neuromuscular monitoring devices, physiological monitors, electronic health records, alarms, and team communication [3]. Information from these sources often comes in isolated formats. This requires clinicians to integrate information across devices, thus increasing cognitive burden and the likelihood of missed or delayed recognition of critical events. Neuromuscular monitoring (NMM) represents one such domain in which gaps between available technology and clinical practice remain persistent, where clinicians encounter barriers to consistent utilization, face challenges in retrieving and integrating data across heterogeneous systems, and lack workflow structures that support reliable interpretation and action on neuromuscular data within the intraoperative environment. Addressing these challenges requires not only technical solutions but also collaborative approaches to workflow redesign that engage practitioners in co-developing monitoring displays and decision support structures better aligned with the realities of intraoperative care. Furthermore, there remains a lack of practical, theory-informed tools for practitioners and implementation teams to systematically identify, interpret, and act on sociotechnical dynamics as they unfold in real-world practice.

Sensemaking-based frameworks may offer a promising lens for understanding how clinicians recognize, interpret, and respond to signals in complex care environments such as anesthesiology, but few have been operationalized for routine use in the context of learning health systems. This study applies and evaluates an adapted sensemaking framework, an approach that structures how teams capture and organize cues over time, to support the implementation and evaluation of sociotechnical aspects of learning health system activities in an academic anesthesiology department focused on systems integration and perioperative safety and reliability. The study has three primary research questions: (1) Construct validity: To what extent does the sensemaking framework capture

salient sociotechnical factors relevant to anesthesiology? (2) Feasibility: Is the framework applicable and acceptable when applied through a researcher-practitioner partnership model in a high-acuity clinical setting, such as anesthesiology? (3) Utility: How can the framework be translated into low-burden, practice-oriented tools that support clinicians and implementation teams in routinely mapping, reflecting on, and redesigning work systems?

II. Methods

A. Study Design and Simulation Environment

We employed a single-session, expert elicitation design to examine neuromuscular monitoring practice within the intraoperative anesthesia environment. The session was conducted with one board-certified anesthesiologist with documented clinical experience in neuromuscular monitor utilization. The approach integrated a think-aloud protocol within an operating room simulation context, along with a semi-structured interview concurrently. Together, these components were intended to elicit expert knowledge on NMM practice patterns, characterize barriers and facilitators to device utilization, and explore data integration and interoperability challenges within the perioperative information environment. The simulation environment consisted of a high-fidelity manikin, a multi-parameter physiological monitor displaying active vital signals, and standard intraoperative equipment representative of a functioning operating room. Two members of the research team, TO (human factors engineer) and VS (informatician), served in dual roles as active interviewers during the session. Probing questions were used throughout to elicit elaboration on clinical reasoning, decision-making processes, and perceived system-level constraints. The session was both audio- and video-recorded with the knowledge of all parties. The expert anesthesiologist (KJ) contributed to the session as a member of the research team and co-designer rather than as a study participant.

B. Neuromuscular Monitoring Setup and Train-of-Four Data Simulation

Neuromuscular monitoring functions by delivering electrical stimuli to a peripheral nerve and measuring the evoked muscle response to quantify the depth of neuromuscular blockade (Fig. 1). In clinical practice, surface electrodes are positioned along the ulnar nerve at the wrist with the recording sensor placed at the adductor pollicis muscle of the thumb. Once electrodes are applied and a baseline signal is confirmed, the train-of-four stimulation pattern is initiated, delivering four successive electrical impulses at two-second intervals. The resulting twitch responses are processed by the monitor, which displays a numerical train-of-four ratio representing the amplitude of the fourth twitch relative to the first. A ratio of 1.0 indicates no blockade, a count of zero (0) confirms adequate blockade before intubation, and a ratio of 0.9 or greater at the adductor pollicis is the accepted threshold for confirming adequate neuromuscular recovery before extubation.

Although a dedicated neuromuscular monitoring device was not physically present during the simulation session, train-of-four data were simulated and displayed on the multi-parameter physiological monitor to approximate the quantitative output clinicians encounter under routine operative conditions. The expert anesthesiologist (KJ) engaged with this simulated output throughout, narrating electrode placement, train-of-four ratio interpretation, and the clinical decisions that those values would prompt at each phase of the operative workflow. This approach was selected to foreground the cognitive and workflow dimensions of neuromuscular monitoring use rather than device operability per se.

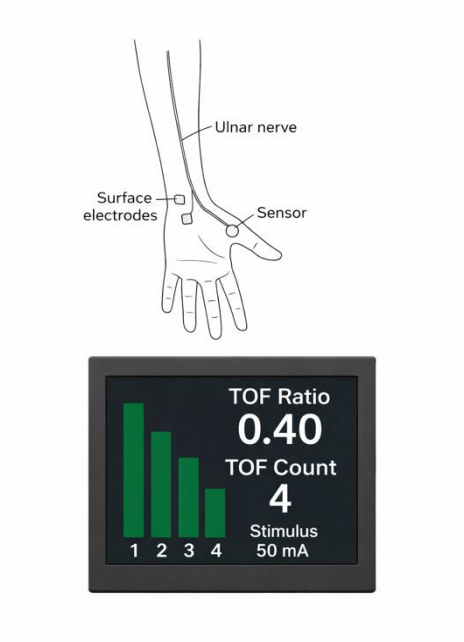

Fig. 1. Neuromuscular monitoring setup showing surface electrode and sensor placement alongside a monitor display depicting a train-of-four ratio of 0.40, four successive twitch responses with progressive fade from T1 to T4, and a stimulating current of 50mA

C. Adapted Sensemaking Framework

The analytical framework was structured a priori around five themes operationalized from our adapted sensemaking framework, grounded in Weick's organizational sensemaking theory [4] and Klein et al.'s data-frame theory of sensemaking [5]. Unlike prior applications of these theoretical foundations, which have largely served as retrospective conceptual lenses, the adapted framework advances their use by operationalizing sensemaking constructs into a structured analytical instrument with observable behavioral indicators designed for prospective application in active clinical environments.

As summarized in Table 1, each theme is defined by its conceptual scope and accompanied by a set of observable behavioral indicators developed to guide systematic coding of the transcript data. These indicators, captured in the "what to look out for" column, served as practical anchors for deductive thematic analysis. This ensured that each theme was

mapped to identifiable clinician behaviors as they emerged across the think-aloud simulation session.

TABLE 1. ADAPTED CLINICAL SENSEMAKING FRAMEWORK OPERATIONALIZED FOR NEUROMUSCULAR MONITORING

Property	What it means	What to look out for
Familiarization	How does the clinician orient to the clinical situation before engaging with the NMM?	First actions after the patient arrives. When does the clinician check the NMM? How do they size up the case?
Cue Extraction	Noticing and focusing on specific signals from the NMM	Watch eye movement, what gets verbalized, what gets ignored?
Plausibility	Judging whether the NMM reading makes sense given the clinical picture.	Moments of hesitation, double-checking, comparing NMM to clinical signs.
Trust Calibration	Adjusting reliance on the NMM based on experience, context, device familiarity, or prior results	Overriding, ignoring, or over-relying on NMM data. Comments about the device or its accuracy
Collaborative Sensemaking	Interpreting NMM data together with other care team members for shared noticing, questioning, or decision-making.	Conversations about NMM readings with other care team members. Who initiates? Who defers?

D. Qualitative Data Analysis

Transcript data from the think-aloud simulation session were analyzed using a systematic qualitative coding process informed by established thematic analysis procedures. The video recording was rewatched, and the transcript was read in full to develop familiarity with the language, actions, and reasoning patterns verbalized by the expert anesthesiologist. Analysis proceeded in two sequential phases: an initial coding phase followed by focused coding.

In the initial coding phase, five coding strategies were used in combination to generate a broad set of initial codes. (1) Structural coding was applied to segment the transcript according to the five a priori themes of the adapted sensemaking framework. (2) In-vivo coding preserved the clinician's own language, where it offered direct insight into clinical reasoning or attitudes toward neuromuscular monitoring. (3) Descriptive coding captured observable actions and workflow behaviors narrated during the simulation. (4) Process coding identified actions and interactions over time, particularly those reflecting how the clinician moved through the workflow. (5) Value coding was applied to determine the assumptions, beliefs, and priorities embedded in the clinician's verbal reasoning.

In the focused coding phase, initial codes were reviewed and organized into logical categories based on conceptual similarity and relevance to the research questions. Categories were then examined for thematic coherence. This process corresponded to Braun and Clarke's stages of searching for, reviewing, and defining themes [6]. An inductive pass was conducted in parallel to identify patterns in the data not anticipated by the a priori framework.

The final stage of the analytic process involved writing up the thematic structure that synthesized both the deductive and inductive findings into a coherent and interpretively grounded account of the expert anesthesiologist's neuromuscular monitoring practice

III. RESULTS

A. Deductive Thematic Analysis

The following results are derived from the deductive thematic analysis of the think-aloud simulation session conducted with the expert anesthesiology clinician (KJ). Themes were applied deductively to the transcript data, with subthemes generated through focused coding within each thematic boundary.

Theme 1: Familiarization. The clinician demonstrated a structured orientation to the operative environment prior to patient arrival, organizing room preparation around the SOAPMM (Suction, Oxygen, Airway, Pressure, Monitors, Medications) framework and verbalizing device functions and measures such as Train-of-four and electroencephalogram, as part of an internalized cognitive readiness routine. "*First one is that I would prepare the room…and I often use an acronym for that. It's called SOAPMM."* Familiarization extended to the pharmacological context, with the clinician articulating blockade agent mechanisms and implications of reversal timing before the patient arrived. *"We use numerous blockade [agents] to facilitate putting the breathing tube through the vocal cords."* Pre-operative steps, including monitor placement, sensor placement, and care team communication, were narrated as sequential components of an established workflow.

Theme 2: Cue Extraction. The clinician's attention was directed most consistently toward Train-of-four readings, with two moments identified as threshold-driven confirmation events: complete blockade prior to intubation and complete

reversal prior to extubation. *"At two times. The first time, you want them to have complete neuromuscular blockade… and then you want the neuromuscular blockade to be completely reversed."* Beyond active signal monitoring, the clinician reflected on patterns of selective inattention in broader departmental practice, noting that neuromuscular monitoring was frequently conditioned on procedure type and surgeon. *"….yes it depends on the procedure…if the surgeon wants it…we have to monitor it to maintain it."*

Theme 3: Plausibility. Plausibility judgment was complicated by cases in which pharmacological expectations conflicted with device output, such as when diaphragm recovery patterns diverged from surgeon observations about patient movement. *"And our sensors will say, they're fully paralyzed, but the diaphragm's laughing at them."*

Theme 4: Trust Calibration. The clinician distinguished between two drivers of reduced reliance on neuromuscular monitoring, including active distrust tied to predefined mental models, and knowledge gaps resulting from inadequate training and limited clinical exposure. *"They have a lot of distrust in the monitor."* The clinician estimated that fewer than ten percent of providers possessed working knowledge of definitions and interpretations related to neuromuscular monitoring, framing this as the more consequential and prevalent form of trust failure.

Theme 5: Collaborative Sensemaking. Interpretation of the blockade status did not occur in isolation; the clinician described negotiated sensemaking with the surgical team, particularly when diaphragm movement prompted intraoperative disagreement that required reinterpretation of device data. Blockade decisions were at times deferred to surgeon preference, distributing clinical judgment across role boundaries. *"And then we also use it during the case if the surgeon requests it."*

B. Inductive Thematic Analysis

In addition to the five deductively derived themes, inductive analysis resulted in an emergent theme not anticipated by the a priori framework. This theme, termed *Consequence Awareness*, captures the clinician's active reasoning about the downstream patient safety, institutional, and systemic implications of neuromuscular monitoring or sensemaking failure within the perioperative workflow. Unlike the five deductive themes, which describe the cognitive and collaborative processes through which the clinician engages with NMM data, *Consequence Awareness* is outcome-oriented. It reflects a parallel cognitive layer in which the clinician simultaneously reasons what is at stake when the sensemaking process breaks down. Relevant codes included recognition of undetected residual blockade as a patient safety risk, acknowledgement of pulmonary complication incidence rates and their severity gradations, post-operative knowledge gaps among providers, structural barriers to NMM integration, including manual data entry into electronic health records and device availability, and the framing of technology adoption within institutional quality improvement and regulatory contexts.

C. Barriers to Neuromuscular Monitoring

At the individual provider level, the most pervasive barrier was a significant knowledge gap. The clinician expert estimated that fewer than ten percent of providers possessed working knowledge of NMM definitions, and that inadequate training and limited exposure during clinical formation had produced predefined mental models and resistance to change. Inability to interpret device output compounded this, as providers who could not derive meaning from Train-of-Four readings had little incentive to integrate the technology into their workflow.

At the workflow level, barriers included the physical absence of NMM devices from most operating rooms, the additional times and steps required for sensor setup and placement, sensitivity issues with electrode adhesion, and the requirement for manual data entry into the electronic medical record.

At the institutional and policy level, NMM was characterized as absent from the normative workflow despite existing professional society guidelines [7] recommending its use. This gap between guideline existence and practice adoption reflected an organizational culture in which non-compliance carried insufficient consequence to drive behavioral change. Also, the technology has not been fully embedded into standard perioperative protocols.

D. Opportunities for Neuromuscular Monitoring

At the clinical decision support level, the clinician identified NMM as uniquely positioned to provide objective confirmation at the two high-stakes moments in the perioperative trajectory: (1) complete blockade at induction and complete reversal at emergence, and (2) replacing subjective visual observation with quantifiable data.

At the technology level, the clinician envisioned continuous electronic health record integration as an important opportunity, eliminating the manual documentation barrier and embedding NMM data directly into the perioperative record. Interoperability improvements, including larger unified display screens aggregating multiple monitor outputs, were identified as ways to reduce cognitive load and increase the visibility of NMM data within the clinical field.

IV. Discussion

The findings are discussed in relation to the three primary research questions.

Construct Validity: To what extent does the sensemaking framework capture salient sociotechnical factors relevant to anesthesiology? The five deductive themes had some coherence with the transcript study data, which suggests that the adapted framework is well-suited to the sociotechnical complexity of anesthesiology. Themes 1 to 3, *Familiarization*, *Cue Extraction*, and *Plausibility*, collectively map the cognitive architecture of engaging with

intraoperative neuromuscular monitoring. This reflects a pattern consistent with existing human factors research characterizing anesthesia as a domain requiring vigilance and expert pattern recognition under uncertainty [1], [8]. The *Trust Calibration* theme also extends the existing literature in a useful way. Studies suggest that many anesthesia providers may be overconfident about their ability to assess neuromuscular recovery without objective monitoring [9], [10]. Rather than treating this as simply an educational or training problem, the framework reframes it as a sensemaking problem, one rooted in how clinicians form and maintain mental models about technology. This opens up different and potentially more effective avenues for intervention. One of the more significant findings was the emergence of *Consequence Awareness* as a theme not originally anticipated by the framework. In addition to describing what the NMM does, the clinician also reasoned about what could go wrong when it was not used. This is important because it reflects the current clinical reality that residual neuromuscular blockade remains widely under-recognized by perioperative professionals, despite evidence linking it to postoperative pulmonary complications, and the need for appropriate neuromuscular block management remains a persistent clinical concern [11]. Incorporating *Consequence Awareness* as an additional sensemaking construct is thus proposed as a direction for subsequent theoretical refinement.

Feasibility: Is the framework applicable and acceptable when applied through a researcher-practitioner partnership model in a high-acuity clinical setting? The think-aloud simulation methodology, conducted with the expert anesthesiologist in a high-fidelity simulated environment, demonstrated that the framework is both applicable and acceptable. The clinician engaged substantively with all five thematic domains across a single session, generating sufficient depth to populate subthemes, surface an emergent construct, and yield analytically tractable data. This suggests that expert elicitation through a researcher-practitioner partnership is a viable and efficient mode of framework application.

Utility: How can the framework be translated into low-burden, practice-oriented tools that support clinicians and implementation teams in routinely mapping, reflecting on, and redesigning work systems? Perhaps the most practical contribution of this study is that it translates the abstract structure of a sensemaking framework into concrete, clinically recognizable terms. The five themes, now populated with subthemes and grounded in expert elicitation, provide a promising first step for developing structured observational tools, debriefing guides, or practice assessment instruments.

Neuromuscular Monitoring Barriers and Opportunities

The barriers identified in this study also refine where and how implementation tools should be targeted. For example, a provider who distrusts the neuromuscular monitor due to predefined mental models requires a fundamentally different intervention than one who simply lacks training in how to interpret neuromuscular monitor data. Finally, the opportunities identified around electronic health records integration and interoperability are consistent with broader calls in the literature for system-level changes, including integration of NMM devices into anesthesia workstations in every operating room, standardized monitoring routines, and departmental tracking tools to support guideline adherence [9]. The contribution of the sensemaking framework is a recommendation that technology integration only improves care if clinicians can make sense of what the technology is telling them. Designing for interoperability without designing for interpretability is unlikely to close the practice gap that this and prior studies have consistently identified.

V. Limitations

Several limitations of this study warrant acknowledgment. First, the findings are derived from a single think-aloud simulation with one expert clinician, which limits the generalizability of the thematic structure. Second, the adapted sensemaking framework applied in this study remains a researcher-constructed conceptual framework that is yet to be validated. Finally, the emergent theme of *Consequence Awareness* is grounded in a single data source and requires replication across additional participants and settings before it can be formally integrated into the framework.

VI. Conclusion

The study demonstrated that an adapted sensemaking framework applied through a collaborative researcher-practitioner partnership can meaningfully capture the cognitive and sociotechnical dimensions of neuromuscular monitoring across the perioperative workflow. The findings position the adapted sensemaking framework as a viable foundation for developing low-burden, practice-oriented measurement and implementation tools in complex clinical settings.

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