

Training and Assessment of Non-Technical Human Factor Skills Among Anesthesiology Residents: An Exploratory Educational Quality Improvement Initiative

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ABSTRACT

Introduction. Safe anesthesia requires technical and non-technical skills to prevent adverse events. Non-technical skills training is not routinely incorporated into formal anesthesia education in the United States. This quality educational improvement initiative aimed to provide clinical anesthesia (CA) residents with non-technical skills training.

Methods. Three anesthesiologists completed virtual Anaesthetists' Non-Technical Skills (ANTS) training in May 2023. An anesthesiologist developed two high-stress simulation scenarios. Fourteen residents were randomized into dyads for the first simulation/post-simulation survey, followed by a two-part didactic seminar on human factors based on the ANTS framework and a post-didactic survey. One hundred twenty days later, residents were re-randomized for a second simulation and another post-simulation survey. Two ANTS-trained anesthesiologists reviewed video recordings of both simulations.

Results. Cohen's kappa demonstrated moderate agreement ($\kappa = 0.43$; 95% CI, 0.36-0.49; $p < 0.001$) between evaluators. Wilcoxon signed-rank tests indicated improved non-technical skill use among CA1 residents, while senior residents generally performed better during the first simulation. Fisher's exact tests showed no significant associations in resident knowledge or confidence following training.

Conclusions. Non-technical skills training may benefit residents early in CA training, while senior residents may have different learning needs. Simulation-based training appears feasible; however, formal, recurring, and consistent education may be needed to reinforce these skills throughout residency.

INTRODUCTION

Non-technical skills are important in health care but often lack structured, dedicated training during graduate medical education in the United States. One exception is Stanford University's immersive sim-

ulation-based learning program through the Center for Immersive and Simulation-based Learning, which offers training in holistic technical/non-technical skills through immersive simulation learning.¹ Establishing a structured training regimen that integrates technical and non-technical skills during residency may therefore facilitate the application of human factor principles in clinical practice.

Safe and efficient anesthesia care requires both technical and non-technical skills which work together to support effective task management and prevent adverse events.² Although technical skills routinely are taught and practiced, non-technical skills receive less structured attention.³ One study has demonstrated that non-technical skills can be taught through cognitive aids, repeated scenario-based training, and systematic approaches to patient care, with systematic approaches associated with improved problem-solving skills and confidence in high-stress situations.⁴ Non-technical skills encompass a range of interpersonal, cognitive, and behavioral skills, whereas human factors refers to the effects of communication, teamwork, task management, situational awareness, culture, and organizational factors on human behavior and performance, as well as the application of this knowledge in clinical settings.⁵

Although human factors are addressed throughout anesthesiology residency, they are not always taught through structured, dedicated curricula.⁶ This is important because human factors and non-technical skills substantially contribute to patient safety, particularly during high-stress situations. Studies have reported that 82% (294/359) of incidents resulting from preventable adverse events were associated with human error,⁷ with communication breakdowns between health care professionals at different levels contributing substantially to these errors.⁸ Another study found that deficits in nontechnical skills contributed to 47.7% (2,677/5,610) of reported incidents, with task management identified as the most prevalent contributing factor.⁹ Deficiencies in non-technical skills may therefore increase the risk of errors and adverse events.¹⁰ Structured training in these skills is becoming increasingly common during residency, particularly in European and Asian countries.^{6,11-13}

Despite these findings, relatively few anesthesiology studies have examined the effects of non-technical skills training in clinical settings, particularly in the United States.^{14,15} In contrast, research in other specialties is more

extensive.^{9,13-20} The Royal College of Anaesthetists in the United Kingdom developed the Anaesthetists' Non-Technical Skills (ANTS) framework and associated training and evaluation program.¹² ANTS evaluates four categories of non-technical skills: Situation Awareness, Team Working, Task Management, and Decision Making across 15 behavioral elements. Each element is rated from poor (1) to good (4), providing a structured assessment of non-technical skill performance (Table 1). Research has demonstrated that ANTS is a reliable and valid tool for evaluating anesthesiologists' non-technical skills in simulated and clinical settings.^{21,22} Its versatility also allows for implementation across different study designs and educational interventions.²³

Table 1: Summary of the elements included in the Anaesthetists' Non-Technical Skills protocol and evaluation.

Skill Elements	
Task Management	Planning and preparing
	Prioritizing
	Providing and maintaining standards
	Identifying and utilizing resources
Team Working	Coordinating activities with team
	Exchanging information
	Using authority and assertiveness
	Assessing capabilities
Situation Awareness	Supporting others
	Gathering information
	Recognizing and understanding
	Anticipating
Decision Making	Identifying options
	Balancing risk and selecting options
	Re-evaluating

Note: There are 15 skill elements categorized into four main groups.

The aim of this exploratory educational quality improvement initiative was to educate anesthesiology residents about human factors and evaluate their use of non-technical skills during one-off simulated high-stress scenarios. Using the ANTS framework, we assessed residents' non-technical skills during an initial simulation, followed by two didactic sessions on human factors, and then a second simulation. We hypothesized that residents would demonstrate higher ANTS scores during the second simulation after receiving human factors education and targeted training in non-technical skills.

METHODS

Quality Initiative Design and Protocol

Three anesthesiology faculty members virtually attended the ANTS training course in May 2023 to learn about human factors and standardize future evaluations. Following the training, one faculty member independently developed two high-stress simulations for use at a simulation center (Supplemental S1: Simulation Scenarios; only available online at journals.ku.edu/kjm). Residents in their clinical anesthesia (CA) years (CA1 = 4, CA2 = 5, CA3 = 5; n = 14) were randomly assigned to dyads and participated in a baseline simulation with less than 24 hours' notice in September 2023 (Supplemental ST1: Group Combinations). Randomization was used because resident pairings vary during routine clinical duties and may involve different levels of experience.

Each dyad was debriefed immediately after the simulation by the faculty member who developed the scenario. Debriefing was conducted at the faculty member's discretion without standardized questions but followed the PAUSE format (Provide summary, Analyze initial reactions, Understand the sentiment, Silence for introspection, and Education).²⁴ Within 1 month of the baseline simulation, the same faculty member presented a two-part, 3-hour didactic seminar on non-technical skills based on the ANTS training course. Each session lasted approximately 1.5 hours and was delivered 3 weeks apart because of faculty scheduling. Pre- and post-didactic surveys assessed residents' perspectives on non-technical skills training (Supplemental S2: Didactic Survey).

Approximately 120 days after the baseline simulation, residents were re-randomized into dyads and participated in a second, distinct simulation with less than 24 hours' notice in January 2024 (Supplemental ST1: Group Combinations). No dyad was repeated between simulations. The 120-day interval was selected based on several factors: (a) evidence that long-term skill retention is assessed beyond 3 months,²⁵ (b) availability of the University of Kansas School of Medicine-Wichita Simulation Center, (c) allowing residents time to practice skills in the clinical setting following the didactic intervention, (d) faculty availability, and (e) facilitating program planning for resident absences from clinical duties. Residents were immediately debriefed after the second simulation using the same approach as the

baseline simulation. Post-simulation surveys were collected after both simulations to assess the usefulness of the scenarios (Supplemental S3: Simulation Survey).

Simulation Development

Two distinct simulations were developed in conjunction with the Simulation Center to evaluate non-technical skills after training. New simulations were developed to prevent residents from anticipating the scenarios, ensure that cases reflected anesthesiology-specific situations, and minimize familiarity with previously used simulations. The Simulation Center facilitated the simulations and provided real-time changes in vital signs, manikins capable of simulating breath sounds and heart rates, and video recording for subsequent evaluation. An experienced operating room nurse was available as a resource during each simulation.

The simulated operating room was arranged to reflect the layout familiar to residents, except that an anesthesia machine was unavailable at the Simulation Center and therefore was not included. Before entering the simulation room, residents received a case description indicating that the patient was prepped and draped and that the surgeon was scrubbing in but was not yet in the room. Residents were given several minutes to familiarize themselves with the room and equipment before the scenario began (Supplemental S1: Simulation Scenarios). The baseline simulation involved anaphylaxis, whereas the follow-up simulation involved local anesthetic systemic toxicity. Each simulation lasted approximately 40 minutes, including debriefing.

Following both simulations, video recordings from three camera angles were obtained from the Simulation Center. Videos were edited to remove extraneous downtime, such as room setup, and resident debriefings. Edited recordings were provided to the two remaining ANTS-trained anesthesiology faculty members for evaluation using the ANTS framework.¹² Evaluators were blinded to the simulation sequence and were unaware of which recording represented the baseline or follow-up simulation. However, they were aware of group composition because they knew the residents and could identify the dyads during video review. They had no prior knowledge of the order in which the simulations were conducted. Resident debriefings were excluded from the recordings provided to evaluators to minimize potential assessment bias. Evaluations were conducted from February through March 2024.

Statistical Analysis

Quadratic weighted Cohen's kappa was calculated to assess inter-rater reliability between evaluators. Baseline and follow-up assessments were compared using the Wilcoxon signed-rank test for individual residents' ANTS element scores. Residents were analyzed individually rather than as dyads. Statistical significance was set at $p < 0.05$.

Given the small sample size ($n = 14$) and the estimated effect size (Cohen's $d = 0.09$), the study had limited statistical power and a corresponding high probability of Type II error (94.5%). Cohen's d was used to quantify the magnitude of the observed effect independent of sample size. Statistical power and the corresponding probability of Type II error were estimated using a power analysis.

Survey results were used to provide additional information regarding residents' knowledge and confidence in nontechnical skills. The surveys were developed specifically for this study and were not formally validated; however, three ANTS-trained faculty members reviewed the surveys for clarity and content relevance.

Fisher's exact tests and Cramer's V were used to evaluate associations among survey responses. Fisher's exact test was used to assess associations involving the Likert-type response categories, which ranged from Very Low to Very High. Cramer's V was used to estimate the effect size for each Fisher's exact test.

Thematic analysis was used to evaluate responses to the simulation surveys. Three authors independently identified keywords and concepts within the responses and subsequently discussed and categorized them into themes using predefined characteristics. All statistical analyses were performed using R[®] statistical software (version 4.1.1; R Foundation for Statistical Computing, Vienna, Austria),²⁶ and figures were created using the R package ggplot2 version 3.4.0.²⁷

IRB Statement

This study was reviewed and approved as a quality improvement initiative by the Ascension Health Institutional Review Board (RKS20230030). Written informed consent was obtained from participants for publication of the findings. The manuscript adheres to the Standards for Quality Improvement Reporting Excellence (*SQUIRE* 2.0) guidelines for quality improvement reporting.²⁸

RESULTS

Assessment of Non-Technical Skill Use in Simulations

Upon completion of the resident evaluations, quadratic weighted Cohen's kappa was used to assess inter-rater reliability between the two evaluators. The analysis demonstrated moderate agreement ($\kappa = 0.43$; 95% CI, 0.36-0.49; $p < 0.001$). A Wilcoxon signed-rank test was then used to compare ANTS scores between the baseline and follow-up simulations for each individual resident within each evaluator (Table 2).

According to Evaluator 1, 75% of CA1 residents ($n = 3$) demonstrated a significant improvement in the use of non-technical skills between the baseline and follow-up simulations. Among CA2 and CA3 residents, 40% ($n = 4$) demonstrated a significant decline in non-technical skill use, while the remaining 60% ($n = 6$) showed no significant difference between simulations.

According to Evaluator 2, 100% of CA1 residents ($n = 4$) demonstrated a significant improvement in non-technical skill use between simulations. Among CA2 and CA3 residents, 10% ($n = 1$) demonstrated a significant improvement, 50% ($n = 5$) demonstrated a significant decline, and 40% ($n = 4$) showed no significant difference between simulations (Table 2).

Simulation and Didactic Survey Evaluation

Residents completed anonymous surveys following each simulation (two surveys per resident, one for each simulation) and the didactic seminar series. Qualitative analysis of the post-simulation survey identified six themes that residents recommended be retained in future simulations and six themes for improvement (Table 3; $n = 23$; 82.1% response rate). The most frequently identified theme for retention was the uncommon nature of the cases, with residents noting that simulation provided an opportunity to practice rare clinical scenarios without consequences to patients. The most frequently identified area for improvement was the design of scenarios to facilitate one-on-one training.

The post-didactic survey assessed residents' perceptions of the seminar's usefulness in developing nontechnical skills (Figure 1) and their confidence across nontechnical skill areas (Figure 2; $n = 13$; 92.9% response rate). Overall, residents were receptive to the seminar, with 84.6% ($n = 11$) reporting confidence in their nontechnical skills, although

Table 2: Wilcoxon Signed-Rank tests between baseline and follow-up simulations for each resident. ANTS scores were averaged between both evaluators for each element.

Baseline	CA1-1	CA1-2	CA1-3	CA1-4	CA2-1	CA2-2	CA2-3	CA2-4	CA2-5	CA3-1	CA3-2	CA3-3	CA3-4	CA3-5
Task Management	3	2	3	2	3	3	3	3	3	3	4	3	3	4
	2	3	3	2.5	4	3	3	3.5	3.5	3	3.5	4	3	3.5
	2.5	2.5	3	2.5	4	3	3.5	3.5	3.5	3	3.5	4	3	3.5
	2.5	3	3	2.5	3	2.5	3	3.5	3.5	2.5	3.5	3.5	2.5	3
Team Working	3	2.5	3	2.5	4	3	3	3.5	3.5	3	2.5	3.5	3	2.5
	2.5	3	3.5	2	3.5	2.5	3	3.5	3.5	2.5	3	3.5	3	3.5
	2.5	2.5	2.5	2	4	2.5	3.5	3.5	4	2	3.5	4	3	3
	2.5	2	2.5	2.5	3.5	3	3	4	4	3	3.5	3	3	3
Situation Awareness	3	3	3	3	3.5	3	3	3.5	3.5	3	4	3.5	3.5	4
	2.5	2.5	3	2.5	3.5	3	3	3.5	3.5	3	3.5	4	3.5	3
	1.5	2	3	1.5	4	3	2.5	4	4	3	3.5	4	3	3.5
	1.5	2	3	1.5	4	3	3	4	4	3	3.5	4	3	3.5
Decision Making	2.5	2	3	2	4	2.5	2.5	4	4	3	3	3.5	3	3
	2	2.5	2.5	2	4	3	2.5	4	4	3	3.5	4	3	3.5
	2.5	2.5	3	2	4	3	3	4	4	3	4	4	3.5	4
Follow-up	CA1-1	CA1-2	CA1-3	CA1-4	CA2-1	CA2-2	CA2-3	CA2-4	CA2-5	CA3-1	CA3-2	CA3-3	CA3-4	CA3-5
Task Management	4	3	3	2	3	3	3	2	4	3	3	3	3	4
	3	3	3	2.5	3	3.5	3	3	3.5	2.5	2.5	4	2.5	3
	3.5	2.5	3	2.5	3	3.5	3	3	3.5	3	3	3.5	3	3.5
	3.5	3	3.5	2.5	3	3	3	2.5	3.5	2.5	3.5	3.5	2	3.5
Team Working	4	3.5	4	2.5	3.5	3	3	3	4	2.5	3	4	2.5	3.5
	4	3.5	3.5	2.5	3.5	3.5	3	3.5	3.5	2.5	3	4	2	3.5
	3.5	3.5	3.5	2.5	3.5	3	2.5	3.5	4	2	2.5	3.5	2	3.5
	3	3	3.5	2	2.5	3.5	2.5	2	3.5	2.5	2.5	3.5	2.5	3
Situation Awareness	4	3.5	4	3.5	3.5	3.5	3	3.5	3	3	3	3.5	3	3.5
	3.5	3	3.5	3	3.5	3	2.5	3.5	3.5	2.5	2.5	3.5	2	3.5
	2.5	3.5	3.5	2.5	3	3.5	2	3	3.5	2	2	3.5	2	2.5
	3	3	3.5	2.5	2.5	3	2	2.5	3	2	2	3.5	2	3
Decision Making	3.5	3.5	3.5	2.5	3.5	3.5	2	2.5	3.5	2	2	4	2	3.5
	3.5	3	4	2.5	3	3.5	2	2.5	3.5	2.5	2	4	2.5	3.5
	3.5	3.5	3.5	3	3.5	3.5	2.5	3	3.5	2.5	2.5	3.5	2.5	3.5
p-value	<0.001	<0.001	<0.001	0.006	<0.001	<0.001	0.001	<0.001	0.207	0.001	<0.001	0.546	<0.001	1
Direction	▲	▲	▲	▲	▼	▲	▼	▼	—	▼	▼	—	▼	—

Note: ANTS elements are rated on a scale of 1 (poor) to 4 (good). ▲ indicates a significant difference in evaluation between simulations, where the resident performed better during the follow-up simulation. ▼ indicates a significant difference in evaluation between simulations, where the resident performed worse during the follow-up simulation. No ▲ or ▼ indicates no significant differences in performance between simulations. ANTS = Anaesthetists' non-technical skills; CA = clinical anesthesia year.

Table 3: Thematic analysis of the post-simulation surveys.

Question	Theme	Responses	Definition of Theme
Positive points in the simulation session that should be repeated in the future?	Scenario	18	A good balance of uncommon but potential case that could and should be experienced during residency.
	Critical Thinking	2	Fast pace and high stress situation, coupled with unknown scenario, resulted in deeper levels of thinking.
	Peer Partner	8	Approaching stressful situations with a peer enhanced the experience.
	Nursing Staff	4	Having an experienced OR nurse participate in the simulation made the experience more realistic and immersible.
	Simulation Environment	9	The setup of the simulation (draped/prepared manikin, connected IV, available syringes, etc.) made the situation more believable and realistic while allowing a safe environment to make mistakes.
	Debrief	6	Immediate debriefing by the attending following the simulation allowed for highlighting of strengths and deficiencies.
Some areas for improvement for future sessions?	Lab Familiarity	4	Let residents familiarize themselves with the simulation lab before the beginning of the scenario.
	Real-time Feedback	4	As the monitors can be delayed when making changes, provide real-time changes to numbers as the case progresses, if residents are moving too quickly.
	Equipment Availability	4	Have more equipment available for the simulations (i.e., ultrasound, ECHO).
	Simulations	6	Have more simulations: one-on-one, more complex, and/or cases pertaining to the resident's current level of training.
	Handoffs	4	Present the case details in the form of a handoff to make the simulation more realistic.
	Chaos	3	Introduce more chaos to the simulation to make it more high stress (i.e., have music on in the background, provide more ambiguity to the case details) to help highlight non-technical skills a bit better.

Note: The specific response categories to each question are displayed as themes, with the number of similar responses falling into that theme. The theme definitions provide a further explanation of the responses.

OR = operating room; IV = intravenous; ECHO = echocardiogram.

fewer residents expressed interest in additional didactic training (Figure 1). Fisher's exact test showed no statistically significant association between the seminar and residents' knowledge of nontechnical skills ($p = 0.743$). Cramer's V was 0.337.

Regarding resident confidence, responses indicated some uncertainty across each of the four major nontechnical skill categories (Figure 2). Fisher's exact test showed no statistically significant association between the seminar and residents' confidence in their nontechnical skills ($p = 0.949$). Cramer's V was 0.223.

DISCUSSION

The authors of this educational quality improvement initiative hypothesized that residents would have higher ANTS scores during the follow-up simulation after receiving didactic education. The observed improvement in non-tech-

nical skill behaviors was evident among residents early in their clinical anesthesia training but was not observed among CA2 and CA3 residents (Table 2). However, given the small sample size and high likelihood of Type II error, these findings should be interpreted cautiously.

The lack of observed improvement among CA2 and CA3 residents may have been influenced by opportunities to incorporate non-technical skills into their developing clinical practice. Residents were expected to actively practice non-technical skills between simulations. Although senior residents may have had more opportunities to incorporate these skills into clinical practice, they may also have already developed established approaches to managing high-acuity situations. In contrast, junior residents generally are more closely supervised by attending physicians, providing greater opportunities for faculty instruction, even when faculty have not received formal training in non-technical skills. Additionally, the improved scores among CA1 res-

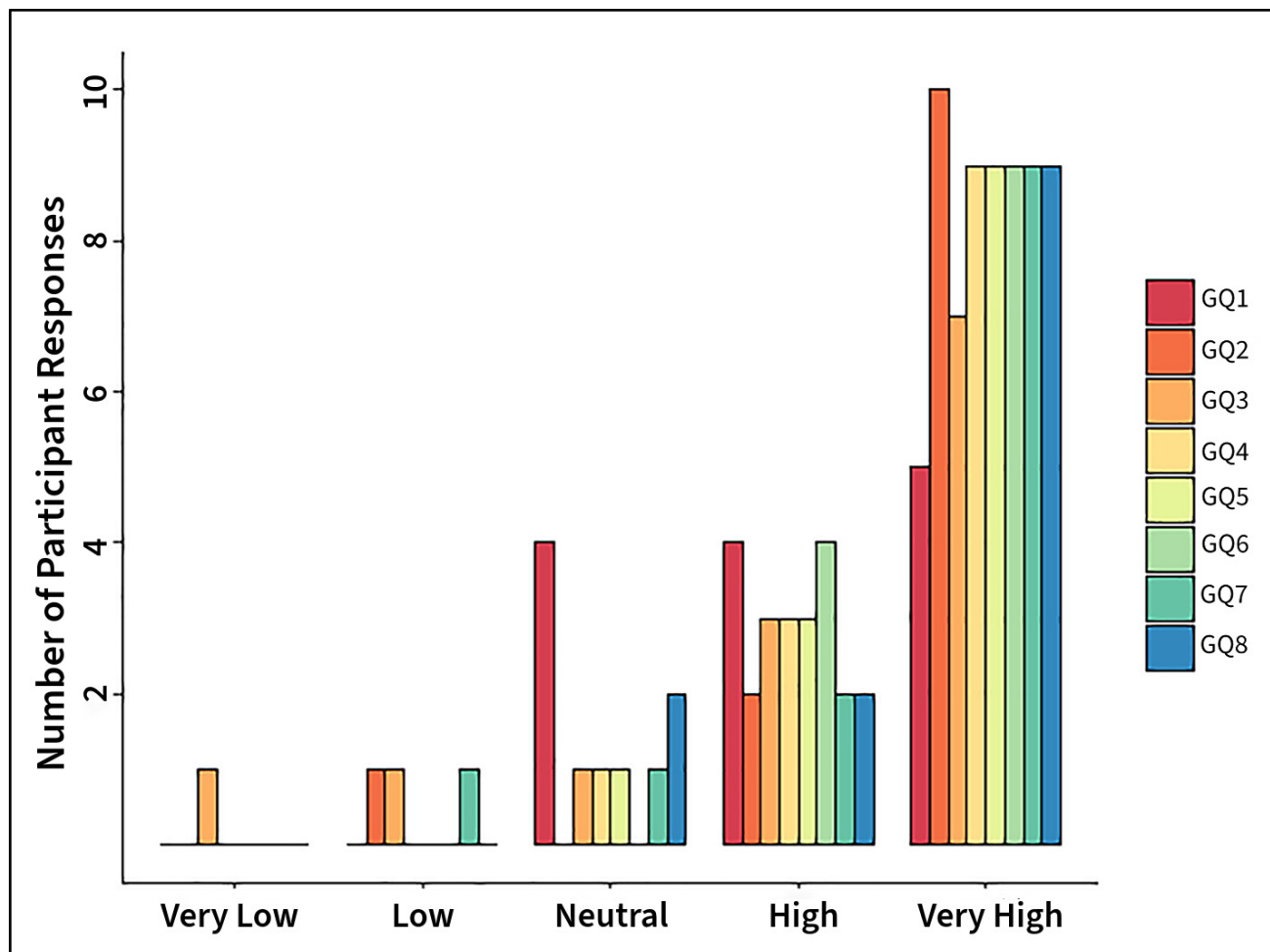


Figure 1: Survey responses from the residents about the general helpfulness of the didactic seminar in the development of non-technical skills.

Notes: GQ1: You were aware that non-technical skills could influence patient outcomes before the didactic presentation. GQ2: Did the didactic presentations further your understanding of non-technical skills? GQ3: Would you like more didactic presentations about non-technical skills in the future? GQ4: Are you likely to practice your non-technical skills more than before the didactic presentation? GQ5: You will practice your non-technical skills often. GQ6: How likely are you to consciously incorporate non-technical skills into your practice? GQ7: New skills/strategies were gained that you can apply to your practice. GQ8: You feel more confident in handling high-risk, high-stress situations because of your non-technical skill trainings. GQ = general questions.

idents may have been partly attributable to greater confidence during the follow-up simulation and/or an additional 120 days of clinical anesthesia training compared with the baseline simulation. There also is evidence that junior residents may be more receptive to introspection and reflection, whereas senior residents may favor more consistent cause-and-effect reasoning.²⁹ When considered alongside the post-didactic survey findings, which demonstrated a moderate association between the seminar and resident knowledge (Figure 1), and weak-to-moderate association between seminar and resident confidence (Figure 2), these results suggest that senior residents may require more structured and longitudinal non-technical skills education.

However, definitive conclusions cannot be drawn because longitudinal changes in non-technical skills during clinical practice were not assessed.

Previous studies have demonstrated that non-technical skills can be successfully taught⁴ and that training may lead to improvement over time.^{6,11-13} Simulation also has been identified as an effective approach for training non-technical skills.^{4,16,30} Despite evidence supporting effective training methods, evaluation and assessment of these skills have been limited, particularly within trainee programs.^{31,32} However, this area is receiving increasing attention.³³ Our findings support the feasibility of using simulation to train non-technical skills and suggest that developing knowledge

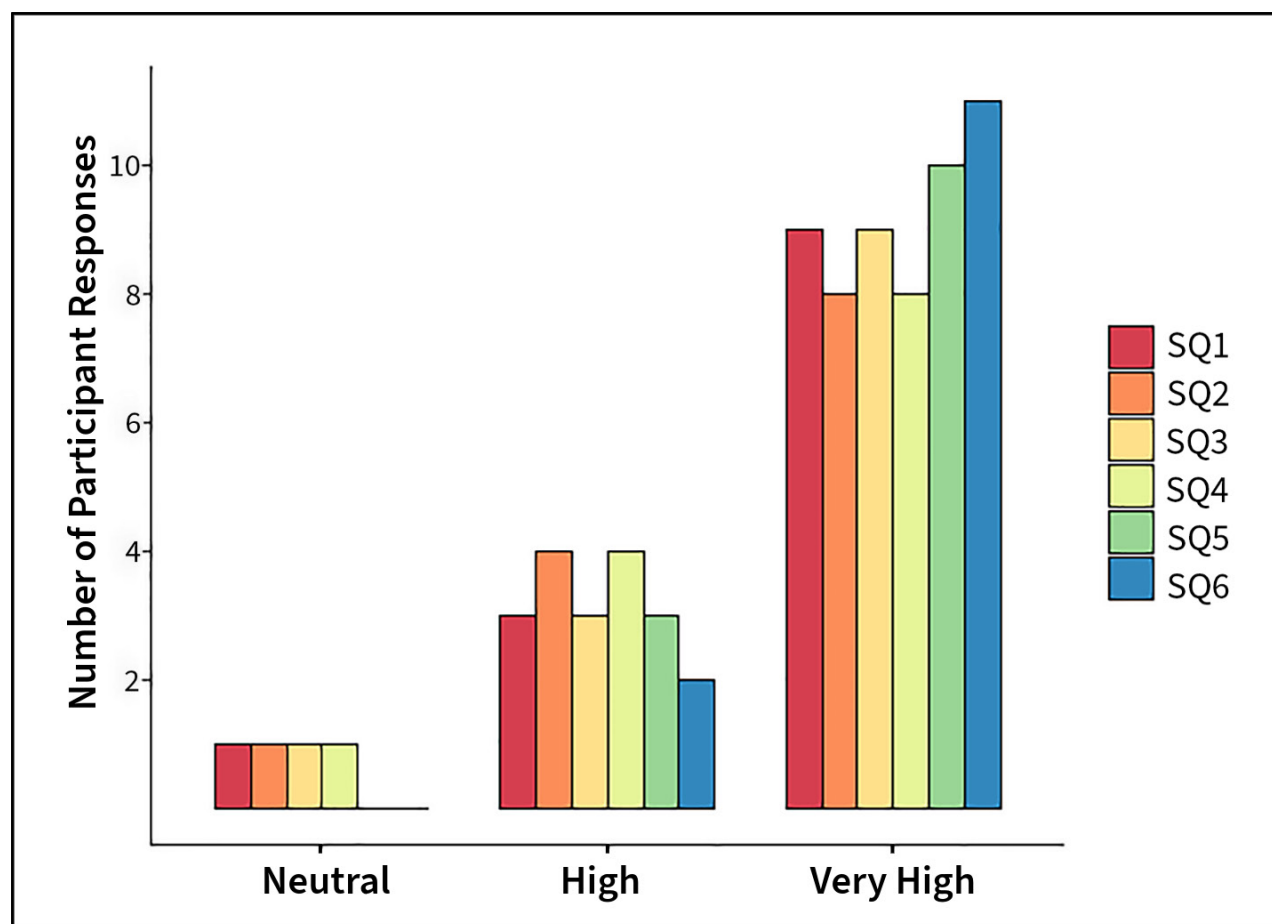


Figure 2: Survey responses from the residents about their confidence in the different non-technical skill areas.

Notes: SQ1: You are confident in your situational awareness skills (gathering information, recognizing and understanding, anticipating) after the didactic presentation. SQ2: You are confident in your decision-making skills (identifying options, balancing risk and selecting options, re-evaluating) after the didactic presentation. SQ3: You are confident in your teamwork skills (coordinating activities, exchanging information, using authority and assertiveness, assigning capabilities, supporting others) after the didactic presentation. SQ4: You are confident in your task management skills (planning and preparing, prioritizing, providing and maintaining standards, identifying and utilizing resources) after the didactic presentation. SQ5: The coping strategies discussed throughout the presentation will enhance your clinical skills and expertise, leading to less mistakes and anticipation of problems. SQ6: You will practice and use the coping strategies in your practice. SQ = skill-based questions.

and awareness of these skills may represent an important initial step toward behavioral skill development. More consistent and longitudinal education may be needed to reinforce these skills. One-time educational experiences may not provide sufficient opportunities for residents to consolidate skill development,^{17,18} which is consistent with findings from this exploratory initiative. Structured curricular training also has been associated with significant improvements in non-technical skills.¹⁹ One study demonstrated significant improvements in three ANTS categories: team working, situation awareness, and decision making; and five ANTS elements following simulation-based team training.³⁴ Another study examined the relationship between

team training delivered through two simulations and team culture and communication using paired-sample *t* tests.²⁰ Participants demonstrated movement away from autonomous cultural ideals, stronger teamwork, and a more favorable communication climate.²⁰ These findings are particularly relevant given the documented contribution of human error, including non-technical skill deficits and communication failures, to adverse events.

In contrast, a meta-analysis by Leuschner, et al.¹⁵ demonstrated substantial variation in non-technical skill levels following training, with no significant improvement among individual surgeons or anesthesiologists but improvement when assessed at the whole-theatre team level. These find-

ings differ from those of a more recent meta-analysis, which found that non-technical skills training was effective among emergency and critical care physicians, although substantial heterogeneity was present.³⁵ Together, these findings suggest that the effectiveness of non-technical skills training may depend on the learners, training approach, clinical context, and level at which skills are evaluated.

Limitations

This exploratory educational quality improvement initiative had several limitations. First, using surveys to assess resident perceptions of the simulations and didactic seminar may have introduced response bias. For the post-didactic assessment, a pre- and post-test of non-technical skills knowledge may have provided a more direct assessment of residents' understanding and knowledge acquisition. However, repeated testing may introduce recall or testing effects. To assess knowledge retention while minimizing the influence of immediate recall, future evaluations could incorporate a delayed retention assessment, such as repeating the assessment at least 90 days after the seminar.²⁵

Second, there was a 7-month interval between the faculty ANTS training and the follow-up simulation. This delay resulted from logistical factors, including the availability of the annual online ANTS course, which has since been expanded, finalization of the simulation scenarios, coordination with the Simulation Center, preparation of the didactic seminars, and scheduling time for all residents to be released from clinical duties. Although the evaluators completed a brief ANTS refresher training before conducting the evaluations, the extended interval may have contributed to the modest inter-rater reliability observed in this study. In addition, the faculty received only one formal training experience in non-technical skills through the ANTS course. This level of training may have been insufficient to ensure consistent evaluation, as suggested by the inter-rater reliability findings. This limitation is particularly relevant given the limited availability of formal human factors expertise within U.S. residency programs.¹⁵

Third, we did not evaluate the clinical impact of non-technical skills training on patient outcomes. Previous research has suggested that improvements in non-technical skills may be associated with reductions in adverse clinical events, including cardiac arrests.¹⁸ Although residents were expected to practice non-technical skills during their clinical

duties following the didactic intervention, adherence to this expectation was not assessed.

Fourth, simulations were conducted with dyads rather than individual residents, preventing assessment of individual performance in isolation. This approach may have influenced skill performance based on residents' learning preferences^{36,37} and level of training. Future studies could evaluate individual and team-based performance separately to better understand these effects. Additionally, more CA-1 residents were paired with senior residents during the follow-up simulation, which may have impacted both residents' ANTS assessments, as the senior resident could have taken on more of a teaching role, compared with the baseline simulation (Supplemental ST1: Group Combinations). Although residents performed the simulation as a dyad, the evaluators were evaluating on an individual basis, to try and mitigate this type of bias.

Fifth, the evaluators could have possibly diagnosed the simulation scenarios due to monitor readings and resident conversations throughout the recordings. However, even if the evaluators deduced the case (i.e., that one was anaphylaxis), they still would not know if that was the first or second simulation.

Finally, separating technical and non-technical skills during evaluation may have been challenging because evaluators were familiar with the participating residents, potentially introducing observer or confirmation bias. The ANTS framework was intended to reduce this potential bias by providing a structured evaluation platform based on 15 defined skill elements.¹² Nevertheless, future studies could further minimize this limitation by using independent evaluators who are blinded to resident identity and training level when feasible.

Overall, the small sample size, single-institution design, use of resident dyads, and limited duration of formal non-technical skills education restrict the generalizability of these findings. However, the methodology could be adapted to other specialties to evaluate the feasibility of developing competency-based curricula for non-technical skills.

One important barrier to the regular incorporation of non-technical skills training is the limited number of faculty formally trained to teach and evaluate these skills. Developing faculty expertise may increase recognition of human factors in the operating room and provide residents with

greater exposure to appropriate behaviors, coaching, and feedback. Similarly, formal and structured resident education can establish a foundation for continued development and application of non-technical skills throughout residency and into independent practice.

As a next step, we aim to expand this experience into a competency-based medical education curriculum by integrating ANTS training into the existing simulation curriculum for the anesthesiology residency. Residents will participate in repeated simulation scenarios with deliberate practice, longitudinal observation by ANTS-trained faculty, and structured faculty evaluation and feedback. This curriculum, combined with didactic instruction in non-technical skills, may provide continuous and structured education throughout residency training.

CONCLUSIONS

This exploratory educational quality improvement initiative evaluated the feasibility and resident acceptability of an ANTS-based approach to non-technical skills education and explored changes in observed non-technical skill performance following a multifaceted educational intervention. The findings support the feasibility of incorporating structured simulation and didactic education into anesthesiology training. Further research with larger samples, longitudinal assessment, trained evaluators, and repeated educational exposure is needed to determine how non-technical skills can be effectively developed, assessed, and sustained throughout residency training.

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