Designing a Coaching Tool

for Optimizing Cardiac Operating Room (cOR) Team Communication

A Dissertation SUBMITTED TO THE FACULTY OF

THE UNIVERSITY OF MINNESOTA by Soo Jin Kang

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY in Design

Dr. Sauman Chu

January 2, 2024

ACKNOWLEDGMENT

I want to express my sincere gratitude to the committee members.

Dr. Sauman Chu, thank you for being my advisor for the past seven years. You have guided me throughout my doctoral studies, the most challenging time in one's life. I respect you both as an educator and a human.

Dr. Cecilia Wang, thank you for giving me the chance to initiate an academic journey in healthcare design research. I learned the basis of conducting design research from you. Thank you for teaching me the A to Z of design research, a valuable asset in establishing my career. It would have been impossible to achieve my academic milestones as well as my industry career without your guidance. You are a role model for many young scholars, including myself.

Prof. Eugene Park, thank you for giving me confidence in my designs. Your studio classes equipped me with state of art usability design principles and techniques which shaped me as today's UX/UI designer.

Dr. Lisa Miller, thank you for providing me with valuable guidance and giving me a chance to work with you on topics that I can truly invest in.

I want to express my special respect and gratitude to the cOR research team.

Dr. Stephen Richardson and Dr. Tjorvi Perry, thank you for trusting me and providing me with numerous opportunities to interact with your cOR team members. Your mentoring and guidance gave me tremendous insights into my research topics.

Lastly. I would like to say thank you to my friends and family who supported me throughout my life: Gabriel Ross, Sun Min Hwang, Hea Kyung Han, and Tasneem Kabli. Hyun Soo Park, my husband, thank you for being by my side and navigating every part of life with me.

ABSTRACT

Effective team communication is crucial for achieving optimal performance and ensuring patient safety in the cardiac operating room (cOR). However, communication challenges within multidisciplinary teams in this context have been underexplored. This dissertation aims to address this gap by conducting two stages of a study that investigate the multidisciplinary aspects of team communication and propose the design of coaching tool technology to enhance the effectiveness of communication.

In the first stage, the complex nature of team communication within the cOR setting is examined through qualitative data collected via in-depth interviews with individual team members of cOR team. The in-depth semi-structured interviews used open-ended questions and a co-created journey map to effectively elicit the pain points and needs of team communication without introducing bias. Findings reveal how team members from different disciplines navigate communication challenges arising from their individual and collaborative tasks. The study identifies the concept of "integrated workflow" as a design theme that can enhance team communication by bridging the boundaries between disciplines. This concept offers valuable insights into addressing communication issues and improving team dynamics in the cOR.

Building upon the insights gained from stage one, stage two focuses on designing a team-based coaching tool prototype tailored to the needs of cOR team members. The prototype is designed to elicit user's ideas for interactive learning opportunities for both individual and collaborative tasks across disciplines. In this second stage, qualitative data is collected through prototype exploratory sessions and follow-up interviews. The follow-up semi-structured interviews with open-ended questions facilitate reflection on communication challenges when working with new trainees and encourage brainstorming for content and feature improvements. Through an exploratory user study utilizing a low-fidelity prototype, the importance of considering team dynamics and integrated workflow as design factors for cOR coaching tool technologies is empirically demonstrated.

The implications derived from both stages of this study contribute to the planning of future research, highlighting the significance of integrating multidisciplinary perspectives and addressing team dynamics in the design of coaching tool technologies. This dissertation aims to advance our understanding of team communication in the cOR and provide valuable insights for the development of effective coaching tool technologies.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Communication in an operating room (cOR) is a critical determinant of team performance. For healthcare professionals to perform a successful and safe operative procedure, in every case of operation, most of the procedure steps require collaboration between more than one healthcare professional (Al Ghofaily et al., 2018; Cumin et al., 2013; Dias, Riley, et al., 2021; Parush et al., 2011; Perry & Fortuno, 2021; Tørring et al., 2019). However, almost no medical and nursing schools include team communication as a part of their official curriculums and courses in the United States (Fleetwood et al., 2018; Korndorffer et al., 2013). Team communication is something that young healthcare professionals are required to pick up naturally when they are thrown into the actual operating room, which is challenging: they have been double burdened with gaining competency in their discipline-specific skills while developing effective communication with experienced team members.

User-centered approach is considered to be one way to improve team communication in OR. Such an approach attempts to dissect individual factors that contribute or deteriorate team communication by observing and empathizing real users (Pantofaru, C., & Takayama, L., 2011). Initially, usability in OR is one of the understudied areas for many decades due to the lack of fundings and overlooked importance when it's compared to clinical trials and technical studies. In the early 2000's user-centered design approach has started to gain attention in mainstream, as the field of human-computer interaction (HCI) has been evolved. In HCI, the human-centered engineering approach drives technology development. As a considerable area of HCI studies started to investigate human factors associated with mechanisms of team communication to develop a tool that support OR team communication.

When defining and assessing OR team communication, studies often consider several measures, including different sources of disruptions occurring during team interactions (Boquet et al., 2021). Ineffective communication can be caused by layout, usability, interruption, noise, or hazard, according to previous studies. The negative effects of ineffective communication among team members (e.g., low alertness, emotional regulation) can impinge on team functions, such as preparing, performing, and

completing tasks as a team (Arora et al., 2010; Boquet et al., 2021). Furthermore, frequent miscommunication often negatively impacts the team's relational dynamics, creating tension between team members and deepening the communication gridlock (e.g., arguments, shutdowns) (Attri et al., 2015). Studies showed that multiple factors could impact team communication, including but not limited to the physical settings of the OR, furniture layout, equipment design, and usability (Boquet et al., 2021; Cohen et al., 2016; Palmer et al., 2013). To address these issues, the growing trend of approaches is adapted to the operating room design. Such a user-centered design approach created new opportunities for researchers to support cOR team communication through the learning needs and pain points of the team. For instance, one study is based on more than one thousand observed cases to learn team interaction and communication in OR (Palmer et al., 2013). This study has shown that the user-centered technique can accurately capture the needs of individual team members as well as shared pain points among the team and provide guidance to improve team communication and performance. However, many studies are still limited to studying team communication within one discipline, such as communication between attending residents sharing the same specialty.

Recent studies have broadened their focus from one discipline to other disciplines consisting of the entire OR team, including anesthesia, perfusion, and surgical technicians (Cumin et al., 2013; Hull et al., 2011; Parush et al., 2011; Salenger et al., 2020; Tørring et al., 2019). For example, during the preoperative phase, tasks are coordinated by nurses, and team members from other disciplines are also invited to collaborate on the task preparation. A recent study indicated that more than 50% of tasks involved collaborative work performed by different disciplines during the preoperative phase (Cvetic, 2011). Team members from different disciplines are required to work collaboratively toward one shared goal to prepare patients and the operating room for safe and timely operation (Hull et al., 2011; Parush et al., 2011; Salenger et al., 2020; Tørring et al., 2019). At the same time, individual disciplines have discipline-specific responsibilities that need to be conducted individually. Such individual responsibilities are not always aligned with shared tasks, which can negatively influence the quality of team communication and performance. Because such goal conflicts can influence the physical, emotional, and

behavioral status of the team members, it is critical to address team communication issues.

To support team communication at the multidisciplinary level, studies have applied cognitive domain analysis at the teamwork level (Ashoori & Burns, 2013; Dias, Zenati, et al., 2021; Franklin et al., 2017) to analyze the taxonomy that constructs team workflow and provide design implications for future communication support technologies. The studies highlighted the importance of supporting team communication for the healthcare professionals by conducting team domain analysis to generate conceptual activity template of ER workflow, illustrating how the team's resources and activities interact with their workflow (Franklin et al., 2017). Compared to the body of literature that views the work domain as an individual workflow per given position inside of an organization, this body of literature focuses more on the relational aspects of workflow across the multiple domains in the healthcare setting. However, despite efforts to dissect the team workflow of the multiple domains as one interlaced entity, these studies still viewed team workflow as a compound of individual tasks that fundamentally belong to one domain and are connected by exchanging resources between domains. They did not capture the critical issues underlying team workflow that originated from the relationships or dynamics of team members, as the studies were focused on specific resources and activities (e.g., equipment, sending and receiving equipment) (Ashoori & Burns, 2013). Although some studies have perspectives on the personal traits of individual team members as contributing factors to team dynamics (Algashami et al., 2019; Orwoll et al., 2018), these studies consider that team dynamics tended to be determined by prepositioned traits brought by individuals team members rather than considering it as a dynamic structure that communication strategies and patterns can change. The specific needs of a team, including synergy and issues arising from interactions between team members, were not addressed.

cOR team members have tried to capture the specific needs of the team but it has been a time-consuming process and not effective due to requiring extra workload outside of regular working hours. For example, one experienced nurse gathered existing preference cards/procedure protocols and created libraries (e.g., printouts organized in a

3-ring binder) for new staff, so they could review and follow required steps/supplies for both common and special procedures without requiring repetitive/unexpected training moments. Such libraries are useful, yet it is difficult to keep them updated with changes in each procedure and individual surgeon's preferences. Therefore, it may be beneficial to design a new interactive channel that allows OR team members to communicate and be trained about changes in supply requirements and procedure updates in real time. It may also be beneficial to transfer existing libraries in an electronic format to account for enhanced editing capability.

Building on the previous studies that emphasized the importance of team-centered approach to improving team communication and performance; this dissertation suggests expanding the range of team communication by looking beyond individual health professionals and his/her discipline in cardiac operating room (cOR) settings. Two types of user-centered design studies, including a need-finding study and a prototype-based user study, are designed and conducted to identify 1) the key factors for facilitating effective cOR team communication;2) the functions of a coaching tool that integrates the key factors; and 3) the type of technologies that can support the functions of the coaching tool. Under guidance of the cOR research team, as a design researcher, I contributed by conducting the following research activities:

1) literature reviews, 2) designed study protocols including interview structure and question design, 3) developed a low fidelity prototype for exploratory sessions, 4) collected data by leading 11 individual in-depth interviews, 5) performed data analysis including thematic and cognitive task analysis, and 6) generated design guidance for a coaching tool based on extracted insights from analysis .

In Chapter 2, existing literature and related studies are reviewed to identify a gap in the field. In Chapters 3 and 4, the two-staged study is delineated in detail, including qualitative semi-structured interview to generate design implications for a novel coaching tool and a prototype-based formative study, respectively. Chapter 5 discusses the findings of the study, followed by the design implications of team coaching tool technologies in Chapter 6, and limitations and future work in Chapter 7. Chapter 8 includes the conclusion of the study.

1.1 Contributions

This dissertation makes three main contributions to the field of user-centered design research.

1. Discloses the types of tacit knowledge that can help design researchers to understand the interdisciplinary challenges of cOR team communication.
2. Proposes four areas of tacit knowledge learning as design frameworks for developing features and contents of cOR coaching tools.
3. Provides guidances for applying technologies that enable tacit knowledge learning among cOR team members

CHAPTER 2: REVIEW OF EXISTING LITERATURE AND RELATED WORK

2.1 Human-centered design approach in designing healthcare system

Numerous health care systems are designed without consideration of users (Johnson et al., 2005). Consequently, such systems make users difficult to perform their tasks and, users are dissatisfied and stop using them. If users choose to continue to use the system by dealing with the difficulty that the system created it could burden users' workload and lead to use error. –To prevent use errors stemming from the lack of usability in application/system design. User-centered design approaches have been adapted in the development cycle of application/system for healthcare (Dopp et al., 2019).

The goal in the user-centered design approach is to design systems that are modeled after how user think and behave while performing their tasks (Johnson et al., 2005). To design such system, the system designer should gain profound understanding of users' Human factors. Human Factors of users includes physical and cognitive abilities and limitations as well as work environment of the users. Human Factors/usability engineers focuses in disruptions in workflow as pain points leading to the majority of errors in the healthcare settings (Johnson et al., 2005; Palmer et al., 2013). Human Factors/usability issues in the healthcare settings tended to be overlooked and considered to be trivial when it's compared to clinical/technical issues. However, usability issues as seemingly trivial, such as taking several pages to find a button to press or hard to read labels and text on the screen, introduce unwanted distractions and errors in clinical workflow of healthcare professionals (Palmer et al., 2013).

Human Factors/usability engineering utilize various methodologies to understand user's existing workflow and pain points of healthcare professionals. FDA and other usability studies provide a list of the methodologies in Human Factors Engineering guidance for medical device design (Johnson et al., 2005; Food and Drug Administration, 2016). The list methodologies include task analysis, contextual inquiry, and work domain analysis. These user analysis methods are designed to investigate user needs by performing manual review, field observation, or in-depth interview with users (Pantofaru

et al., 2011). Understanding user needs through such techniques allows system designers 1) to gain insight that can generate concrete solutions for prototypes, 2) to create design frameworks for research directions, and 3) to come up with technologies that can enable the design solutions (Pantofaru et al., 2011). System and application according to design solutions rooted from concrete user needs and pain point is crucial in optimizing workflow and maintaining patient safety in healthcare settings.

2.2 Cardiac Operating Room Team Communication and Tacit Knowledge

Cardiac operating room (cOR) teams caring for complex, high-risk cardiac surgical patients require close teamwork and precise communication (Wahr et al., 2013). Team members include surgeons, anesthesiologists, nurses, a perfusionist, and technicians. Each team member is highly trained in discipline-specific technical skills and is expected to collaborate closely with team members from other disciplines (Gurses et al., 2012). To optimize efficiency and ensure patient safety, clear and uninterrupted communication is of utmost importance as (Brown et al., 2017) the quality of communication within and between disciplines in the cOR correlates directly with surgical performance and patient safety (Wahr et al., 2013). One of the key qualities of team communication is openness and accuracy within and between team members from different disciplines (Salas et al., 2008; Hoonakker et al., 2011). However, according to a study by Schlutz et al. (2005) found that information supposed to be carried through team communication is often missing and delayed when needed. That's because a large proportion of communications in the cOR relies on implicit knowledge and cannot be found in written policy, instructions, or manuals (Salas et al., 2008; Paige et al., 2021). Implicit knowledge, also known as tacit knowledge, is learned during long-term collaboration and experiences. As it is not uncommon for team members in the cOR to frequently change, the need for an extended learning process may result in medical errors in the cOR (Paige et al., 2014).

Both tacit and objective knowledge are important for effective and efficient communication. Objective knowledge can be documented, explained, understood, and shared (Sobol & Lei, 1994). Tacit knowledge has the opposite attributes to objective

knowledge (Ambrosini & Bowman, 2001). Polanyi who first introduced the term described the tacit knowledge as follows: 'I shall reconsider human knowledge by starting from the fact that we can know more than we can tell'(Polanyi, 1962). Tacit knowledge is, therefore, hard to be documented and explained (Ambrosini & Bowman, 2001). Even people who fluently use tacit knowledge find it difficult to articulate their reason behind decision-making in the situation (Nonaka, 1998; Wagner & Sternberg, n.d.). Finally, tacit knowledge is context-specific, acquired while performing a task in a specific situation, and continued to evolve through practice (Ambrosini & Bowman, 2001; Leonard & Sensiper, 1998; Nonaka, 1998; Wagner & Sternberg, n.d.). Nonaka (1998) explains, 'tacit knowledge is...deeply rooted in action and in an individual's commitment to a specific context – a craft or a profession, a particular technology or product market, or the activities of a workgroup or team'. Thus, tacit knowledge is personal, procedural, and contextual to people and the organization to which these people belong (Eraut, 2000; Kothari et al., 2011; Winter & Nelson, 1982).

Tacit knowledge is difficult to mimic or emulate by people outside of an organization or team precisely because tacit knowledge has been experientially cultivated between members of a specific team (Sobol & Lei, 1994). Tacit knowledge is commonly used during many types of team communication and can be especially useful when acuity and complexity are high, such as in the cOR, where information often needs to be conveyed in a succinct and timely manner (Paige et al., 2014; Wahr et al., 2013). Without tacit knowledge, communication can be interrupted, resulting in task failure (Bennet & Bennet, 2008). To date, little is understood about how tacit knowledge is learned and effectively used (Andrews & Smits, 2019; Bennet & Bennet, 2008; Leonard & Sensiper, 1998). Herein, we describe communication patterns between disciplines in the cOR of a large academic medical center in an effort to better understand how tacit knowledge can play a role in effective and efficient communication, and how we might expedite communication training for new members of a team.

There are five distinct disciplines in a cOR team: a cardiac surgeon, a technician, a circulating nurse, a perfusionist, and an anesthesiologist, and all five disciplines should share one or more mental models through effective communication at various times

during a procedure to ensure surgical success and patient safety (Brown et al., 2017; Gurses et al., 2012). Current training strategies, however, exist in isolation, i.e., each member learns their role in the absence of team members from other disciplines (Cumin et al., 2013; Fleetwood et al., 2018; Kothari et al., 2011; Paige et al., 2021). While training in isolation can be ideal for learning explicit knowledge by allowing members to focus on their own tasks (Fleetwood et al., 2018), it does not provide a contextual understanding of collaborative tasks. Alternatively, training programs may offer an opportunity whereby a number of experiences can be lived together by the entire team (Bennet & Bennet, 2008; Brown et al., 2017). Unfortunately, these types of training programs require prohibitively laborious and costly sessions, e.g., training with all possible combinations of other team members to handle various cases (Eraut, 2000). Instead, we suggest converting tacit knowledge into explicit knowledge by further characterizing challenging situations for each role.

2.3 Technologies for Team Collaboration that Affirm Or Challenge Existing Social Dynamics

In previous training technology studies in medicine, team communication and workflow have been continuously investigated as important design factors; however, there were two approaches to studying team communication and workflow. One group of studies understands the team's existing ways of communication and finds an effective way to share them. The other group incorporates new technologies to cultivate improved team communication patterns and strategies.

First, studies have investigated the role of technologies in facilitating an existing team communication and workflow in OR settings. By promoting team members' awareness of each other's mental model (Lowe et al., 2016), cognitive process (Dias, Zenati, et al., 2021), and current task status (Bracq et al., 2019), studies showed how technologies helped the team members coordinate their existing communication and workflow to achieve tasks. For example, there are considerable bodies of study attempting to transfer existing protocol and checklists for teamwork into interactive technologies such as mobile apps or desktop interface (Blondon et al., 2017; Bonn et al., 2022; Clark, 2009; Orwoll et al., 2018). These studies found that interactive technologies,

including self-check and reminder features, help team members more actively follow team protocols and checklists. Similarly, studies focus on finding an effective way to share existing mental models and cognitive processes of team members. These studies adapted technologies to deliver often invisible and nuanced information used in team communication (Dias, Zenati, et al., 2021; Franklin et al., 2017; Huang et al., 2018). One study conducted cognitive domain analysis and displayed the findings via an online dashboard for other team members' learning (Dias, Zenati, et al., 2021). Other studies incorporated augmented reality to share procedure instructions (e.g., line induction) simultaneously among team members. This increased shared mental model worked as a facilitator, which enabled effective team communication and workflow (Huang et al., 2018).

While the first group of studies focused on effectively sharing existing strategies and patterns for team communication by using technologies, the other group of studies investigated how technologies challenge existing team dynamics among team members (e.g., roles, and responsibilities) (Morey et al., 2002; Pons Lelardeux et al., 2017; Salerno et al., 2018). They showed the relationships between team dynamics in clinical settings, and the use of new and existing training technologies. For example, several studies showed how role-playing via VR technology challenges the existing team dynamics of ER team members, particularly regarding how they can effectively reach shared decision-making (Salerno et al., 2018). One study supported multiple communication channels, such as forums, live chat, and messengers, to allow team members to cultivate and practice their communication strategies (Pons Lelardeux et al., 2017). Similarly, other studies investigated how gamification can cultivate effective team communication and collaborative workflow. Morey (2002) developed a team competition game as an ER training tool allowing one team to solve virtually simulated case scenarios and compete against the other ER team. This virtual scenario practice allowed team members to actively analyze the situation and update their clinical insights via the virtual platform to communicate with other team members to solve the case regardless of their experience level. These studies suggested that restructuring the roles and responsibilities of the team members improved team communication and workflow. These studies showed how

sociotechnical systems can influence and reshape the existing roles, responsibilities, and dynamics of the healthcare professional team.

Building upon these previous studies, this study seeks to show how technology design can leverage multidisciplinary team communication and workflow. A coaching tool technology that visualizes discipline-specific and collaborative workflow is designed to support effective team communication. Also, the coaching tool is used to identify implications from team communication experiences, deriving future technology design iteration. By designing and implementing coaching tool technologies for the cOR team, this study provides opportunities to consider team members' collaborative and effective communication in managing team workflow in cOR.

2.4 Research Questions

Based on the previous work, three research questions guide this dissertation:

1) **What are the types of tacit knowledge facilitating effective cOR team communication?**
2) **How can the coaching tool integrate and address tacit knowledge learning for effective cOR team communication?**
3) **How can technology enable the coaching tool?**

To investigate these research questions, a two-stage study is conducted. For the first and second research questions, six semi-structured interviews were performed with cOR team members from the five key disciplines and captured their experiences with team communication and workflow (Stage 1). The findings from the first study inform the design of the multidisciplinary team coaching tool used in the second study. To address the third question, a formative study was conducted as Stage 2, including prototype exploratory sessions and semi-structured interviews with the same team members from Stage 1.

CHAPTER 3: STAGE 1 Visualizing Tacit Knowledge of cOR Team Communication through Need-finding

3.1 Study Methods

In this first stage of the study, tacit knowledge for cOR teams was investigated through the need-finding of all team members. Need-finding is a human-centered design approach for understanding users' unmet needs and identifying their latent challenges (Rous & Nash, 2020; Schaffhausen & Kowalewski, 2015). Through direct observation and in-depth interviews where researchers empathize and immerse themselves in team members' perspectives, we are able to gain a deep understanding of their actual behavior, an approach that often reveals users' internalized intention behind behaviors (Blindheim et al., 2016; Patnaik & Becker, 1999; Schaffhausen & Kowalewski, 2015). As such, a need-finding approach can be useful to investigate internalized information such as tacit knowledge. Observing team communication and listening to individual team members' stories provides clues on the unconscious process of the cOR team's tacit knowledge use (e.g., picking up the right idea from a simple gesture) (Ambrosini & Bowman, 2001; Bennet & Bennet, 2008).

The primary aim of this study was to delineate tacit knowledge gaps in team communication via the need-finding of five team members: cardiac surgeon, technician, circulating nurse, perfusionist, and anesthesiologist in the cOR. We performed a qualitative cOR team communication need-finding study to learn: (i) what communication support each member of the cOR team wants, and (ii) what spectrum of tacit knowledge is needed to support effective team communication. Our investigation included structured in-depth interviews of individual team members to better understand those categories. In the formative structured in-depth interviews, team members were asked to list their roles, identify problem areas, and brainstorm ways of improvements that they would like to implement.

3.1.1 Team Cognitive Work Analysis for Need Finding

To apply a systematic approach to the need finding of cOR team, Cognitive Work Analysis (CWA) was performed. Cognitive analysis is designed to identify existing

workflow including its structure and patterns. Considerable bodies of previous studies applied Cognitive Work Analysis in designing user interfaces for healthcare settings. These studies used CWA to develop a user interface (UI) supporting the communication of healthcare teams and helped designers understand the constraints (Algashami et al., 2019). Understanding constraints is crucial as they often shape the existing communication patterns and structures. In other words, designers should study what they are dealing with first thoroughly before trying to come up with a solution (Dadashi et al., 2010). Many usability issues of an existing system that designers need to understand are often hard to consolidate at first because the problems are rooted profoundly in the way the users behave or think. The way the users behave, and think is formed by previous experiences over a long period of time (Fidel & Pejtersen, 2004). Thus, designers should dissect detailed layers of cognitive work involved with users to identify constraints. The analysis method includes manual review, observation, and in-depth interviews with a domain expert (Ashoori & Burns, 2013).

Cognitive Work Analysis could provide designers with an analytical framework to capture constraints in a work environment where users perform work tasks by interacting with a system (Lintern, 2009). The framework includes six stages analyzing the different aspects of user behaviors and the cognition behind the work while interacting with the complex systems (Ashoori & Burns, 2013). It includes multiple stages, such as Work Domain Analysis, Cognitive Processing Analysis, and Social Transition Analysis and they can be grouped in different combinations to provide a foundation for analytic methods by assimilating concepts, practices, and metrics of the user system (Lintern, 2009). However, such stages tend to capture users' behavior from the perspective of one single domain, although many user tasks require interactions with other domains to complete.

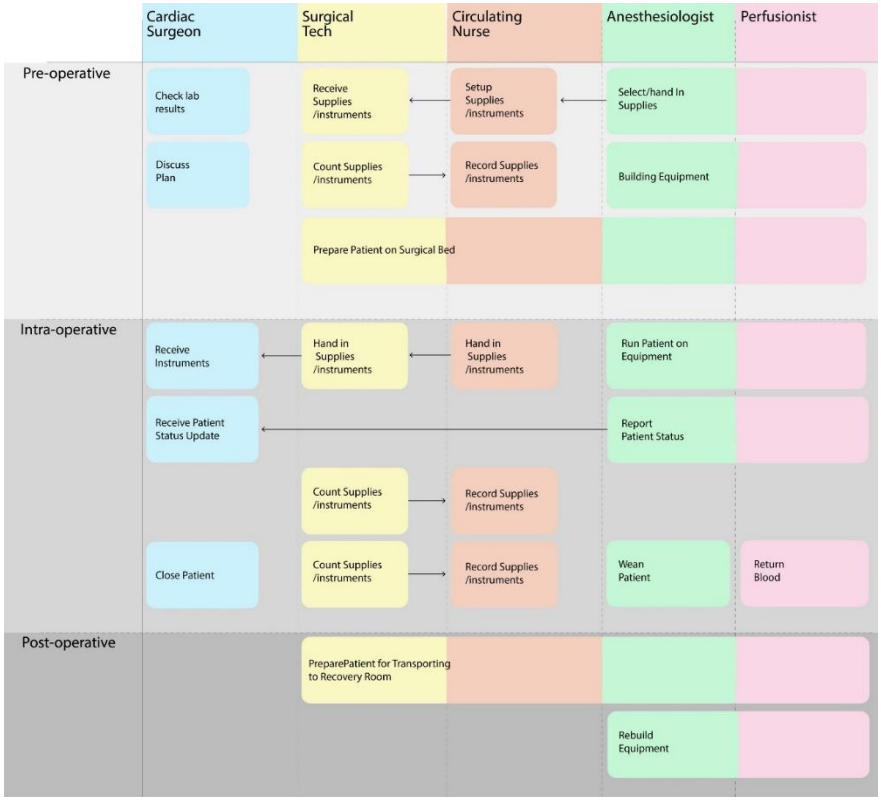
To understand users' behaviors in the context of interactions between different domains, Ashoori and Burns (2013) introduced Team Cognitive Work Analysis which can help designers to understand the reasoning sequence among multiple users of different domains. In the process, they can capture implicit aspects of user behaviors and cognitions behind them while interacting with a system (Ashoori & Burns, 2013). To

design a user interface for a complex information system such as a system supporting healthcare team communication, the user requirements for both individual and other team members' domains should be fully analyzed. This study performed Team Work Domain Analysis (WDA) to identify steps and orders of individual and collaborative tasks among multidisciplinary cOR team. Team WDA allows our research team to examine the shared values, purposes, and priorities (Ashoori et al., 2014) of the cOR team. The analysis methods to perform Team WDA include manual reviews, observations, and in-depth interviews with experts from each domain (e.g., cardiac surgeon, circulating nurse, perfusionist). Through Team WDA we were able to identify various aspects of collaborative work and requirements of the team.

In Team WDA, Control Tasks Analysis (CTA) is used to examine a series of tasks that takes to accomplish functions to achieve the purpose of the team (Ashoori, 2014). Based on Team WDA which focused on types and stages of tasks, Team CTA particularly focuses on how such tasks are shared between team members. **To identify such interactions between cOR stakeholders, we found in-depth interviews with individual stakeholders to be a prime tool to dissect required actions between domain experts to complete individual and team tasks.** Based on the in- depth interview data, the diagram of CTA is generated to visually elaborate on the process of collaboration in different situations (e.g., preoperative) and functions (e.g., the domain of team members) of cOR team (Figure 1).

Figure 1

Contextual Activity Template Diagram for cOR Team Communication



Note. In the Contextual Activity Template, The X-axis of the template indicates work situations, and the Y-axis indicates work functions. The rounded rectangles contain the list of tasks associated with the work situations and functions in the template, and the shared tasks between team members are illustrated by a solid line connecting rounded rectangles. This diagram illustrates the level of complexity of cOR team communication and those of emerging needs. In the first row, team communication needs are organized by three operative phases (pre, intra, and post). The following rows represent simplified instances of team communication-based tasks per team member. *(Diagram courtesy of authors)*

3.1.2 Data Collection

Semi-structured interviews were performed with team members of cOR team. The basis for the questions was derived from the initial on-site observations that needed further clarification. The interviews were to verify that what was seen during the observations was representing the typical work and understood in a good way. In total, six interviews were conducted with a cardiac surgeon, anesthesiologist, perfusionist, surgical technician, and circulating nurse. All the participants have worked in the same cOR team for at least two years. The key team members with at least two years of cOR work experience are selected as interviewees from each discipline. These key members were previously introduced to kick-off meetings of this research team and agreed to share

their expertise and professional opinions for this study during their working hours. However, a disadvantage of this method was that a person could feel that they were forced to participate due to their initial involvement and it would impact the way they answered the questions (e.g., favoring). On the other hand, an advantage of it was that participants were not asked to volunteer and were familiar with the background and context of the study, which lessened the risk of getting unrelated feedback or answers, which resulted in outliers in data.

The interviews were initially conducted through face-to-face meeting or video conference calls and on an individual basis to get more in-depth and personal information from the interviewees. For the nature of a semi-structured interview, open-ended questions were prepared where questions served as a guide without interfering with the interviewees' thought flow. The full interview template and questions are enclosed in the Appendix. The interviewees' discipline title is used to identify them to protect their privacy. The consent form is waived as participants agree to provide their professional opinions and expertise as consultants of the research team.

The structured interviews were conducted with key team members of the cOR team at M Health Fairview University of Minnesota Medical Center. The interview questionnaire consisted of open-ended questions to foster the sharing of unanticipated information. Interviews were conducted either in cardiac operating rooms (Figure 2) or using audio-visual conferencing. The average length of interviews was 55 minutes, ranging from 25 minutes to 100 minutes; due to the time constraint of team members, two interviews were done in 30 minutes. We recorded all interviews with the permission of team members. Video data was auto transcribed by the audio-visual conferencing software used for interviews and the transcribed data were manually compared to the original audio by authors to ensure its accuracy. Each interview started with an introduction and a brief explanation of the study being conducted. Team members were then asked about their general roles, their responsibilities during a procedure, team communication challenges, and ideas for changes that they thought would improve OR communication.

Figure 2

A Panorama View of cOR

Note. The structured in-depth interviews were conducted in a cardiac operating room in order to effectively capture and elicit the OR team member's challenges and needs by walking through their workflow side by side. (*Photo courtesy of cardiac OR research team at University of Minnesota)*

To standardize the interview process and to guarantee that participants would identify and describe the specific cognitive processes about team communication that we intended to explore, we asked all interviewees to create a user journey map to identify their communication needs and existing patterns during a procedure. The journey map is structured to generate specific responses regarding each of the cognitive processes for each surgical step in the operative timeline (e.g., pre, intra, post). By following the structure, participants are asked to "Identify and describe all steps of tasks in which you need to communicate with other team members" to identify steps that require team communication; "Describe the contents of the communications during this step" to explore what they communicate for the step; "Who do you work with to perform this task?" to identify which team members are involved in each communication; "What problems may occur during this communication?" to explore pitfalls; "What strategies do you use to solve and/or prevent communication problem?" to identify the existing

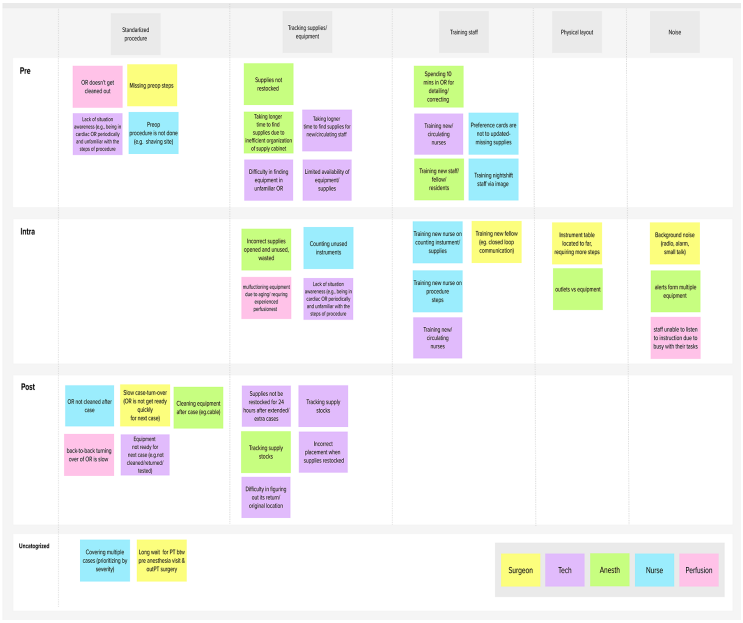
communications strategies. The interviewer also used follow-up questions to investigate the factors that are obstacles to team communication and to explore participants' ideas about how to improve team communication. A Contextual Activity Template (Figure 3) is created as one of the interview analysis results to visualize the steps of tasks and the flow of communication involved with each step.

3.1.3 Data Analysis: Thematic Analysis

We transcribed a total of 5.5 hours of audio recordings. First, we used open coding for all transcripts. An open coding method was utilized to identify labels, themes, keywords, and interpretations of the text, artifacts, or other relevant data without the use of a predetermined coding scheme (Williams & Moser, 2019). Open coding was used to identify relevant phrases or short descriptive sentences to potentially reveal new insights. Codes were transferred into digital Post-it notes via the web application Mural (Fig. 4). We then conducted a thematic analysis of the digitized notes by grouping related codes into themes. As a part of the thematic analysis, axial coding was performed to form a hierarchy of themes, requiring several rounds of grouping notes, creating keywords, and summarizing each group (Williams & Moser, 2019). The codes and themes were regularly presented to the entire research team for further refinement. Refined codes and themes were inspected by the second author separately for validity and reliability.

Figure 3

Affinity Diagram Created in Mural App



Note. each digital post-it contains short phrases, labels, and keywords identified by open coding from transcribed interview data. Total 17 themes emerged, and they were narrowed down to five key themes by additional axial coding and further categorized by three operative phases; preoperative phase, intraoperative phase, and postoperative phase.

3.2 Results

From a directed content analysis conducted on transcribed interviews and workshops, we developed a series of common categories of needs, including a) standardization of pre-and postoperative processes, b) reliable tracking methods for supplies/equipment, c) adaptive training for new staff, d) physical layouts to minimize wasted movements, and e) noise reduction. These categories of findings are visualized on a team communication diagram, providing a comprehensive understanding of both team member specific as well as shared tacit knowledge gaps of the team.

3.2.1 Standardization of Pre and Post-Operative Procedure

cOR team members suggested missing procedure steps or required supplies as a reason for surgical case delay. Less common during the intraoperative phase, missed procedure steps or missing supplies occur more often during the pre and postoperative phases, especially if team members do not have a well-established procedure routine. For example, a cardiac surgeon suggested that because many people from different domains work on different parts of a procedure simultaneously, some steps become discordant,

causing incomplete or incorrect task completion, and delays (e.g., spending extra time to correct the issue). Circulating nurses and technicians use surgeons' preference cards as a guide to ensure steps are not missed and/or supplies are available. The preference cards include a list of required steps, supplies, and equipment per procedure for each surgeon. Accurate preference cards are essential to ensure efficiency and avoid incomplete or inaccurate information. Delays due to incomplete or inaccurate information due to inaccurate preference cards can be a source of poor communication between team members, especially during the preoperative phase. Team members also explained that maintaining up-to-date preference cards was challenging due to time constraints and inadequate resources. To maintain up-to-date preference cards, team members suggested developing and maintaining a comprehensive case guide for comparing supplies used from one case to another. Such a case guide might enable team members to interactively and automatically discover common and uncommon supplies and resources used from one surgical case to the next and facilitate accurate and up-to-date preference cards.

Most team members (4/6) expressed a strong desire to develop and maintain a comprehensive guide for pre/post-operative procedures. They were curious about capturing recurring steps required for setting up and cleaning up before and after routine procedures. Because recurring steps indicate refactoring opportunities to standardize its process and how to perform them appropriately. For instance, although surgeons and anesthesiologists share a common goal of working efficiently, how to achieve the goal can differ by individuals which can cause confusion among the team members and possibly leading to medical errors and adverse patient outcomes. To meet these needs for standardized procedure for preoperative setup, we plan to create a virtual coaching tool that allows different team members to seamlessly collaborate as an integrated team.

"There are many steps that need to take place. From coming in the physical door of the operating room. And I don't know if you guys have watched Formula One car racing. That process should be like a formula and car pit stop. Like every person in the operating room should have a list of tasks and know exactly when and how to do those things." [Cardiac surgeon]

3.2.2 Reliable Tracking Methods for Supplies/Equipment

Currently, the organization of the cOR supply cabinets lacks standardization. Most team members complained that time and energy are wasted searching for appropriate supplies before and during an operation. Many team members suggested a universal standard to organize commonly used supplies and equipment across all cOR cabinets; case-specific sections within each cabinet can be reserved to accommodate special needs and to track and maintain needed supplies and resources more easily.

Team members mentioned that a lack of consistency in organizing supplies and equipment causes major delays during the entire operative phases. Past efforts to improve the layout and processes to restock supply cabinets have not been successful, and team members who are not regularly in the cOR's have significant challenges locating supplies. Team members suggested developing a tool to communicate the organizing system more effectively with team members who are less frequent in OR to improve consistency and reduce errors among all team members. In particular, an anesthesiologist and a scrub nurse suggested developing an organizing system based on its usage patterns because such a system would be more likely to fit the existing mental model of the team members, regardless of their level of experience.

While studying usage patterns, error-inducing events and recurring human mistakes can also be identified. The new system design should implement mechanisms targeting such recurring challenges. This calls for OR cabinet design to appeal to the existing mental model of team members, to prevent errors, to reduce delays due to searching for supplies, and ultimately reduce ambiguity in team communication.

"So one of the reasons why we redesigned this cabinet is because the person from the head of the supply chain came in and said, this is where these things fit. I can lay this out in this order and all my bins fit properly…But the problem is, if you need a syringe and a needle, you must go to two cabinets. So, we said no, we don't want that. We would like you to put the syringes and needles together…because you want to be efficient with your movement and spend the least amount of energy gathering things. So, we had them readjusted…one issue that we are still having with this is, when you're having supply people, they are only followed by a number…So, if this number (numbers on supply

package) doesn't match what they see on that shelf. They may not know what substitute to put in it. Or they may bring a substitute because it looks similar, but it doesn't function the same." [Scrub technician]

3.2.3 Knowledge Transfer and Adoption: Supporting Implementation and Replication through Documentation and Training Materials

There were two types of issues caused by training moments. First, training moments burden experienced team members with repetitive teaching, especially about basic tasks common for routine procedures (e.g., setting up patient posture on OR bed, setting up surgical tray). Second, training moments often emerge during stressful events. For instance, a surgeon mentioned that teaching moments can be easily turned into heated conversations with training staff in the process of resolving pressing or critical issues. Anesthesiologists also pointed out that they have to spend a considerable amount of their time teaching and correcting new staff about routine procedures, and it becomes a challenge as such lessons should be provided on a daily basis. Interestingly, one experienced nurse gathered existing preference cards/procedure protocol and created libraries (e.g., printouts organized in a 3-ring binder) for new staff, so they can review and follow required steps/supplies for both common and special procedures without requiring repetitive/unexpected training moments. Such libraries are useful, yet it is difficult to keep them updated with changes of each procedure and individual surgeon's preferences. Therefore, it may be beneficial to design a new interactive channel that allows OR team members to communicate and be trained about changes in supply requirements and procedure updates in real-time. It may also be beneficial to transfer existing libraries in an electronic format to account for enhanced editing capability.

All OR team members wished to gather several major clues to understand experienced team members' training needs, including the intent of using a teaching moment, how the moment was discovered, what steps it took to train unfamiliar information, how long it took, where new trainees often make mistakes. By understanding the details of such training needs, inconsistent expectations between experienced staff and new staff can be identified, and teaching methods/training tools can be enhanced to reduce such confusion and learning barriers.

"I asked her (new trainee) what we're doing. Do you understand it, you know, you don't understand what you do or what surgery. So, kind of hope she did as well…if she doesn't know what it is we'll look at this (three-ring binder), look and see if I have something." [Experienced nurse]

The experienced nurse said teaching procedures before cases and watching her trainee over their shoulders helped her understand what the trainee was familiar with, what was misunderstood, and what they had not learned yet. Several participating team members mentioned that they could get a sense of where they are not on the same page with their trainees by asking questions of them before a procedure, to anticipate training needs that will come next. However, it is not a simple task (in addition to clinical tasks) for experienced team members to comprehensively plan every single teaching moment ahead in an attempt to optimize team communication in OR.

3.2.4 Physical Layouts Minimizing Wasted Movements

Team members mentioned that they also pointed out the layout of sterile trays that could be simplified to minimize footsteps and simplify team communication, shortening surgery time. For example, a cardiac surgeon said the current layout required a scrub technician to travel between the tray location and the end of the patient bed numerous times to deliver requested surgical instruments to the surgeon. To increase team communication by protecting them from physical and mental fatigue, team members underscored their need for optimized physical layouts of furniture and equipment in the OR. To address such an issue, it would be beneficial to analyze the architectural flow (e.g., arrangement of equipment) during different operative phases and redesign based on naturally emerged patterns of team members' movement (Palmer et al., 2013).

3.2.5 Noise Reduction

Noise in a cardiac operating room was manifested in several ways. First, there were multiple pieces of equipment and devices simultaneously generating similar tones of alarms to alert team members, so team members had to investigate which devices

caused which alarms. In addition, one device might produce different alarms in different contexts, making it hard to distinguish the root cause of the alarm without additional efforts to investigate. Such ambiguity caused by alarms and alerts fueled frustration among team members and delayed surgery time. Second, noise can be generated by humans. A leading cardiac surgeon stated that sometimes it is hard to communicate his directions to team members because they are in the middle of a different conversation, or the volume of the radio is set too high. Systematically reducing the noise level of the OR is challenging in various aspects, since it requires redesigning of alarm systems as well as analyzing team dynamics. Thus, implementing techniques and strategies that can effectively streamline the chain of team communication in noisy environments is much needed.

3.3 Design Implications

cOR teams including surgeons, anesthesiologists, nurses, a perfusionist, and technicians caring for complex, high-risk cardiac surgical patients require close teamwork and precise communication. Teams leverage both tacit and objective knowledge to learn how to optimally communicate and perform. Tacit knowledge (insight and intuition) can be especially useful when acuity and complexity are high, such as in the cOR, where information often needs to be conveyed in a succinct and timely manner. Without tacit knowledge, communication can be interrupted, resulting in task failure. In this study, tacit knowledge for cOR teams was investigated through need-finding, a human-centered design approach for understanding team members' unmet needs and identifying their latent challenges. From the directed content analysis conducted using transcribed interviews and workshops with team members from each discipline in the cOR, we identified a series of common categories of needs. These included a) standardization of pre and post-operative processes, b) reliable tracking methods for supplies/equipment, c) adaptive training for new staff, d) physical layouts minimizing wasted movements, and e) noise reduction.

During the interviews, most team members touched upon the tension that emerges during team communications. The tension often came from the fact that one team

member made certain implicit decisions and tradeoffs that were not articulated. The complexity of tasks/steps increases exponentially as the number of team members increases. While teaching tacit knowledge can improve communications, there are still several challenges of tacit knowledge training.

- First, it is challenging to keep tacit knowledge between team members up to date due to time constraints and inadequate resources.
- Second, it was also difficult to track most tacit knowledge use cases in team communication and include them in training.
- Third, team members were concerned about the applicability of tacit knowledge if the training contents became overly extensive (e.g., covering every single skill and know-how of each team member in performing every operative task/step), and it would take a long time to be studied and mastered.

Hence, team members are in need of not only tool support for identifying use cases of tacit knowledge in team communication but also a new toolkit for effectively disseminating identified tacit knowledge among the team. Identifying commonly shared categories for knowledge gaps between team members in the cOR is an initial step toward understanding how tacit knowledge contributes to these gaps, and how this investigatory team can design programs to facilitate communication and performance through tacit knowledge.

3. 3. 1 Interactive Diagram as a Team Communication Tool

Team Cognitive Work Analysis helps identify cognitive processing and strategies required for collaborative work among team members. The analysis also provides an extensive framework for how to represent identified processes and strategies via diagrams, such as flow charts. The ultimate goal of the analysis is to make implicit processing and strategies embedded in teamwork explicit and thus they can be shared and communicated with people outside of the analyzed domain. Literature of Team Cognitive Work Analysis adapts modified Contextual Activity Template or Discission Wheel diagram (Ashoori & Burns, 2013). In the modified version, individual team members'

diagrams are combined into one diagram to effectively represent overlaps and shares of values, properties, and functions between team members. The overlaps and shares between members are delineated with connected solid lines (Ashoori & Burns, 2013). Such a diagram tends to have a convoluted composition with multiple lines facing different directions and connecting more than one element. Thus, it loses the key purpose of the analysis, a clear representation of complex team interaction.

Large amounts of information should not be displayed at once when visualizing complex data as it is difficult to look for meaningful information in a convoluted diagram or chart. Such a convoluted diagram or chart often requires extra written explanation to be fully understood, losing the purpose of data visualization, the intuitive representation of data. To improve the intuitive understanding of Team Cognitive Work Analysis, interactions are utilized to visualize shared processes and strategies among team members. The ultimate goal of this iterative diagram development is to create an effective learning tool for increasing the distributed cognition of the team and communicating better as a team.

In Stage 1, an improved approach to representing Team Cognitive Work Analysis is presented by developing an interactive flowchart diagram. The improved approach incorporates interactions in data visualization. Such interactions include select, explore, encode, abstract/elaborate, filter, and connect. These interactions allow the illustration of complex relationships between multiple variables in data. For example, one type of variable is selectively explored by filtering out the rest, variables are encoded with the same color to indicate their connections and the values of each variable can be abstracted with an overview or elaborated with details. Visualizing data with interactions provides the right information at the right moment. Different types of interactions allow focusing on a certain aspect of data by expanding needed information and hiding unneeded information.

CHAPTER 4: STAGE 2 Investigating Design Implications through Coaching Tool Prototype

Stage 2 builds on Stage 1 by 1) designing cOR team coaching tool to incorporate the main design implications from Stage 1, 2) running exploratory formative sessions on the prototype, 3) conducting semi-structured interview sessions to solicit team members' impressions and ideas about improvement on the prototype, and 4) suggesting future design implications of the coaching tools.

In Stage 2 low-fidelity prototype is used in the exploratory formative session and the follow-up-semi-structured interview. By inviting team members to explore the low-fidelity prototype in desktop screen devices, this phase of the study aimed to examine the cOR teams' experience with, and acceptance of, using technologies to help improve team communication and workflow. Based on these findings, how the user experience of the coaching tool can be further improved to support teams' collaborative workflow during the preoperative phase is investigated. Implications derived from Stage 2 are applied in future iterative design processes.

4.1 Overview of System Design

Stage 1 interviews revealed that communicating about each other's workflow is critical in team collaboration. In Stage 2, the prototype is designed to help team members identify what aspects (e.g., timing, order of tasks) of workflow should be communicated. Similarly, although the appropriate distribution of collaborative tasks is essential to maintaining effective team workflow in cOR preoperative phase, it has not been widely used in coaching tools as a design concept. The designed cOR coaching tool is aimed to 1) visualize cOR workflow of discipline-specific and collaborative tasks in one timeline across all five disciplines and 2) equip new trainees with fundamental knowledge about workflow, which is an often invisible but critical component of team communication. The design rationale, process, and components of the coaching tool prototype are discussed in this chapter.

4.1.1 Design Rationale

Stage 1 revealed team members' needs to share four categories of information with other team members to communicate their workflow: 1) discipline-specific tasks, 2)

collaborative tasks, 3) space, and 4) timeline. Team members have relied on their experiences of repeatedly working as a team for the long term to share these categories of information with team members outside of their discipline. There is no fast and simple way to understand other disciplines' workflow besides repetitively working with them since there is no formal training about such information. Through trial and error, while working side by side, team members can gradually pick up four categories of information and eventually build mental models about other disciplines' workflow. Furthermore, this is even more challenging for new trainees who must build a mental model about their own discipline-specific workflow at the same time. These findings inspired our team to design the coaching tool prototype to visualize discipline-specific and collaborative tasks of all five disciplines according to task space and operative timeline in one integrated platform. This integrated platform is simulated with a 180-degree view of cOR, both individual and shared tasks can be displayed by highlighting its associated task space and operative timeline.

After generating overall design directions with four main themes, other design components are also laid out for the coaching tool prototype, including an interactive learning platform for preparing patients on a surgical bed (e.g., positioning, padding, ECG placement, pressure points) to help new trainees to cultivate fundamental knowledge about a preoperative workflow which often requires frequent communication about such knowledge among team members to complete. These knowledge components are based on the factors identified as facilitators of team communication during the interviews in Stage 1. For example, many experienced team members mentioned that they experience communication challenges with new trainees, as they are slow in picking up what they intend to do during collaboration due to a lack of such knowledge. It often led to mistakes among new trainees and caused extra work for the experienced team members to correct them. Such discordance in the collaborative workflow has a continuous impact on the entire operative phases. Based on this finding, the coaching tool is developed by incorporating an interactive learning platform for key knowledge of preparing patients for surgery. In summary, each design component of the system was

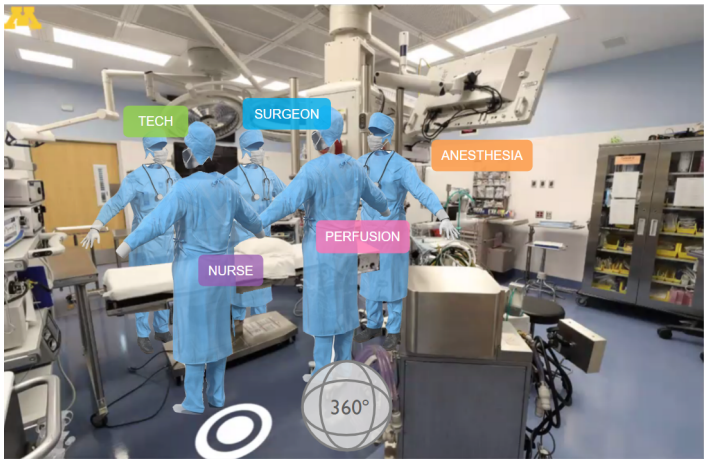
based on the participants' strategies and experiences related to their team communication and workflow (identified in Stage 1).

Customization and diversifying these components could be considered to fulfill team members' preferences. For example, the selection of tools or equipment for some collaborative tasks can be varied by individual team members' preferences. Such information might easily be elicited from co-design activities with team members. However, as Stage 2 aimed to test the feasibility of the four main themes identified in Stage 1, it focused on the main design implication found in Stage 1 by using knowledge contents based on general cardiac surgery cases.

4.1.2 Design Process

After detailed design ideas were developed, the iterative design method was implemented to create working prototypes. Initial sketches were created in Adobe Photoshop to visualize the details of design ideas and sought feedback from a group of experts, the cOR design research team, including one graphic design professor, an industrial engineering professor, and two anesthesiologists. Once the sketch was revised based on expert feedback, individual snapshots of user interface screens were produced in Adobe Illustrator and Photoshop. Finally, user interactions between screen snapshots of the coaching prototypes are simulated in Invision, an online prototyping platform. Invision prototype allows designers to communicate design ideas with others and to assess potential weaknesses and benefits of design outcomes in the early stage of prototype development. It's also effective in communicating detailed design components with programmers (e.g., interaction types: click, hover, tap) in the future developmental phase for a working prototype (Figure 4).

Figure 4 *Digital Sketch*



Note. Initial ideas for coaching tools are shared with team members via digital sketches to gather feedback

4.1.3 Prototype as a Coaching Tool to Work Together on Effective Team Communication by Learning Multidisciplinary Workflow

By incorporating the concept of integrated workflow into the coaching tool design, this tool aimed to provide users with opportunities to collaboratively work towards effective team communication within the cOR setting. To illuminate the existing team workflow, functions that display collaborative tasks and distinguish discipline-specific tasks is included in the tool.

The system has three main components: 1) space layout indicators 2) operative timeline tabs and 3) visual diagrams. The space layout indicators allow users to learn what types of tasks and where they are performed in the highlighted area. In the 180-degree view of cOR image, the area of space associated with the specific task is color-coded to indicate the type of disciplines performing the task in the area. The operative timeline tabs allow users to review both discipline-specific and collaborative tasks based on the different operative timelines (e.g., pre, intra, post). The visual diagram allows users to get familiar with key knowledge about patient preparation for the operation, such as positioning, padding, and placing EKG on the patient on the surgical bed (Figure 5, interactive prototype link). Such diagrams not only help visual learners but also logical learners by illustrating the reasoning behind the instructions (e.g., pressure points are also included in addition to instructing padding positions).

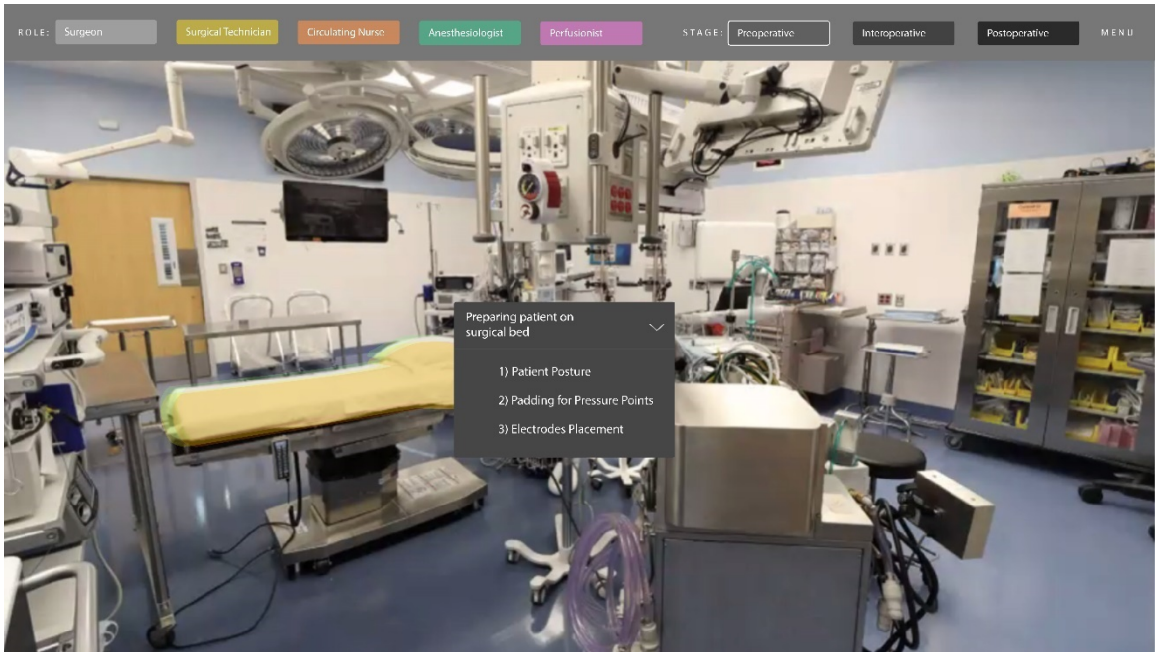
Studies showed that interactive components that accommodate individual user's learning paces and styles increase motivation and effectiveness of the learning process

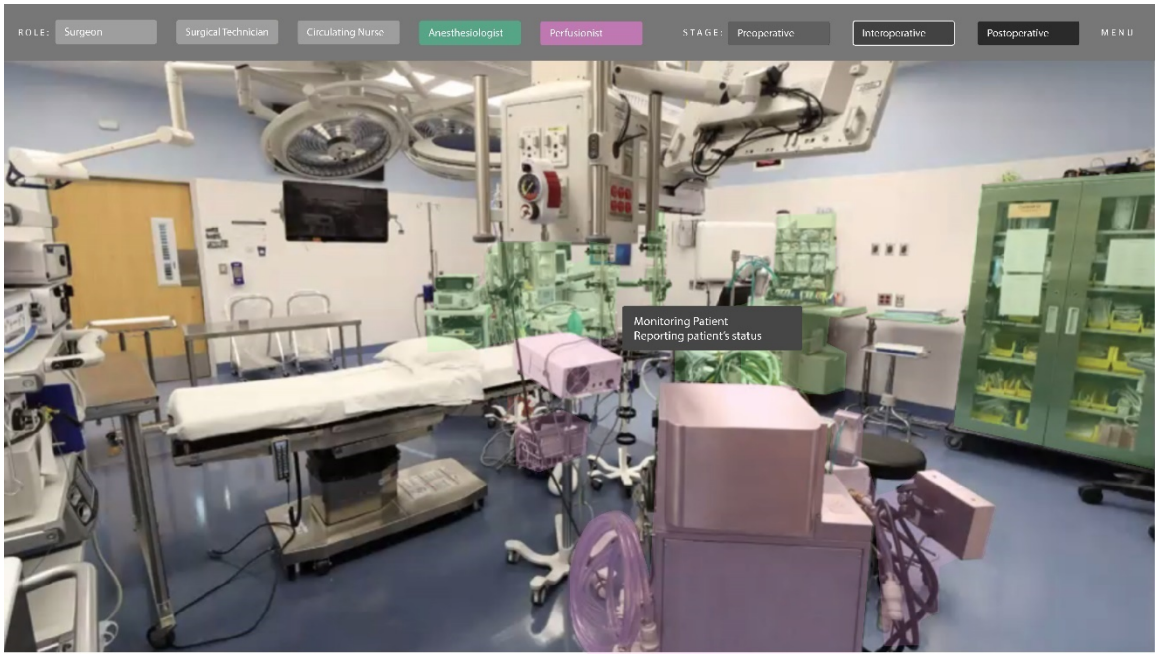
(Dias, Zenati, et al., 2021; Huang et al., 2018; Orwoll et al., 2018). One previous study utilized an interactive dashboard to display the cognitive processes of cardiac surgeons to enhance trainees' learning outcomes (Dias, Zenati, et al., 2021). Also, there is a body of studies supporting the finding that simulated knowledge in realistic settings (e.g., in 3D space, by scenarios) would increase the acceptance and application of the knowledge (Bracq et al., 2019). Several studies developed virtual learning tools for nursing students where they are allowed to interact with surgical instruments and furniture through wearable devices (e.g.,VR glasses, kinetic joysticks) (Bracq et al., 2019; Huang et al., 2018; Tacgin, 2019). Similarly, the coaching tool is designed to deliver learning materials through various mediums (e.g., 180-degree view image, visual diagram) and user interactions (hover, click, sort, filter) to support different learning styles and increase the application of knowledge in actual practices.

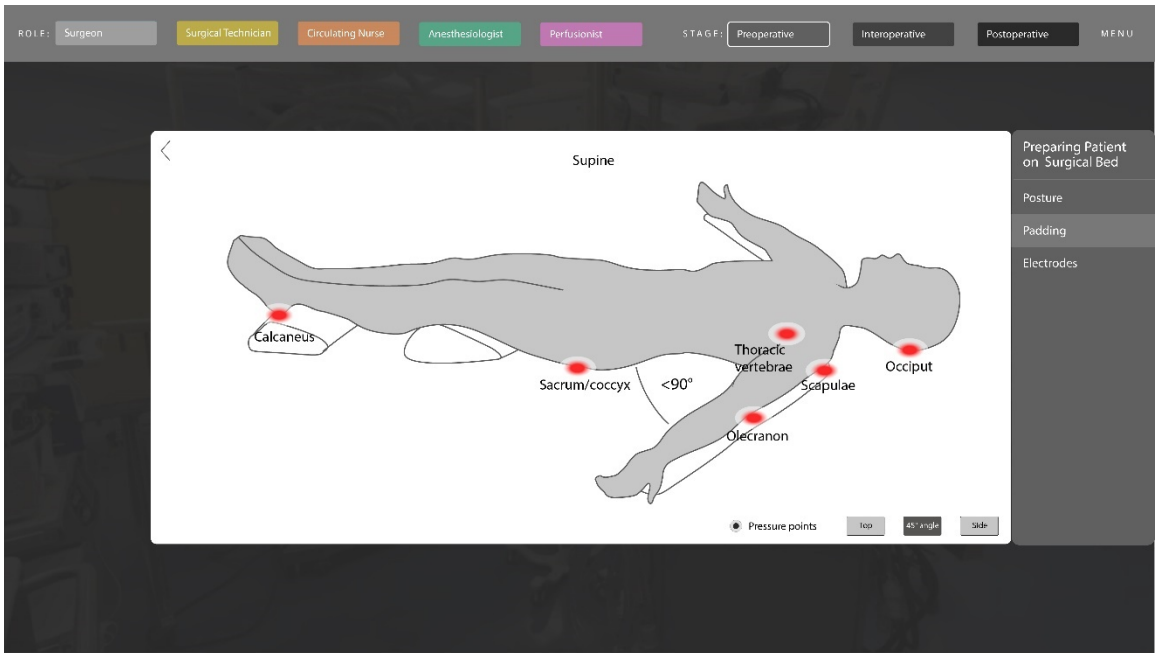
Figure 5

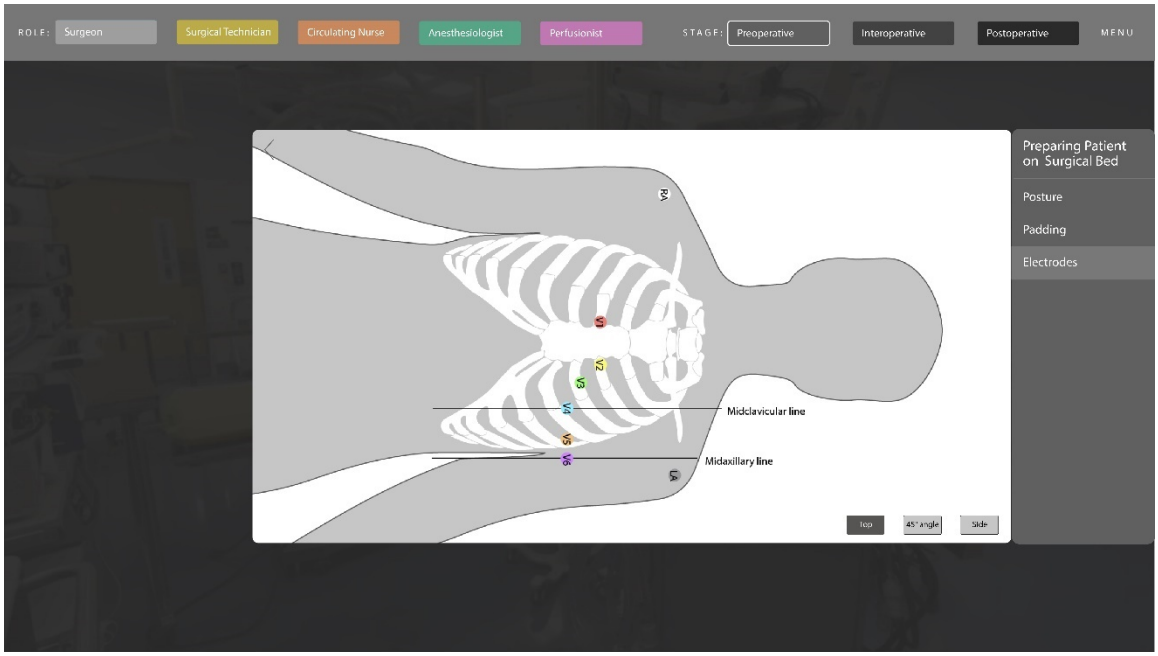
Screenshots of Low-fidelity Prototype for Interactive cOR Coaching Tool

(Interactive prototype link: https://invis.io/U9134JMA4NZM#/470877872_COR_Proto_Default)




ROLE:
Surgeon
Surgical Technician
Circulating Nurse
Anesthesiologist
Perfusionist
STAGE:
Preoperative
Interoperative
Postoperative
MENU
Monitoring Patient
Reporting patient's status


ROLE:
Surgeon
Surgical Technician
Circulating Nurse
Anesthesiologist
Perfusionist
STAGE:
Preoperative
Interoperative
Postoperative
MENU
Supine
Calcaneus
Sacrum/coccyx
<90°
Thoracic vertebrae
Scapulae
Occiput
Olecranon
Pressure points
Top
45° angle
Side
Preparing Patient on Surgical Bed
Posture
Padding
Electrodes



Note. The first and second images: Each discipline's key working areas are color-coded in a 180-degree view of cOR. The details of tasks associated with the working area can be reviewed by hovering the mouse cursor on the top of the color-coded working area. The third and fourth images: Visual diagrams for key collaborative tasks (e.g., posturing, padding, EKG placement for patient) during the preoperative phase encourage interactive learning among new trainees.

4.2 Study Methods

Data was collected through prototype exploratory sessions and follow-up semi-structured interviews over Zoom video conferencing. A formative study was performed as it was necessary to understand how users would utilize the coaching tool and incorporate it into their workflow. The prototype explanatory session and follow-up interviews were conducted in a row and lasted up to one hour for each participant. Compensation is not given, as participation in the co-design process of this research was considered to be part of their roles working at a research institution and counted as their working hours. Five team members from each discipline of the cOR team completed both prototype exploratory sessions and the follow-up interviews.

4.2.1 Participants

Participants were five team members, one from each discipline in the cOR team. The eligibility criteria of the participants were the same as in Stage 1. To understand how

cOR team members would use the coaching tool, the same five team members were recruited out of six participants from Stage 1. Because this study required frequent researcher-participant interaction, participants who already had developed a rapport with the researcher were intentionally included again. These returning participants had a stronger sense of ownership as continuous collaborators because the prototype was developed based on their feedback in Stage 1, and they were willing to provide rich data to improve the prototype further. There was one participant from Stage 1, who was not recruited for Stage 2 because Stage 1 interview with her revealed that she works at the management level, coordinating the schedule of nursing staff for the entire cOR department rather than working as a team member of a cOR team. As a result, her feedback was not closely related to team communication and collaboration. The number of participants (5) was within the normal range for a formative study of system usability recommended by FDA and statistical studies. In these studies, five participants are considered to be the minimum number of participants that can reach data saturation (Mason, 2010; Saunders et al., 2018). A formative study can be considered to reach data saturation when researchers start to receive redundant feedback from participants. Aligned with these studies, I observed overlapping participant feedback when interviewing 5th participants. All five participants are recruited from the same teaching institution, Caucasian aged between age 30-50, and have experience working as a team in the same cOR for at least 2 years.

4.2.3 Semi-structured Interviews

Along with prototype exploratory sessions, the same participants were invited for a 45-minute semi-structured interview with the researcher via Zoom. Individual team members were asked to share details of their experiences with the prototype after the prototype exploratory session. To minimize influences from the other team members, each team member was interviewed individually. While in Stage 1, participants were asked to provide general information about their discipline-specific and team workflow, in Stage 2, they were asked to share their impression on technologies, concerns, and strategies related to team workflow delivered via prototype.

The interview included in-depth questions (insert questions in appendix) about participants' impressions and ideas for improvement about the coaching tool prototype (see Appendix A). The main themes of the interview included details about what type of content and what type of technologies and features participants desired to include in the coaching tool to improve communication about their workflow. When participants mentioned the contents and features, they would like to include in the tool, they were asked to describe their experience using them, such as what they liked and disliked and things to improve. The interview session was video recorded and transcribed via Zoom to gain a comprehensive understanding of participants' experiences with the prototype through data analysis.

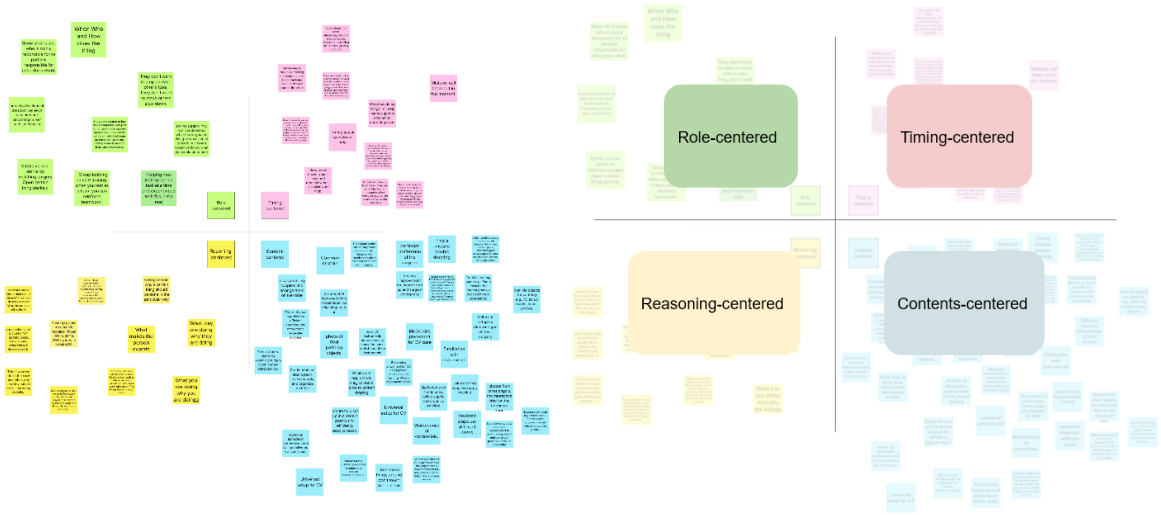
4.2.4 Data Analysis

In the current study, the conversations with individual participants during the interviews were analyzed. The thematic analysis approach is applied to the interview data. This approach allowed the researcher to capture team members' insights on the cOR coaching tool and have in-depth discussions on the impact on team communication and workflow, without a predetermined theme. Ultimately it also allowed the researcher to consolidate further design implications based on identified themes. During semi-structured interview sessions, the interview questions were actively modified based on their feedback to evoke richer details about impressions and ideas for further improvement of the system design. To perform open coding, the online Mural platform was used to manually extract transcribed phases from the interview data. Once the initial coding was done, 67 codes were iteratively aggregated based on their commonalities until they were mutually exclusive; this resulted in 25 representative codes. An affinity diagram is created out of them in Mural.

In the affinity diagram, the 25 codes were written on a separate memo pad and clustered depending on the relationships among the codes: similarity, differences, and hierarchy. This yielded four distinctive themes: 1) role 2) timing 3) reasoning and 4) contents-centered learning (Figure 6). Data analysis resulted in these four learning categories that cOR team members desired for the coaching to support. Subthemes under each category are discussed in detail in the following result section.

Figure 6

Affinity Diagram



Note. Affinity diagram was created via Mural app in the process of open coding. Four themes are identified from coded phases, and they are categorized under four themes.

4.3 Results

In the second interview, cOR team members explored the low-fidelity prototype of a coaching tool for trainees, shared their opinions about the contents and features of the coaching tools, and described various factors that delay their setup process during the preoperative phase in cOR. Those delaying factors included new trainees coming into cOR 1) without knowing basic protocols, 2) asking help/questions at an inappropriate moment, 3) lacking understanding of other team members' roles, 4) having difficulty in tracking supplies/instruments/equipment, and 5) lacking case-specific knowledge.

cOR team members also shared their efforts to minimize these delaying factors during the preoperative setup process. These efforts include providing a written list of case-specific instruments, supplies, and equipment to inform their new trainees beforehand. The results indicate that the most critical factors that affected the preoperative setup process involved more than providing written learning materials for them. The deeper issues of cOR setup stem from the indefinite transition between

different team members' responsibilities and the unclear expectation for providing help and support as a team member. The team members noted that, during setting up cOR, their criteria to determine whether they optimize the process shifted from an individual working on their own tasks to more complex issues involving team dynamics. For example, the optimizing setup process can be achieved only if the team members understand each other's role and what and when needs assistance. If a team member's role was not understood and assisted incorrectly, this drastically affected the whole setup process. This new perspective on cOR setup shows that collaboration among team members is essential.

In this section, major findings in the participants' feedback and ideas about coaching tools of cOR setup are reported and associated with team member dynamics and individual roles. They include: 1) role-centered 2) timing-centered 3) reasoning-centered 4) contents-centered learning.

4.3.1 Role-centered Learning

When participants described their cOR setup process, they frequently discussed how the process depended on other team members' roles during the preoperative phase. For the team members, the time to work on their individual tasks and opportunities for performing collaborative tasks should be achieved at the same time. Performing collaborative tasks took much time and labor from individual team members and made it hard to focus on their individual tasks during the setup. Five team members (5/5) described this process as "teamwork", "supporting each other", and "working together for a common goal" and said that they used this process to improve efficiency and performance by fulfilling their own specialty tasks and supporting each other's roles, including setting up instrument/supplies/equipment, positioning a patient on the surgical bed, and prepping the patient for a procedure. Because of the complexity of the cOR setup, they found supporting each other - both physically and mentally - to be a delicate matter. For example, a perfusionist mentioned that although she enjoyed and valued the time helping other team members, having multiple roles throughout the setup process made it difficult to get her individual tasks done in a timely manner.

"I'm trying to prepare my stuff, then if people are asking me to help them at the same time, I feel like there could be maybe a little bit of a better flow to it so that when I have pockets of time, then I could help the other departments… it could like make me slower at my task because I'm trying to help somebody else. [Perfusionist]"

As the quote shows, her individual setup time provided her with efficient, streamlined moments, and opportunities to focus on her own responsibility instead of her team members' tasks or needs. Other participants shared how they secured individual setup time by indicating when to be available to help others. Securing individual setup time for each team member was as important as cultivating collaborative culture as a team. For this reason, understanding each other's responsibilities and roles within the team is crucial, especially for new trainees in identifying the appropriate way to ask for help and questions without disrupting individuals' workflow.

"*I would offer my help if I'm done, but like the really good experienced, like my really good, experienced coworkers will kind of know they can like look at what I'm working on and be like, oh, that looks ready to go. But a new trainee wouldn't be able to look over and tell that I'm done. So you have to like communicate with them. [Perfusion]*"

In a similar way, the anesthesiologist mentioned that he would do anything to ensure understanding of each other's boundaries and responsibilities because it provides him with a more efficient workflow without overstepping on each other.

"We want them to be fast or we want them to get better or be more efficient or explain like the nuances of, so, people who are, say, training in the cardiac operating room, it might be, sort of the first level audience might be someone who is, they already learned how to scrub, they're a nurse, but they just need to learn how to scrub the cardiac operating room. They just wanna see, okay, how does like, you know, how does Dr. Shumway like it? Or like, how does a procedure flow with this person? How do they do this procedure? And what are the steps for it?" [Anesthesiologist]

Therefore, he would encourage all team members to get on the same page about who is responsible for what, which could provide team members with confidence in working together as a team. He mentioned that if he could list all tasks and map out every single task per team member the ambiguity around responsibilities could be eliminated. When team members ask or offer help without a clear understanding of their own responsibilities and those of others, it negatively impacts the entire team's performance. Team members mentioned that although all team members are subjected to ask or offer help to other team members, what kind of help is asked or offered is crucial for maintaining the efficiency of the setup process. To ask for or offer appropriate support and help, besides their own individual tasks, team members should be familiar with other team members' setup tasks and how they look when it's performed correctly. When inappropriate help is offered or asked, this often leads to prolonged setup time, particularly for experienced staff as they are required to cope with such requests, despite the benign intent to be a team player or enthusiastic learner.

For example, perfusionists and anesthesiologists described how inexperienced trainees can affect the OR setup process negatively, which causes delays in the entire surgery time. Because inexperienced new trainees lack understanding of what is going on with experienced staff, being busy with performing their individual tasks (e.g., building up equipment, gathering supplies), experienced staff's workflow is often interrupted by inappropriate help requests or offers. Inexperienced trainees can repeatedly disrupt the experienced team member's task performance without awareness. Experienced team members are concerned that this would disturb every OR setup process. Teaching the inexperienced new trainees took a significant amount of time and energy, and the anesthesiologist said that he often found himself spending a considerable amount of time refocusing back from such interruptions and correcting mistakes caused by them. He wanted to have more time for collaborating efficiently without correcting the same mistakes or explaining the same instructions repeatedly.

"we're just like teaching the same things like over and over and over again, where someone tries to set something down and it slides off the bed and that slides off the bed, it's like, put it over here, and it won't slide down to be able to show people that like this is why you do it before and then they go in here beforehand and say.. [Anesthesiologist]"

During the interviews, cOR team members also shared how they could help inexperienced trainees become familiar with other team members' roles and responsibilities. The cardiac surgeon mentioned that role-play games in virtual reality would help other team members understand each other's tasks and roles. By playing other team members' roles in 3D cOR space team members could explore different roles from different perspectives. Putting oneself in another's perspective via role-playing promotes more active learning compared to reading various unfamiliar tasks from a written list.

"He does this like funky thing and I can never remember how to do it. And so I was having him show me again. And it's like, if I just had a picture or like a little clip of like, hey, this is how this person does it. It would be awesome. But it's just like, you know, right now you'd have to like print the thing off and put it in the room. And you know, where do you keep it? So you really cool to see, okay, yeah, who does this? [Anesthesiologist]"

The other idea mentioned during the interview about role-centered coaching tools is the interactive dashboard. The anesthesiologist stated that he would like to have a dashboard that is actively updated about assigned tasks per each team member participating in cOR setup. He also wanted to have tasks labeled with the level of responsibilities per team member such as mandatory versus optional. The perfusionist added her ideas about the interactive dashboard to display the status of tasks: in progress versus completed. The indication of the task status could help inexperienced trainees to know the availability of experienced team members, allowing new trainees to ask or offer an appropriate type of help.

"It's almost like role playing, right? They can do the role playing instead of this kind of study. So they can choose the role which one they wanna play today, then see how they fit in well in the process.[Surgeon]"

In summary, the results show that the criteria for "effective team performance" squarely rely on having appropriate anticipation about each other's roles and responsibilities during the preoperative setup processes. The most important agenda for effective team performance was asking or offering support without overstepping each other because it provides an efficient balanced workflow for each team member, getting individual and collaborative work done. This team workflow is guaranteed only by an active understanding of each other's roles and responsibilities.

4.3.2 Timing-centered Learning

To support other team members' corroborative needs, cOR team members reported that the timing of support asked or offered was crucial throughout the entire setup processes. However, for cOR team with inexperienced new trainees, identifying the appropriate timing is always a challenge. How a team member identifies an appropriate time to ask or offer help to other team members throughout the setup process has a direct impact on the duration of surgery as well as the efficiency and safety of patient care. During the interview, they shared how they plan their teams' setup routine based on their collaborative tasks, such as positioning, padding, and draping patients on the surgical bed. According to the cOR team members, nurses are usually in charge of taking action in prepping patients on the surgical bed. The circulating nurse said they always keep "a preference card: a list of things to do per case" handy to navigate through the process and maintain structured schedules. cOR team members emphasized the importance of maintaining a stable setup routine to have the patient get ready for surgery on time, and the combination of the two could result in patient safety.

"You should recognize when it's appropriate for you to come and do the next part. So, you know, if you don't recognize if the, like, part of the teaching tool could be something that, you know, prompts them or maybe deducts from their score if they don't do

something in the, you know, in a timely fashion. If they're just sitting there not doing anything. So maybe if we put something like that in the tool where depending on who's taking the test, they're prompted or tested on their recognition of when they should come do the next step [Surgeon]".

For example, all team members mentioned that with new trainees, coaching the steps and order of the setup process is a critical factor for maintaining a timely setup routine and error prevention. Trainees often confused the steps or order of the process and made mistakes, and this made it difficult for experienced team members to follow planned setup schedules. To avoid having erroneous activities (e.g., placing padding in the incorrect order, applying drapes too early) affecting the timeline of the cOR setup, experienced team members tried to coach such a timing-sensitive setup process for trainees prior to entering cOR. The surgical tech reported how her team tried to cultivate their trainees with the appropriate anticipation of what process followed by what process beforehand. Also, the circulating nurse shared how she encourages her trainees to research an upcoming case to gain an understanding of the required steps and orders for the case to help them develop appropriate anticipation about the processes.

"…the preference card kind of gives you a brief overlay of what you need to open in addition to what's in the pack… there's a definite order in which you would open things. Okay. So that you can coordinate it with your counting so that you can be the most efficient in your movements and the most productive in the shortest amount of time so that we can expedite getting the patient in the room and caring for them. we meet and we're going over a timeline when we want to do these things… So all of those things that were each team members doing has to be done chronologically and simultaneously [Surgical tech]"

The appropriate anticipation, and also timely correction of mistakes have an impact on the entire team's performance. Four team members shared that they had an experience with correcting their trainee's mistakes, leading to delayed surgery time. For

example, the circulating nurse stated that when her new trainee forgot to place padding in the upper back of a patient the entire cOR team had to go over the previous prepping processes to fix the issue. In cOR, due to sterile protocol, many setup processes are required to stick to strict orders. If one of the steps/orders is missed or disrupted, the sterile process should be done from the beginning to correct the mistake. Although many team members agreed that new trainee learns from their mistake caught at the moment, they also mentioned that there are many common mistakes that can be learned beforehand without causing such aftermath, delaying the process, and risking patient safety.

"…when somebody makes a mistake, usually they don't make that mistake again you know it's one of those things too that the mistake teaches them…But teaching the basics for any operating room, sterile technique is the big basic because you want to keep sterility and so that's what you really look out at when you first start training somebody is to make sure that they're not making the common mistakes of contaminating something and not realizing that they contaminated it. Sure. Things like that you just I don't know of any you know besides I mean I write things down yeah but I think it's just by doing it that you get it. I mean it's good initially to explain things and to have visuals, but actually doing it is just repetitive. Sure, yeah that totally makes sense [Circulating nurse]."

Although the experienced team members listed the steps and orders of OR setup carefully in the preference cards and reminded them of common mistakes, the team was not always error-free. If cOR setup routine were delayed or interrupted, and the surgery could not begin on time, the team performance on patient care also suffered, and eventually, prolonged surgery time could jeopardize patient safety. When the steps and orders are omitted or mistaken, this affects the entire workflow of cOR setup. For example, particular processes such as handling non-sterile surfaces or objects can be done before sterilization begins prior to the dressing and draping of the patient. If non-sterile tasks are not done or done incorrectly, dressing and draping of the patient should be redone, causing a major delay in setup and surgery time.

"…everybody's just trying to help, but you have to, you know, explain like this is sterile and this is the zone that, you know, we cannot touch anything. And then with anesthesia, like, they've prepared this, and so don't move things around because they're not going to know where stuff is. So a lot of times new perfusionists trying to be helpful will maybe be a little bit not help, like maybe a little over eager. So just like knowing what steps we can help with and don't help with. And then yeah, from the nursing department, for them, it's kind of what we mentioned before, just like knowing when a good time to ask for help is versus when a time, you know, we're doing something and the surgeon's doing something and then the new nurse will be like asking questions. [Perfusionist]"

These quotes underscore that not only what to ask/offer as help but also when to ask/offer help is crucial in working together as a team during a preoperative setup. The experienced team members shared various strategies that could help maintain their setup time and process in an efficient manner. These included gamification of learning orders and steps of cOR setup. The cardiac surgeon mentioned that new trainees/new hires would memorize the routine setup process by testing their knowledge through a game. When they clear the process in the correct steps and order, they will be rewarded with coins or tokens. If they experience a close call, hints or reminders could be utilized as an item that can be purchased by earned tokens/coins. He also shared that playing such a game would work as a team-building activity, strengthening their team performance and communication without pressure in an engaging manner.

"If you do it the wrong way, the patient can get a bad infection or the setup could be wrong and you can have problems, you either have to redo it or you can have problems during the operation if the setup's wrong. So those are all, they're simple tasks but they're very important tasks. And they should be 100% reproducible. They're repeated every day, every case that we do every day. It should be done the same way every time…Because like, if it's, you know, a lot, oftentimes we get a lot of stuff that's like a video that you have to listen to and then you get a written test afterwards. Maybe something that's kind of like

a game and interactive could be a little more fun. And I think if it's fun, then you retain it better.[Surgeon]"

New trainees are still learning the steps and orders of cOR setup process, and thus a visual learning tool is recommended where the game is staged in a 3D cOR space. The 3D cOR space could be divided into sections where each section is associated with a different setup process by individual team members. A 3D model of cOR layout would help the trainees visualize the steps and orders of the setup process and build them into muscle memory. The surgical tech mentioned that some trainees particularly desired a visual-based learning tool for themselves to get familiar with the new environment where they can alleviate their anxiety about trying new knowledge beforehand.

This subsection shows that cOR team appears to be affected by the time management of the setup process and by new trainees' understanding of the steps and orders; these also provide improved performance for both experienced staff and new trainees. The connection between time management and the quality of team performance led experienced team members to develop unique strategies for their trainees to maintain awareness about what should happen and when.

4.3.3 Reasoning-centered Learning

The findings suggested that the implementation of appropriate task and time management was critical for the successful setup of cOR team members. To successfully collaborate to manage their setup processes, team members divided their tasks depending on their roles and responsibilities. At the same time, they coached new trainees to practice and perform small tasks as part of their teaching responsibilities. Experienced team members mentioned that having a textbook about the case setup reviewed before the case is helpful for new trainees in terms of freshening up their memories. Furthermore, they explained that they provided more teaching opportunities for their trainees by adjusting their individual tasks to accommodate the extra learning needs of their trainees. Because these practices happened throughout the entire operative phase and were not restricted to the preoperative phase, participants noted that the coordination of frequency

and length of teaching moments affects the setup process and eventually the entire operation time.

cOR team members mentioned that teaching moments could happen during any tasks and timing during operation. One type of teaching moment happens particularly at the moment when experienced staff attempt to share their insights and know-how with trainees. These insights and know-how often cannot be learned from textbooks and are difficult to pick up by new trainees without extended explanation. Anesthesiologists reported that even with an extended explanation, his new trainees often missed the point, and when he/she asked to perform the learned technique, they made a mistake without applying the taught technique. The circulating nurse also pointed out that although some of the tips and know-how are written out on the preference card, her trainees make mistakes. The circulating nurse pointed out that the tips and know-how only can be learned from repetition, repeating of making and correcting mistakes by oneself. This was the most frequently mentioned type of how-to teach tips and know-how and was particularly helpful for securing learning opportunities for new trainees.

For instance, the anesthesiologist shows the way to place the ultrasound wire on the patient's arm and explains why it should be placed under the arm instead of above the patient's arm because the wire can slip and fall off when it's placed on the top of the arm when ultrasound machine is operated. Although the tips and reason behind it are verbally shared by him, his trainees still tend to place the wire on the top of the patient's arm and have to reposition the wire to the underarm after experiencing the foretold difficulty by themselves. The anesthesiologist added that it's one example out of many; such a learning curve happens most of the time when he shares his know-how and tips. Trainees cannot fully understand it until they identify and experience the issue from their own perspectives.

"there's a lot of different ways to do it, and then have everybody weigh on each step of the process and say, you know, what is the best way to do this thing? And of course, there may be two completely alternative ways to get to the same end product. But going through each of like an arterial line procedure and say, if you're going to do it with X,

then the best practice is to do it this way and then have a, okay, why do we want the ultrasound here? [Anesthesiologist]"

The circulating nurse mentioned that one of her jobs as an experienced nurse is to update a list of tips and insights about individual cases and surgeons on the performance cards to help new trainees be informed about case/surgeon-specific tips and insights before joining the case. Furthermore, she instructs her trainees to get familiar with cOR setup by assigning small sections of a task. The trainee is supposed to pre-learn what kind of instrument setup is required by learning from the preference card before entering the OR and try to apply the learned knowledge in a real OR setup situation. The experienced circulating nurse would supervise and check whether all required instruments are retrieved and organized on the surgical tray correctly. If an incorrect instrument is found in the tray, she explains reasons why certain instruments are needed for the case. She mentioned some instruments could look almost identical to new trainees, and explaining their use differences helps them distinguish them more easily rather than simply calling them by different names.

"…to try to explain why you're doing what you're doing. You know, especially in open heart surgery, we do a lot of things. You know, there's different assist devices that we use. You know, a case can turn into an emergency really quick, things like that. So, you know, it's a slow, like I said, it can be six months to a year to train somebody to really feel comfortable in there... it's just such a busy environment. That's why it takes a while to train them because you still have a patient and you still have to get things done. You can spend a little more time here and there, but you can't spend a lot of time, you know, so then that then comes the repetitiveness [Circulating nurse]"

More than half of the team members emphasized the importance of teaching the reasoning behind the instruction so that their trainees could know why a certain thing needs to be done in a certain way. This perspective-sharing of experienced team members enables new trainees to have a deeper understanding of the context around the given

instruction. However, they also pointed out that the current teaching method for perspective-sharing is not as effective as they intended to be. To share their perspectives more effectively, the anesthesiologists shared their ideas about using egocentric VR goggle. He suggests that experienced team members wear wearable cameras such as Google Glass to record themselves performing a procedure/setup by talking out loud about why and how to perform it. The recorded egocentric videos of the experienced team members could be played in VR goggles, such as Oculus, for new trainees. He witnessed that when playing recorded video of a setup/procedure performed by experienced team members outside of OR often leads to an aha moment for his trainees, as they could solely pay their attention to the tutorial video without the pressure of treating real patients in OR. He added that projecting such a tutorial video from VR goggles would be more effective for trainees in emulating the experienced team member's perspective, as it could deliver a more accurate projection of what experienced the team member sees in the situation. Such perspective-taking is important for trainees to immerse themselves in the reasoning behind the experienced team member's actions, know-how, and insights.

"This thing is here and this is why it's here. You know, you to have that information kind of embedded in something that's whether it's a live video that, you know, is paused or just like we take, I think we could definitely get some patients that would be willing to agree to do like a 3D capture the room when they're in there and prepped. You know, if we explain it to them, like, you know, you'll be covered up, we'll put towels over you, whatever. I'm sure we can find some old dude who's willing to, you know, be photographed and captured. And then we can, you know, kind of show like, hey, this is what the end state... we can compress the training time for people by showing them that and letting them just like walk around the room and kind of explore why everything is done the way [Anesthesiologist]"

This subsection showed how sharing the reasoning behind instructions could help new trainees gain tips and insights more effectively. cOR team members' experiences

showed that sharing experienced team members' perspectives is critical for the genuine understanding of the reasoning behind the expertise of the experienced staff. In particular, the results indicated that egocentric glass cameras and VR goggles could be effective tools to share experienced staff's points of view such as cognitive processes with new trainees.

4.3.4 Detail-centered Learning

Although cOR team tried to follow protocols and maintain the efficient process they were not always able to do so when situations changed - either expectedly or unexpectedly. The interview results showed that many details dynamically influenced setup workflow patterns, including the setting variations from standard to branched/deviated cases from the standard. All of the team members participants (5) devised various learning strategies to handle these copious details of settings per various types of cardiac cases. The effectiveness of these strategies is critical for trainees' learning experiences.

First, trainees who are new to cOR need to learn cOR-specific settings and procedures in addition to OR 101, and thus experienced team members are required to educate cOR-specific requirements to their trainees. The surgical tech described her trainees as "not completely newbies". Her trainees are not just coming out of school, instead, they usually have a few years of experience working in general surgical units. She added that her trainees are in need of learning details about cardiac-specific settings and procedures. On the other hand, the circulating nurse reported that her trainees could be completely new to OR, as her trainees are required to circulate through diverse departments and units of the entire hospital. For circulating nurses, training and learning case-specific knowledge are essential parts of their daily jobs that involve new requirements, mistakes, and corrections. They shared how their ongoing and continuous efforts improved their performance and helped them establish reliable expertise as a solid team member of cOR. For example, circulating nurses are in charge of handling both sterile and non-sterile supplies, instruments, and equipment. Because they handle both types of items at the same time, they have to meticulously orchestrate the arrangement and organization of over a couple hundreds of different items throughout the entire

operative phases. The arrangement and organization for hundreds of items differ by case and surgeon leading the case. As the experienced circulating nurse, besides maintaining the preference cards up to date, she volunteered to take extra responsibility for creating an insight binder for the detailed list of case and surgeon-specific requirements. She designed the chichi binder for her trainees or any new team members to cOR to help them gain must-know details of each case performed in cOR. The chichi binder includes details like key steps, required supplies, instruments, and equipment for the procedures. If the procedure is branched out or deviates from the routine or standard procedure the binder also explains differences in detail through bullet points, images, and diagrams. The binder is placed in cOR, readily available for anybody to review quickly right before a case starts.

"It's extremely rare that we would surgical tech and bring them into a heart room. We would almost always make them do other types of procedures first and get some experience underneath them before we brought them into this type of environment or procedures...if you're on Monday, they'll say, hey, tomorrow you're going to be doing aortic valve replacement. So it's the expectation that they would go home and Google it a little bit and see what's going on and just have some idea what it is. We also have that cheat book. And what we did is we typed out particular preferences for each surgeon. Just quick little bullet point notes…the scrub person or the circulator could look at them and say, oh yeah, I need to have X, Y, Z and they can help prepare that and get ready ahead of time [Surgical tech]"

As the quote suggests, although most surgical techs are not completely new to cOR there are always details specific to each cOR team. The surgical tech mentioned that she teaches how to disassemble and arrange instruments on the surgical tray. The package of instruments selected and prepared by circulating nurses differs by case and leading surgeon, and thus it could be seemingly identical to new trainees but there are always variated and detailed nuances that trainees should know to distinguish.

In addition to setting variations per different cases and surgeons, the perfusionist mentioned that there are many detailed guidelines required for new trainees to learn before entering cOR. She reported that even though trainees theoretically know what should do and what should not do in OR settings they have a hard time figuring out how to apply the theory in the real cOR setting; where they can go, what they can touch, or what they cannot do in a particular cOR can be unclear to new trainees as all cOR are arranged and organized differently. Due to such differences, the location of equipment and supplies is another essential detail for new trainees to know. She added that for new trainees, finding supplies and equipment takes longer than for experienced staff and thus getting familiar with the location is important in maintaining cOR setup process efficiently.

"I guess just like even this is something small but just like which power sources which departments use because we've had multiple times where we've overloaded the power grid when we've had new employees and new staff members come because they're plugged into the same thing that other powerful things are plugged into. And then we have to call somebody and pause the surgery. We don't want to blow up or anything. That might be helpful for setup…like maybe having a few like critical things labeled like where to find them like gloves, or like maybe not super specific like types of saw blades or something but just like general things that everybody's gonna need maybe having them labeled in a simulation would help them feel more comfortable [Perfusionist]"

cOR team members shared their ideas about how to effectively teach the detail of guidelines to new trainees while maintaining efficiency in the setup process. The perfusionist mentioned that providing cOR virtual tour would be useful for new trainees to familiarize themselves with the new setting. For example, in the virtual tour, the trainee could explore the fully set cOR as they needed without fear of violating any guidelines or risking patient safety. By clicking on any supplies and equipment, they can learn the details about them such as name, usage, and location. When they violate guidelines in the virtual space, a warning message will pop up and teach them how to

avoid the issue next time. Such an interactive learning tool would be more effective in delivering copious but crucial details. The perfusionist also added that providing an interactive quiz at the end of the virtual tour would be useful. She shared her experience with one of the interactive learning tools from her school. She enjoyed taking an interactive quiz where she was asked to identify mistakes from the screen image of OR setup. According to her, it is more engaging and memorable at the same time as she was able to keep taking the test until she became familiar with the correct setting.

This subsection shows the necessity to teach detailed guidelines to new trainees in an effective manner for both experienced staff and trainees. The details that should be taught not only include standard and universal guidelines in OR for general but also include cOR-specific guidelines that differ by case, surgeon, and institution. The learning tools for such details should allow trainees to continuously interact with the details of guidelines and familiarize themselves with them through trial and error in a safe environment, such as a virtual cOR.

CHAPTER 5: DISCUSSION

5.1 What Are the Type of Tacit Knowledge that Facilitate the Effective cOR Team Communication?

We identified the three types of tacit knowledge that determine the quality of cOR team's communication: when, what, and how to communicate. Communication must occur at an appropriate step (when) with an appropriate task (what) in an appropriate order (how). Without consideration of these factors, communications can interrupt other's workflow, leading to delayed surgery and decreased patient care time. Knowing this tacit knowledge requires experience, which is absent for inexperienced team members. Learning this poses a major challenge for them, which is a strong indicator of competence as a team member.

In previous studies, each discipline ought to learn its own discipline-specific tasks and workflow to properly function in a OR team. Thus, with a few exceptions (Haig et al., 2006; J. Paige et al., 2021; Siu et al., 2016), researchers have mainly focused on how surgeons or nurses manage the OR workflow. The roles of nurses and surgeons in managing cOR workflow were important in our study; however, the roles of other cOR team members, including anesthesiologist, perfusionist, and surgical technician, and the interactions among all team members were important as well. In Stage 1, participants showed how they handled their individual roles and responsibilities amidst collaborative tasks. They emphasized that how individual disciplines' tasks fit together within team workflow was critical. Thus, appropriate order and timing of individual tasks should be considered and trained across disciplines. Particularly, they also shared how having new trainees in their team impacts the preoperative workflow (e.g., delays to task completion due to teaching moments). To maintain their workflow routine, the experienced team members implemented various strategies including manual (e.g., preference cards), protocol (closed loop communication), and training (e.g., pre-research about a case) for the new trainees. Stage 1 showed that in order to properly understand cOR team workflow, it is necessary to consider their individual responsibilities and collaborative tasks and how those fit together in one workflow. In line with these findings, in Stage 2,

participants shared how they would use the coaching tool to implement an efficient team workflow, both on individual and team levels.

To understand such complex issues of cOR workflow, designers need to consider roles and responsibilities beyond discipline-specific roles and tasks. In previous studies, researchers investigated how technologies can improve cOR workflow by providing better operating room layout, checklist, and rehearsal tools (Calatayud et al., 2010; Clapper & Kong, 2012; Hensley et al., 2021; Palmer et al., 2013; Wahr et al., 2013). When Stage 1 participants were asked to freely explain their difficulties that are not limited to their own discipline, they explained issues both inside and outside their discipline. For example, one of the most important team workflow issues tends to emerge when they are asked for assistance from other team members while they are performing their individual tasks. In response to such requests, they needed to make extra effort to alleviate its effect on the original workflow of their individual tasks. This example indicates that the issues that pose challenges in the team workflow are not necessarily bound to the discipline-specific tasks. In other words, Stage 1 indicated that cOR workflow should be examined beyond one or two disciplines, thus, Stage 2 further examined the team workflow by exploring ideas for coaching tools applicable across the multiple disciplines during cOR preoperative phase. Future studies should expand the scope of technology design to various phases of patient care beyond the preoperative phase and operating room.

Performing preoperative tasks for the participants was not considered as a compound of individual tasks but rather as one multifaceted collaborative task. When medical studies investigate team workflow, they evaluate team performance by measuring individuals' performance. These subjects were examined by a knowledge test, and their performance was quantified (e.g., how many tasks are getting done, how long the time to takes to complete the tasks). Because the workflow analysis is based on individuals' tasks and performance, training applications created as a result of medical studies suggested individual-focused solutions to improve one discipline's performance. Few studies have focused on tasks and performance in OR across more than one discipline (Cumin et al., 2013; Franklin et al., 2017; Hull et al., 2011; Perry & Fortuno,

2021; Pons Lelardeux et al., 2017), because they found that both multidisciplinary-centered perspectives and training application have been critical for understanding team workflow management in extended contexts, such as burnout prevention (Sonoda et al., n.d.; Wheelock et al., 2015) and patient care (Salenger et al., 2020; Siu et al., 2016). The findings of these studies indicate that collaborative effort in OR workflow can facilitate successful and safe patient care (Arora et al., 2010; Clapper & Kong, 2012; Forse et al., 2011).

However, the findings from this study suggest that the team dynamics among the team members are considered to understand workflow and evaluate the performance of cOR team. Such team dynamics are often created and shifted by team member changes, such as the addition of new trainees. For example, in both Stage 1 and 2, participants often explained that delayed tasks and mistakes by new trainees pose challenges during the preoperative phase. These situations are particularly challenging due to new trainees failing to perform tasks adequately, which leads to misunderstandings and other communication issues in the rest of the operative phases. Also, in many cases, this diminished performance caused not only the preoperative process delay but also the prolonged operation and increased turnaround time. For the participants, such training issues impinged on their valuable time for patient care. This was especially true for the experienced team members in our study because, in addition to performing and managing their own responsibilities, they were required to work on training new staff. Their new trainee's incompetency was a major interruption to their task performance. Furthermore, this issue reminded them to question why the teaching moment to new trainees should always happen in the operating room rather than outside the operating room. As the findings show, the new trainee's incompetency is not only an individual trainee's issue, posing challenges in team dynamics and workflow.

The other communication issue of the cOR team is ambiguous role distributions and an unclear understanding of other disciplines' roles. Although there are many workflow tracking and task reminder applications that are available through smartphone apps and desktop interfaces, those solutions focus on displaying abundant information among team members by motivating clinicians to adhere to rules and protocols. They do

not take into account the complex social dynamics among team members. Even with an attempt to consider team dynamics in application design, its functionality is limited to sharing task manuals/protocols or tracking trainees' performance. As a result, understanding team dynamics is still not considered to be crucial in designing OR team training applications.

By prototyping team-based coaching tools for learning cOR team workflow, Stage 2 investigated the patterns of existing team dynamics, and team members' stance about using team-based coaching tools. The coaching tools were intended to support participants by allowing them to share collaborative tasks and offer their trainees chances to reflect upon their performance within the team context. The coaching tools aim to provide the cOR team with training practices that could optimize the preoperative tasks and phases. The results from Stage 2 support the implication from Stage 1: to improve the communication of the team members with new trainees, the coaching tool design should take into account the interdisciplinary workflow of the preoperative tasks.

When team workflow problems are examined, evaluated, and addressed within a boundary of individual discipline, there is always the possibility that the solution lies outside the one discipline. Thus, coaching tools that were designed within the constraints of one discipline were not able to properly support complex team workflow issues that stemmed from team dynamics. The limits imposed by the strict boundary between disciplines have been reconsidered in many OR workflow studies to understand complex team issues (Cohen et al., 2016; Cumin et al., 2013; Dias, Zenati, et al., 2021; Gillespie et al., 2010; Palmer et al., 2013; Siu et al., 2016, 2016; Tørring et al., 2019). Cohen (2016) explained how previous OR workflow did not see the complex issues of multidisciplinary healthcare teams, because researchers tend to focus on predefined boundaries, such as one particular discipline, doctors or nurses. Gillespie (2010) discussed difficulties in representing healthcare professionals' unique needs and cultures when designers only focused on general and standardized cases that were limited to one area of specialty. Although application design for OR workflow has improved an understanding of individual team members' task performance during surgery, they often miss less visible factors (e.g., tacit knowledge, mental model shared in team), critical factors determining

the quality of team communication (e.g., new trainees have a difficult time understanding experienced team members' words). This study dissects contributing factors to team performance that led to a better understanding of team workflow issues, which were previously invisible because OR training is widely done by individual disciplines (Cohen et al., 2016; Cumin et al., 2013; Dias, Zenati, et al., 2021; Gillespie et al., 2010; Palmer et al., 2013; Siu et al., 2016, 2016; Tørring et al., 2019). By dissecting contributing factors to team communication and emphasizing its interdisciplinary attributes, the coaching tools are designed to visualize individual team members' responsibilities and expectations, thereby actively sharing and acknowledging the team workflow.

5.2 How Coaching Tools Can Integrate and Address the Types of Tacit Knowledge facilitating Team Communication?

To integrate and address the type of tacit knowledge that facilitate effective team communication, we found that the coaching tool should be able to 1) optimize teaching moments, 2) reduce error corrections, and 3) provide the context of individual and collaborative tasks. According to the findings from the interviews, communication between team members becomes inefficient when these activities are prolonged, leading to interrupted workflow and delayed procedure time. It is vital for the coaching tool to support these activities to allow team members to communicate in an efficient manner.

One of the most salient themes discussed in both Stage 1 and 2 was how participants, especially the experienced team members, wanted to reduce repetitive information and knowledge sharing with new trainees: they wanted to enhance self-learning tools for new trainees prior to entering OR. During interviews, the experienced team members expressed burdens related to managing and providing teaching moments while performing their own tasks, regardless of their discipline. For example, perfusionists said it is their responsibility to gather their own supplies and set up equipment, while she is also often expected to give a hand to new circulating nurses in setting up a patient on the surgical bed. In both Stage 1 and 2, all participants expressed pressure regarding requests to join collaborative tasks in the middle of performing their own discipline-specific tasks. This study was unable to include enough cOR team

members to sample their organizational culture toward collaborative tasks. We attempted to include more participants with various experience levels to understand their views on collaborative tasks. However, new trainees or new hires were unable to take the time to have interviews during the recruitment phases. Despite the limitation, collaborative tasks related to preoperative tasks are still mainly considered as the experienced team member's responsibilities.

In fact, the experienced team members in the study stated that it was primarily their responsibility to create the necessary teaching moments for their trainees. They have to manage learning content as well as coordinate tasks for new trainees. They expressed that distributing their teaching responsibilities outside the OR could be essential not only for improving their work efficiency but also for improving patient safety. New trainees' effective learning not only works as time for the trainees to enhance their proficiency but also saves time for the experienced team members to perform their own tasks (e.g., building equipment). Unlike previous studies focusing on efficient collaboration among team members inside of one or two disciplines (Haig et al., 2006; J. Paige et al., 2021; Siu et al., 2016), the current study attempted to restructure the existing task distributions of cOR team members by the coaching tool to support effective learning for the new trainees.

In medical teaching institutions, the redesigning of coaching tools has been a vital concept for reducing health professional workload and improving the quality of patient care (Clapper & Kong, 2012; Franklin et al., 2017; Gurses et al., 2012; Hayashibe et al., 2005; Palmer et al., 2013; Parush et al., 2011; Wheelock et al., 2015). For example, Dias (2022) found that informatic technologies are used, adopted, and envisioned by different disciplines. It showed how the segmented training/coaching tools for collaborative tasks in OR continued to be reinforced by informatic technologies. She explained how the segmented approach is traditionally, culturally, and institutionally structured in OR medical training and how informatic technologies reflect that segmented training approach. Likewise, the early application-based training tool studies were considered to be limited due to the lack of understanding of team dynamics and the taxonomy of collaborative tasks. More recent studies started addressing multidisciplinary team

dynamics and opened a new direction of training application design (Cohen et al., 2016; Palmer et al., 2013; Siu et al., 2016; Wahr et al., 2013). As team dynamics gain more attention in healthcare applications, researchers have adopted more multidisciplinary approaches in OR training tool design (Brown et al., 2017; Fleetwood et al., 2018; Haig et al., 2006; J. T. Paige et al., 2014; Parush et al., 2011; Pons Lelardeux et al., 2017). These studies used a multidisciplinary lens to understand how application tools can encourage effective collaboration in healthcare settings by establishing a shared mental model (Bracq et al., 2019; Dias, Zenati, et al., 2021; Franklin et al., 2017). For example, Franklin (2017) showed how dashboard design, an important application tool for ER medicine, can help them to amplify the usage of global (shared) knowledge in decision-making in a constantly changing ER environment.

In this study, the coaching tool application is designed to facilitate new trainees' self-learning opportunities in cOR preoperative workflow and collaborative tasks. Such self-learning can encourage the trainees to get familiar with the experienced team members' tasks and workflow, allowing more balanced role-sharing in the team. The coaching tool application gives the capacity to represent OR workflow as shared resources. It visually indicates how time-saving practices in one part of the preoperative tasks (e.g., minimizing repetitive mistakes) can benefit other operative phases (e.g., increased turnaround rate). This would ultimately lead to improving team communication, performance, and quality of patient care of the cOR team. By revealing the invisible roles of team dynamics in team workflow, the coaching tool can emphasize the interconnectedness of the cOR team. This can motivate effective collaboration beyond one's own discipline. With this approach, team dynamics can be restructured, and the experienced team members would become less burdened with managing the teaching moments, securing more time to perform their own tasks.

One of the major contributions of the current study is that it broadens the scope of design input of coaching tools to team dynamics across not only different disciplines but also different experience levels. This study provides a meaningful addition to the existing body of user experience design literature on OR team communication by prototyping cOR coaching tools. The tool aimed to visualize experienced team members' team

knowledge for new trainees. This study illustrated how a coaching tool can support team communication and performance in the cOR environment by inviting team members to participate in restructuring ways of communication beyond its existing patterns.

5.3 How Technologies Enable the Coaching Tool?

The current study identified the types of technologies that can effectively support cOR team communication: 1) gamification, 2) role-playing, and 3) dashboard. According to findings, these technologies simulate team members' roles and needs and invite them to learn each other's perspectives. Understanding each other's perspectives is crucial for team members to identify the right time, context, and way to communicate with other team members. Although the study did not measure the effectiveness of these technologies it suggests design guidance.

In particular, the current study sheds light on the capability to share tacit knowledge through gamification as a coaching tool. Although gamification has been used to explain individuals' improved performance with goal setting and motivation, little has been done to explain how gamification principles (badges, social interaction) can leverage collaboration and eventually support a cOR team members' individual and collaborative tasks. The findings from Stage 2 suggest that coaching tools outside of OR can contribute to more effective collaboration in the preoperative phase between trainees and other team members, which also leads to improvement in the entire team's performance. The experienced team members underscored that new trainees could learn before entering OR about the timing and order of preoperative tasks from the coaching tool prototype. Participants believed such a coaching tool for self-learning could increase the trainees' active engagement and strong collaboration in preoperative tasks. They suggested that gamification in the coaching tool could promote the self-learning process. According to previous studies, gamification allows users to engage in non-game contexts, such as education and healthcare, by motivating them with game elements (de Sousa Borges et al., 2014). The game elements, such as characters, reward points, feedback, and storyline are added to facilitate user engagement in the broader healthcare contexts for quality improvement training (Blondon et al., 2017; Bonn et al., 2022; Isotani & Mizoguchi, 2007; McConaughey, 2008; McKeown et al., 2016; Morey et al., 2002;

Salerno et al., 2018; Wachs, 2005). For example, desktop-based interfaces promote the learning of patient care protocol by rewarding medals and points when assignments are successfully cleared (Bonn et al., 2022; Orwoll et al., 2018). Such rewarding systems also can be incorporated with simulation, which has been widely used in medical fields, to increase motivations for practicing and mastering procedures. Similarly, Salerno (2018) promotes motivation in ER medicine students via an internet-based dashboard displaying the performance data of individual clinicians.

Despite the previous gamification studies that explain how having concrete goals and tasks can improve individual users' performance, team performance and their collaborative goals and tasks in gamification are still not explored well. Therefore, many existing systems and applications are mainly focused on tracking individual tasks, goals, and performance. Only a few systems were developed to support and measure the collaborative performance of teams. Still, they function as a discipline-specific learning tool that helps obtain one type of domain knowledge (e.g., nursing), rather than support collaborative workflow as one cohesive team (e.g., the preoperative task of prepping patients, team communication skills). In line with previous gamification studies, in Stage 2, the coaching tool is designed to interact with new trainees to have visual feedback selectively based on their learning process (i.e., hovering the mouse over equipment in the interactive OR room shows them the order and steps of the related tasks). Also, the visual diagram (e.g., padding, posture) was implemented in the prototype to reduce common mistakes by new trainees. The experienced team members pointed out that new trainees could self-rehearse the steps of preoperative tasks through visual diagrams. Such interactivity in the coaching tool can be perceived as fun and game-like, unlike reading texts line by line in a textbook.

Another possible interpretation of the findings is that the coaching tool could work as a virtual platform for role-playing to increase understanding of other team member's roles and responsibilities. When the application can help users to understand and empathize with others' perspectives, such as physical and emotional challenges, via visual simulation of real case scenarios, users are more likely to engage in collaborative behaviors outside of their own discipline (Martín-Hernández et al., 2020). Previous role-

playing studies have discussed the positive influences in a broader context with general surgical settings (Bracq et al., 2019; Challco et al., 2014; Huang et al., 2018; Pons Lelardeux et al., 2017). For example, with the role-playing interface, Pons Lelardeux (2017) showed its beneficial impact on OR team communication. It allows users to explore the different disciplines' points of view through virtual OR. Users familiarize themselves with the perspective of the different disciplines via case scenarios, storytelling, and real-time messengers. Such features virtually simulate the physical and emotional challenges of different disciplines and help users emphasize other discipline's hardships from their perspectives.

In addition to role-playing and gamification of the coaching tool, the positive impacts of the augmented reality experience via Google Glass drew attention and elicited positive feedback from the participants. Previous studies discussed the feasibility of augmented reality glass as a coaching tool for teaching anesthesia procedures in the preoperative phase (Bracq et al., 2019; Calatayud et al., 2010; Gerup et al., 2020; Huang et al., 2018; Tacgin, 2019). For example, Huang (2018) showed how different types of line induction can be taught via an ego-centric point of view by projecting interactive video on AR glasses. The results indicate that the ego-centric display of the steps and order of the procedure helped the trainees follow the instructions more accurately and internalize the process more quickly. Similarly, in the context of nursing, students showed higher motivation with AR glass experience in learning how to set up instruments in surgical trays. (Bracq et al., 2019; Tacgin, 2019). These studies showed the benefits of AR application in preoperative tasks across different disciplines.

Based on results from the current study, three main design implications are suggested for team coaching tools: 1) Facilitating both individual and shared team workflow to support discipline-specific tasks behind managing collaborative tasks, 2) Supporting restructuring teamwork distribution to optimize team performance, and 3) Cultivating appropriate expectation on other team members' roles and responsibilities to enhance team communication.

CHAPTER 6: DESIGN IMPLICATIONS

6.1 Contents that Understand the complex Interdisciplinary Workflow in Team Collaboration

The findings from this study showed that cOR team members' collaboration during the preoperative phase led to successful management of their workflow across the entire operative phases. Smooth collaboration reduces tension between team members and improves team performance without wasting their time and energy on correcting mistakes and figuring out the confusion. Thus, to facilitate cOR team's effective collaboration during the preoperative phase, it is critical to support each team member's appropriate and effective participation, including those of new trainees.

When people are given tasks and goals that are clear and concrete, they are likely to actively perform them (Locke & Latham, 2002; Lunenburg, 2011). This task and goal setting are one of the frequently used principles in gamification in combination with other application design components, such as feedback, rewards, or badges (Algashami et al., 2019; Fortes Tondello et al., 2018; Jurado et al., 2015; Orwoll et al., 2018). These principles provide useful lenses for future design implications of team-based coaching tools. In particular, previous task and goal-setting studies discussed that team members are more eager to work toward goals when group goals are set along with their own individual goals (Lunenburg, 2011). They also pointed out that when individual goals are aligned with their group goals, they are more likely to stay motivated to achieve the group goals (Vegt et al., 2015). In other words, when team members perceive that other team members also share similar goals, they are more likely to be motivated to work collaboratively as a group. For example, previous studies have used goal setting with gamification (McAuliffe et al., 2020; Vegt et al., 2015). These studies found that the levels of motivation and collaborative behaviors increased when team members shared collective goals (Vegt et al., 2015). It indicates that a collective goal of a team positively influences each team member's contribution. Also, the study found that status checks through a dashboard about how other team members are doing reinforces one's participation (McAuliffe et al., 2020).

In addition to the importance of supporting shared task goals among team members, one of the critical considerations from Stage 1 and 2 was understanding the

needs and anticipation of other team members. Well-understood needs and anticipation of other team members, which are both invisible and discrepant, drive the efficient workflow of cOR team. According to participants of the current study, the preoperative team workflow of new trainees not only includes time to learn new knowledge, but also time to practice their learned tasks under the experienced team member's guidance. These tasks and needs can be altered and changed per case, and thus experienced team members were expected to remind new trainees of newly added and changed requirements of the case. For experienced team members, new trainees' work time means time for performing their own discipline-specific tasks, spending more such time directly leads to improved patient care. As participants in Stage 2 mentioned, the experienced team members desire to spend more focused time on their own tasks without interruptions (e.g., teaching moments and error corrections caused by new trainees). Despite the dynamically changed needs and anticipation of the preoperative workflow, previous existing OR coaching tools only provide one-dimensional task/goal support, such as a checklist (e.g., preference cards) that only allows review and tracking of typical requirements.

Therefore, to design cOR coaching tools that can engage the team members, it is critical to support team members' individual needs (e.g., discipline-specific) related to the preoperative workflow by providing optimized task guidelines. Based on these findings, coaching tools should offer both sub-goal-setting functions elicited from team member's different needs related to their own discipline (e.g. perfusion, nurse, anesthesiology-specific tasks) as well as ways of showing shared goals as a team (e.g., posture, padding). Supporting both individual and discipline-specific goals would facilitate each team member's engagement in collaborative tasks/goals. For instance, the coaching prototype could support team members who are new to the team by allowing them to rehearse team workflow before entering OR. For example, new trainees from different disciplines can overview shared tasks to add padding to a patient after positioning the patient in an appropriate posture on the surgical bed. On the other hand, new trainees also have their own needs and anticipation related to preoperative tasks because of their discipline-specific workload. A team-based coaching tool should visually show different tasks and

goals that satisfy individual workloads. At the same time, the timing and order to perform collaborative tasks should be indicated as well. For example, the coaching tool can indicate the task status (e.g., current steps, estimated completion time) of each discipline which allows team members to navigate when would be an appropriate time to perform collaborative tasks as a team. With the aid of such a coaching tool, each team member can still safely secure their own time for performing individual tasks at the same time they can effectively communicate their availability for collaborative tasks with other team members.

Goal-setting theory also explains the positive influence of having a clear timeline for each goal and task. In many cases, tasks and goals become more effective when there is a concrete timeline set for its completion. When the timeline is displayed clearly for steps of the tasks, people tend to invest more effort to meet the given timeline, compared with when tasks and goals are given without timely order (Lunenburg, 2011). The current design of the coaching tool prototype used visual cues (e.g., color-coded selectable widgets: gradation of light grey to darker grey to represent the operative timeline) to indicate the timeline of the tasks. Participants in the current study shared positive feedback about how tasks and their steps/orders are learned gradually according to different operative phases. Such visual cues indicate the order of the tasks required for trainees to follow. It also allows trainees to track their progress in performing the task throughout the operation. In this way, trainees can rehearse their tasks with the aid of the coaching tool even if they did not fully memorize its exact steps and orders. For experienced team members, it can be useful to post a note in the timeline to remind the trainees of common mistakes. Communicating new trainees about common mistakes in the coaching tool beforehand can allow the experienced team members to have more time to work on their individual tasks without spending time on correcting trainee's errors during operation.

6.2 Features that Supporting the Restructuring of Preoperative Workflow

Previous studies on the workflow of clinical teams have been limited to one or two disciplines, such as doctors and nurses; however, the current study, the coaching tool prototype, is designed to prompt role-sharing among multidisciplinary team members. In

Stage 2, cOR team members who examined the coaching tool prototype expressed their positive feedback on the capacity to learn the responsibilities and tasks of other disciplines via color-coded equipment and space in its virtual cOR. Because of the self-learning nature of the coaching tool, experienced team members can minimize repetitive teaching moments, such as verbal instructions or corrections to new trainees while performing tasks.

In medical training studies, researchers examined different means to share communication strategies (e.g., checklists, dashboards) (Franklin et al., 2017; Orwoll et al., 2018) and invisible cues (Gillespie et al., 2010) of teamwork. However, the current literature has not yet examined the feasibility of such strategies in the context of multidisciplinary settings, thus future studies can benefit from implementing various strategies of the coaching tool to share invisible communication cues across different disciplines. Its impact on multidisciplinary team workflow should be investigated per strategy. To facilitate different strategies in communication cue sharing, the coaching tool needs to actively update information by reflecting on situations and status changes among team members. In this study, participants were asked to address the types of tasks and responsibilities that they desired to include and share with other team members via coaching. Whereas these investigations did not result in the updated coaching tool design, we found outstanding needs for sharing the timing and order of one's own tasks and responsibilities with team members from other disciplines.

In addition to the need to share the steps and order of one's own task, cOR team attempt to establish timeline and guideline for collaborative tasks. Although all participants who were interviewed for both studies have worked in the current cOR team for more than 2 years, each participant reported that they still experience tension about deciding when and who does what while performing collaborative tasks. The team workflow is often nuanced and easily affected by the team dynamics which is subjected to change depending on the team composition of the day. For example, although a team is composed of all experienced team members, the dynamic is still varied depending on different combinations of team members who have different ways of behaving and

communicating. That said, imagine how one new trainee can alter the entire team's workflow significantly.

Due to dynamically changing team composition, all participants who evaluated the coaching tool prototype suggested they implement a capacity to indicate the timing and order of the collaborative tasks. This implies the need for effective communication about when to collaborate and when to focus on an individual's task. In future studies, the coaching tool should help team members to indicate and notify an appropriate timing to collaborate as well as the appropriate order of the collaborative process rather than merely providing a list of tasks. For example, future design for the coaching tool could include a customizable workflow dashboard for each team member during the preoperative setup. This dashboard allows them to share their tasks via one shared timeline by indicating the timing and order of the tasks they plan to perform. The workflow dashboard thus can effectively collect and display discipline-specific information about when and how tasks should be performed and by whom. The timing and orders of tasks can be edited easily depending on individual team member's needs and shared with the rest of the team. Information should be updated and displayed on one integrated timeline in the dashboard. Such configurability is necessary to timely reflect developing needs and requirements of individual discipline. Such an integrated timeline in configurable dashboard would be effective in visualizing information, which is dynamic, yet often invisible, requiring team members to act upon nuanced cues. Due to its nuanced nature, it often leads to a potential source of team tension if it's not shared correctly. Without creating such tension in the team, the integrated timeline can further suggest an ideal tool to negotiate overlapped timing or processes among team members and also be effective in identifying missed orders or steps. In this way, the coaching tool can provide more visual solutions for the cOR team to leverage team communication and ensure patient safety.

6.3 Technologies for Cultivating Appropriate Anticipation about Each Other's Roles and Responsibilities to Enhance Preoperative Workflow Management

In the current study, results showed that team members desired to understand other team members' workflow better through the coaching tool because it could allow

them to collaborate better on their preoperative tasks without stepping on each other's toes. Team members also shared how they perceived the prototype as an integrated learning platform that could provide role-playing opportunities for their team. When technologies offer role-playing opportunities through scenarios (e.g., emergency, routine case), users are more likely to understand the physical and emotional experiences of others (Pons Lelardeux et al., 2017). For example, one study found that when scenarios are presented through visual and auditory stimuli in a virtual setting through an egocentric view, users are likely to take the situation as their own and try to solve it more proactively (Huang et al., 2018; Pons Lelardeux et al., 2017).

Using those virtual role-playing as strategies, future systems can guide team members in creating effective collaborative workflow by providing learning opportunities about each other's responsibilities. Previous studies discussed using rehearsal application as an important tool to simulate hard-to-recreate scenarios for users to handle such situations better in reality (Bracq et al., 2019; Huang et al., 2018; Pons Lelardeux et al., 2017; Salerno et al., 2018). Salerno (2018) observed that team members in OR are equipped with more effective communication patterns and strategies as a team after rerunning emergency scenarios in the virtual interface by taking roles of other disciplines. Also, the virtual interface providing diverse communication channels for team members, such as forums, messenger, and live audio chats, allows the team to develop and practice communication patterns and strategies without binding them to the custom of their own discipline (Pons Lelardeux et al., 2017). Attempting to solve a problem from new perspectives of other disciplines helped the team members to actively gather information and look for effective ways to share new information with others instead of blindly following the known protocol from their own discipline (Pons Lelardeux et al., 2017).

In this regard, features of technologies that could facilitate realistic role-playing should be implemented in coaching tools, and their effectiveness should be investigated. For instance, while the three-dimensional rendering of the operating room can elicit a realistic experience, the kinetic wearable device can facilitate the user's actual movement in 3D space. Further, coaching tools designed for medical training should consider incorporating auditorial and tactile agents to increase reality in role-playing. Future

studies should investigate the multi-sensory features such as tactile that facilitate realistic role-playing among team members.

In Stage 2, participants perceived the coaching tool prototype as useful for preoperative workflow management. Although participants had previously used other interactive applications, such as computer-based training programs and VR glasses, one participant particularly noted that the coaching tool prototype would fulfill the broader training needs of the team because it could allow comprehensive information to be readily accessible through portable screen devices (e.g., tablet, laptop). Similarly, participants noted that providing new trainees with visualized information made it easier to digest copious amounts of knowledge in a shorter period. This may suggest that, for cOR team with new trainees, team knowledge (e.g., mental model) should be shared by interactive visual reference (e.g., touch/monitor screen) that can be shared by multiple team members simultaneously and help themselves to keep in track of their team workflow while in the midst of individual tasks.

By applying the findings from the current study, these design components also should be used to deliver sensory experiences to users. For example, tactile and kinetic experience or cOR case scenarios can be delivered via wearable devices that play auditory recordings of performing procedures in three-dimensional OR via ego-centric view. In the current study, basic visual components are displayed via the prototype, such as a 180-degree view of cOR and interactive infographics activated by touch/click. As several participants mentioned, it would be necessary to diversify the means of delivering information and the types of supported user interactions. In future studies, broader types of information delivery and user interaction should be explored with the user groups to identify cOR-oriented specific features optimizing team workflow and communication.

CHAPTER 7: LIMITATIONS AND FUTURE WORK

While the current study discusses cOR team experiences with team communication and collaborative work toward the coaching tool prototype, this study has several limitations that future studies should consider. Several limitations are recognized in the study design that led to our stated outcomes. Firstly, this study was completed in a

single academic hospital, and we are unlikely to be able to extrapolate our findings to other institutions because the mechanism of team communication can differ by organizational culture. Furthermore, while we made every effort to target a representative group of team members, we did not speak to every member of the cOR team. Future work will include a multi-institutional effort as well as increasing the number of team members with whom we interview. Finally, the knowledge acquisition and learning process is complex, and while the focus of this research has been on sharing tacit knowledge through a team coaching tool, our findings must be understood within the context of many types of knowledge acquisition. In this section, those limitations and a detailed future study plan are described to expand on the current findings.

7.1 Limitations

As all participants were from one team of cardiac operating rooms at a teaching institution in the midwestern United States, the populations of both Stage 1 and 2 were relatively homogeneous, Caucasians aged between 30 and 50. Participants with varied years of cOR experience were unable to be included; all the participants worked in the same department and institution in the same team for at least 2 years. The current study could only capture experienced team members' voices, not those of trainees or new hires. Particularly, the outcomes of Stage 2 were supplementary materials that prompted participants' answers regarding how team members would use and react to the coaching tool prototype. Feedback on the coaching tool from team members with less experience was not collected and identified in the current study. For future phases, it will be necessary to understand how less experienced team members perceive their team communication and what are their required implications for coaching tool design. Given that OR teams in teaching institutions consist of healthcare professionals with varied years of experience, expanding study populations (e.g., trainees, new hires) could help researchers be reflexive regarding the conventional composition of OR teams and their needs. It would be useful to compare groups of participants with varied experience levels, such as proficiency and years of training. Future research should provide more comprehensive design concepts that facilitate team communication and workflow depending on each team's unique compositions and needs.

When designing technologies targeted at multiple team members, one issue to consider is the adverse impact of peer pressure. One of the coaching tool features desired by team members was a dashboard to overview other team members' task status and performance, and this could create unnecessary tension among team members (Algashami et al., 2019; Fodor & Barna, 2020). Studies have shown concerns about the adverse impact that can lead to over-competition or negative emotions among the team members with less participation or progress (e.g., shame, guilt) (Algashami et al., 2019; Fodor & Barna, 2020). Each team member's reactions, especially concerns around team tension possibly occurring in adopting a new tool, should be taken into account in designing future studies.

Another limitation of the current study is the possibility of the novelty effect, initial positive reactions about the coaching tool can wear off over time (Koch, von Luck, Schwarzer, & Draheim, 2018). Such a well-known impact in user study makes it difficult to determine whether the participants' positive appraisal of the prototypes was primarily due to the prototypes' benefits, or simply to the novelty effect (Zhang et al., 2018). For example, studies showed that in a couple of weeks, application usage declined (Woringer et al., 2019; Zhang et al., 2018). Ultimately, many users do not continue their regular use of smartphone applications (Stallard et al., 2016). To properly understand its usage, user interaction with the application should be studied for more than a couple of weeks. The long-term study should investigate how users adopt new applications and abandon them (Stallard et al., 2016). For future studies, it is crucial to build working prototypes and put them to use in the cOR setting for at least 12 weeks.

Furthermore, as the main purpose of Stage 2 was to understand the acceptability and feasibility of the coaching tool in terms of team communication and workflow support, the results presented in this paper were acquired using a low-fidelity prototype rather than a working prototype. Thus, participants' actual interactions around the prototype were not identified. The study results were based on participants' impressions and feedback about what would work and would not work as well as their ideas about improvement. For instance, although participants mentioned the positive influences that the coaching tool may have on team communication, the correlation with its efficacy was

not examined. In future phases, the objective measurements for team communication and performance should be included to evaluate the effectiveness and usefulness of the working prototype of the coaching tool.

7.2 Future work

In the future phase, more numbers of cOR team members for co-design and follow-up interviews should be included to elucidate the input of users, particularly trainees or new hires, whose insights will assist in the design of team-centered coaching tool technologies. Also, the co-design process would include scenario-based activities with users to draw out more concrete ideas from them during the working prototype design phase.

Stage 1 and 2 revealed team members' positive perceptions towards the functions of the coaching tools, such as integrated timeline, dashboard, role-playing capacity, and gamification. During the next phase of the co-design process, team members will be provided with a participatory paperback prototype made from the magnetic board, inviting them to rearrange features and contents based on their preferences. During the follow-up interviews, team members will be asked about their reasoning behind the newly arranged layout and design. Recurring design requirements across the team members will be transferred to design input for the working prototype along with the core design concepts identified in the current study (e.g., integrated timeline, dashboard, role-playing).

With the refined outcomes from the co-design phase, a usability study should be conducted on the working prototype to determine the proper length, the number of participants, and the measurement scales for an efficacy study. Given that the usage of many smart applications declines after 12 weeks (Stallard et al., 2016), a refined working product will be tested for at least 12 weeks to observe usage patterns, longevity, and effectiveness. During the study, objective measurements of team communication and performance will be applied to participants (e.g., length of usage, number of errors/interruptions, self-survey, and questionnaires). The outcomes of this phase will be used to determine the details of the further summative study.

CHAPTER 8: CONCLUSION

In this dissertation, two stages of user studies were conducted with team members of cOR. The study showed that team communication is a complex experience entangled with team dynamics between team members that should be understood across disciplines. Previously team communication and team workflow were studied within one or two disciplines where technologies that support team workflow in healthcare settings are considered to be effective if they accurately convey lists of tasks, protocols, or checklists of one discipline. When the team members were interviewed, however, the most salient and critical themes that emerged were communication issues between team members that stemmed from discrepant needs and expectations behind managing collaborative tasks. The participants' experiences showed that effective team communication could only be achieved when team members understand each other's individual workflow and work together based on such a clear shared mental model. This new perspective on effective team communication would expand the design possibilities for team coaching technologies that actively support the team's existing team dynamics and optimize both individual and team workflow and performance. This study provides cOR team with opportunities to reflect on the technology-based strategies of team communication and to improve their team performance as well as their quality of patient care.

REFERENCES

Al Ghofaily, L., Mitchell, J. D., & Woodworth, G. (2018). Anesthesia Residency Training in Cardiac Anesthesia: Development of a Model Curricula and Educational Resources: The Anesthesia Toolbox. *Journal of Cardiothoracic and Vascular Anesthesia*, *32*(2), 621–630. https://doi.org/10.1053/j.jvca.2017.11.040

Algashami, A., Vuillier, L., Alrobai, A., Phalp, K., & Ali, R. (2019). Gamification Risks to Enterprise Teamwork: Taxonomy, Management Strategies and Modalities of Application. *Systems*, *7*(1), Article 1. https://doi.org/10.3390/systems7010009

Ambrosini, V., & Bowman, C. (2001). Tacit Knowledge: Some Suggestions for Operationalization. *Journal of Management Studies*, *38*(6), 811–829. https://doi.org/10.1111/1467-6486.00260

Andrews, M., & Smits, S. (2019). Using Tacit Knowledge Exchanges to Improve Teamwork. *ISM Journal of International Business*, *3*(1). https://www.proquest.com/openview/d0f3d26628e7a647fe1d40274d9faed5/1?pq-origsite=gscholar&cbl=586298

Arora, S., Hull, L., Sevdalis, N., Tierney, T., Nestel, D., Woloshynowych, M., Darzi, A., & Kneebone, R. (2010). Factors compromising safety in surgery: Stressful events in the operating room. *The American Journal of Surgery*, *199*(1), 60–65. https://doi.org/10.1016/j.amjsurg.2009.07.036

Ashoori, M., & Burns, C. (2013). Team Cognitive Work Analysis: Structure and Control Tasks. *Journal of Cognitive Engineering and Decision Making*, *7*(2), 123–140. https://doi.org/10.1177/1555343412445577

Ashoori, M., Burns, C. M., d'Entremont, B., & Momtahan, K. (2014). Using team cognitive work analysis to reveal healthcare team interactions in a birthing unit. *Ergonomics*, *57*(7), 973–986. https://doi.org/10.1080/00140139.2014.909949

Attri, J. P., Sandhu, G. K., Mohan, B., Bala, N., Sandhu, K. S., & Bansal, L. (2015). Conflicts in operating room: Focus on causes and resolution. *Saudi Journal of Anaesthesia*, *9*(4), 457–463. https://doi.org/10.4103/1658-354X.159476

Bennet, D., & Bennet, A. (2008). Engaging tacit knowledge in support of organizational learning. *VINE*, *38*(1), 72–94. https://doi.org/10.1108/03055720810870905

Blindheim, J., Wulvik, A., & Steinert, M. (2016). USING SECONDARY VIDEO MATERIAL FOR USER OBSERVATION IN THE NEEDFINDING PROCESS FOR NEW PRODUCT DEVELOPMENT AND DESIGN. *DS 84: Proceedings of the DESIGN 2016 14th International Design Conference*, 1845–1854.

Blondon, K. S., Chan, K. C. G., Muller-Juge, V., Cullati, S., Hudelson, P., Maître, F., Vu, N. V., Savoldelli, G. L., & Nendaz, M. R. (2017). A concordance-based study to assess doctors' and nurses' mental models in Internal Medicine. *PLOS ONE*, *12*(8), e0182608. https://doi.org/10.1371/journal.pone.0182608

Bonn, J., Mulkey, D., & Goers, J. (2022). Using Gamification to Engage Clinical Nurses in Quality Improvement. *Journal for Nurses in Professional Development*, 10.1097/NND.0000000000000898. https://doi.org/10.1097/NND.0000000000000898

Boquet, A., Cohen, T., Diljohn, F., Cabrera, J., Reeves, S., & Shappell, S. (2021). A Theoretical Model of Flow Disruptions for the Anesthesia Team During Cardiovascular Surgery. *Journal of Patient Safety*, *17*(6), e534. https://doi.org/10.1097/PTS.0000000000000406

Bracq, M.-S., Michinov, E., & Jannin, P. (2019). Virtual Reality Simulation in Nontechnical Skills Training for Healthcare Professionals: A Systematic Review. *Simulation in Healthcare: The Journal of the Society for Simulation in Healthcare*, *14*(3), 188–194. https://doi.org/10.1097/SIH.0000000000000347

Brown, E. K. H., Harder, K. A., Apostolidou, I., Wahr, J. A., Shook, D. C., Farivar, R. S., Perry, T. E., & Konia, M. R. (2017). Identifying Variability in Mental Models Within and Between Disciplines Caring for the Cardiac Surgical Patient. *Anesthesia & Analgesia*, *125*(1), 29–37. https://doi.org/10.1213/ANE.0000000000002087

Calatayud, D., Arora, S., Aggarwal, R., Kruglikova, I., Schulze, S., Funch-Jensen, P., & Grantcharov, T. (2010). Warm-up in a Virtual Reality Environment Improves Performance in the Operating Room. *Annals of Surgery*, *251*(6), 1181–1185. https://doi.org/10.1097/SLA.0b013e3181deb630

Challco, G. C., Moreira, D. A., Mizoguchi, R., & Isotani, S. (2014). An Ontology Engineering Approach to Gamify Collaborative Learning Scenarios. In N. Baloian, F. Burstein, H. Ogata, F. Santoro, & G. Zurita (Eds.), *Collaboration and Technology* (pp. 185–198). Springer International Publishing. https://doi.org/10.1007/978-3-319-10166-8_17

Clapper, T. C., & Kong, M. (2012). TeamSTEPPS®: The Patient Safety Tool That Needs to Be Implemented. *Clinical Simulation in Nursing*, *8*(8), e367–e373. https://doi.org/10.1016/j.ecns.2011.03.002

Clark, P. R. (2009). Teamwork: Building Healthier Workplaces and Providing Safer Patient Care. *Critical Care Nursing Quarterly*, *32*(3), 221. https://doi.org/10.1097/CNQ.0b013e3181ab923f

Cohen, T. N., Cabrera, J. S., Sisk, O. D., Welsh, K. L., Abernathy, J. H., Reeves, S. T., Wiegmann, D. A., Shappell, S. A., & Boquet, A. J. (2016). Identifying workflow disruptions in the cardiovascular operating room. *Anaesthesia*, *71*(8), 948–954. https://doi.org/10.1111/anae.13521

Cumin, D., Boyd, M. J., Webster, C. S., & Weller, J. M. (2013). A Systematic Review of Simulation for Multidisciplinary Team Training in Operating Rooms. *Simulation in Healthcare: The Journal of the Society for Simulation in Healthcare*, *8*(3), 171–179. https://doi.org/10.1097/SIH.0b013e31827e2f4c

Cvetic, E. (2011). Communication in the Perioperative Setting. *AORN Journal*, *94*(3), 261–270. https://doi.org/10.1016/j.aorn.2011.01.017

Dadashi, N., Wilson, J. R., Sharples, S., & Golightly, D. (2010). Cognitive Work Analysis practicality and limitations in complex control systems: A case of alarm handling. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *11*.

de Sousa Borges, S., Durelli, V. H. S., Reis, H. M., & Isotani, S. (2014). A systematic mapping on gamification applied to education. *Proceedings of the 29th Annual ACM Symposium on Applied Computing*, 216–222. https://doi.org/10.1145/2554850.2554956

Dias, R. D., Riley, W., Shann, K., Likosky, D. S., Fitzgerald, D., & Yule, S. (2021). A tool to assess nontechnical skills of perfusionists in the cardiac operating room.

The Journal of Thoracic and Cardiovascular Surgery. https://doi.org/10.1016/j.jtcvs.2021.06.052

Dias, R. D., Zenati, M. A., Conboy, H. M., Clarke, L. A., Osterweil, L. J., Avrunin, G. S., & Yule, S. J. (2021). Dissecting Cardiac Surgery. *Annals of Surgery*, *274*(2), e181–e186. https://doi.org/10.1097/SLA.0000000000003489

Eraut, M. (2000). Non-formal learning and tacit knowledge in professional work. *British Journal of Educational Psychology*, *70*(1), 113–136. https://doi.org/10.1348/000709900158001

Fidel, R., & Pejtersen, A. M. (2004). From Information Behaviour Research to the Design of Information Systems: The Cognitive Work Analysis Framework. *Information Research: An International Electronic Journal*, *10*(1). https://eric.ed.gov/?id=EJ1082064

Fleetwood, V. A., Veenstra, B., Wojtowicz, A., Kerchberger, J., & Velasco, J. (2018). Communication through simulation: Developing a curriculum to teach interpersonal skills. *Surgery*, *164*(4), 802–809. https://doi.org/10.1016/j.surg.2018.05.037

Fodor, S., & Barna, B. (2020). An empirical study on factors affecting user engagement in a gamified team building environment. *International Journal of Serious Games*, *7*, 81–95. https://doi.org/10.17083/ijsg.v7i3.355

Forse, R. A., Bramble, J. D., & McQuillan, R. (2011). Team training can improve operating room performance. *Surgery*, *150*(4), 771–778. https://doi.org/10.1016/j.surg.2011.07.076

Fortes Tondello, G., Premsukh, H., & Nacke, L. (2018, January 3). *A Theory of Gamification Principles Through Goal-Setting Theory*. https://doi.org/10.24251/HICSS.2018.140

Franklin, A., Gantela, S., Shifarraw, S., Johnson, T. R., Robinson, D. J., King, B. R., Mehta, A. M., Maddow, C. L., Hoot, N. R., Nguyen, V., Rubio, A., Zhang, J., & Okafor, N. G. (2017). Dashboard visualizations: Supporting real-time throughput decision-making. *Journal of Biomedical Informatics*, *71*, 211–221. https://doi.org/10.1016/j.jbi.2017.05.024

Gerup, J., Soerensen, C. B., & Dieckmann, P. (2020). Augmented reality and mixed reality for healthcare education beyond surgery: An integrative review. *International Journal of Medical Education*, *11*, 1–18. https://doi.org/10.5116/ijme.5e01.eb1a

Gillespie, B. M., Chaboyer, W., Longbottom, P., & Wallis, M. (2010). The impact of organisational and individual factors on team communication in surgery: A qualitative study. *International Journal of Nursing Studies*, *47*(6), 732–741. https://doi.org/10.1016/j.ijnurstu.2009.11.001

Gurses, A. P., Kim, G., Martinez, E. A., Marsteller, J., Bauer, L., Lubomski, L. H., Pronovost, P. J., & Thompson, D. (2012). Identifying and categorising patient safety hazards in cardiovascular operating rooms using an interdisciplinary approach: A multisite study. *BMJ Quality & Safety*, *21*(10), 810–818. https://doi.org/10.1136/bmjqs-2011-000625

Haig, K. M., Sutton, S., & Whittington, J. (2006). SBAR: A Shared Mental Model for Improving Communication Between Clinicians. *The Joint Commission Journal on Quality and Patient Safety*, *32*(3), 167–175. https://doi.org/10.1016/S1553-7250(06)32022-3

Hayashibe, M., Suzuki, N., Hashizume, M., Kakeji, Y., Konishi, K., Suzuki, S., & Hattori, A. (2005). Preoperative planning system for surgical robotics setup with kinematics and haptics. *The International Journal of Medical Robotics and Computer Assisted Surgery*, *1*(2), 76–85. https://doi.org/10.1002/rcs.18

Hensley, N. B., Grant, M. C., Cho, B. C., Suffredini, G., & Abernathy, J. A. (2021). How Do We Use Dashboards to Enhance Quality in Cardiac Anesthesia? *Journal of Cardiothoracic and Vascular Anesthesia*, *35*(10), 2969–2976. https://doi.org/10.1053/j.jvca.2021.04.034

Hoonakker, P., Carayon, P., Douglas, S., Schultz, K., Walker, J., & Wetterneck, T. B. (2011). Communication in the ICU and the Relation with Quality of Care and Patient Safety from a Nurse Perspective. *Int J Healthc Inf Syst Inform*, *1*(6), 1.

Huang, C. Y., Thomas, J. B., Alismail, A., Cohen, A., Almutairi, W., Daher, N. S., Terry, M. H., & Tan, L. D. (2018). The use of augmented reality glasses in central line

simulation: “See one, simulate many, do one competently, and teach everyone.” *Advances in Medical Education and Practice*, *9*, 357–363. https://doi.org/10.2147/AMEP.S160704

Hull, L., Arora, S., Kassab, E., Kneebone, R., & Sevdalis, N. (2011). Assessment of stress and teamwork in the operating room: An exploratory study. *The American Journal of Surgery*, *201*(1), 24–30. https://doi.org/10.1016/j.amjsurg.2010.07.039

Isotani, S., & Mizoguchi, R. (2007). Deployment of Ontologies for an Effective Design of Collaborative Learning Scenarios. In J. M. Haake, S. F. Ochoa, & A. Cechich (Eds.), *Groupware: Design, Implementation, and Use* (pp. 223–238). Springer. https://doi.org/10.1007/978-3-540-74812-0_17

Jurado, J. L., Fernandez, A., & Collazos, C. A. (2015). Applying gamification in the context of knowledge management. *Proceedings of the 15th International Conference on Knowledge Technologies and Data-Driven Business*, 1–4. https://doi.org/10.1145/2809563.2809606

Korndorffer, J. R., Arora, S., Sevdalis, N., Paige, J., McClusky, D. A., Stefanidis, D., & PEGASUS Research Group. (2013). The American College of Surgeons/Association of Program Directors in Surgery National Skills Curriculum: Adoption rate, challenges and strategies for effective implementation into surgical residency programs. *Surgery*, *154*(1), 13–20. https://doi.org/10.1016/j.surg.2013.04.061

Kothari, A. R., Bickford, J. J., Edwards, N., Dobbins, M. J., & Meyer, M. (2011). Uncovering Tacit Knowledge: A Pilot Study to Broaden the Concept of Knowledge in Knowledge Translation. *BMC Health Services Research*, *11*, 198. https://doi.org/10.1186/1472-6963-11-198

Leonard, D., & Sensiper, S. (1998). The Role of Tacit Knowledge in Group Innovation. *California Management Review*, *40*(3), 112–132. https://doi.org/10.2307/41165946

Lintern, G. (2009). *Cognitive Work Analysis*.

Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist*, *57*, 705–717. https://doi.org/10.1037/0003-066X.57.9.705

Lowe, D. J., Ireland, A. J., Ross, A., & Ker, J. (2016). Exploring situational awareness in emergency medicine: Developing a shared mental model to enhance training and assessment. *Postgraduate Medical Journal*, *92*(1093), 653–658. https://doi.org/10.1136/postgradmedj-2015-133772

Lunenburg, F. C. (2011). *Goal-Setting Theory of Motivation*.

Martín-Hernández, P., Gil-Lacruz, A. I., Gil-Lacruz, M., Tesán, A. C. T., & Beteta, J. L. A. (2020). WORKING AND FEELING AS A TEAM USING GAMIFICATION AMONGST UNIVERSITY STUDENTS. *EDULEARN20 Proceedings*, 1729–1735. https://doi.org/10.21125/edulearn.2020.0552

Mason, M. (2010). Sample Size and Saturation in PhD Studies Using Qualitative Interviews. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *11*(3). https://doi.org/10.17169/fqs-11.3.1428

McAuliffe, J. C., McAuliffe, R. H., Romero-Velez, G., Statter, M., Melvin, W. S., & Muscarella, P. (2020). Feasibility and efficacy of gamification in general surgery residency: Preliminary outcomes of residency teams. *The American Journal of Surgery*, *219*(2), 283–288. https://doi.org/10.1016/j.amjsurg.2019.10.051

McConaughey, E. (2008). Crew Resource Management in Healthcare: The Evolution of Teamwork Training and MedTeams®. *Journal of Perinatal & Neonatal Nursing*, *22*(2), 96–104. https://doi.org/10.1097/01.JPN.0000319095.59673.6c

McKeown, S., Krause, C., Shergill, M., Siu, A., & Sweet, D. (2016). Gamification as a strategy to engage and motivate clinicians to improve care. *Healthcare Management Forum*, *29*(2), 67–73. https://doi.org/10.1177/0840470415626528

Morey, J. C., Simon, R., Jay, G. D., Wears, R. L., Salisbury, M., Dukes, K. A., & Berns, S. D. (2002). Error Reduction and Performance Improvement in the Emergency Department through Formal Teamwork Training: Evaluation Results of the MedTeams Project. *Health Services Research*, *37*(6), 1553–1581. https://doi.org/10.1111/1475-6773.01104

Nonaka, I. (1998). The Knowledge-Creating Company. In *The Economic Impact of Knowledge* (pp. 175–187). Elsevier. https://doi.org/10.1016/B978-0-7506-7009-8.50016-1

Orwoll, B., Diane, S., Henry, D., Tsang, L., Chu, K., Meer, C., Hartman, K., & Roy-Burman, A. (2018). Gamification and Microlearning for Engagement With Quality Improvement (GAMEQI): A Bundled Digital Intervention for the Prevention of Central Line–Associated Bloodstream Infection. *American Journal of Medical Quality*, *33*(1), 21–29. https://doi.org/10.1177/1062860617706542

Paige, J., Garbee, D., Bonanno, L., & Kerdolff, K. (2021). Qualitative Analysis of Effective Teamwork in the Operating Room (OR). *Journal of Surgical Education*, *78*(3), 967–979. https://doi.org/10.1016/j.jsurg.2020.09.019

Paige, J. T., Garbee, D. D., Kozmenko, V., Yu, Q., Kozmenko, L., Yang, T., Bonanno, L., & Swartz, W. (2014). Getting a Head Start: High-Fidelity, Simulation-Based Operating Room Team Training of Interprofessional Students. *Journal of the American College of Surgeons*, *218*(1), 140–149. https://doi.org/10.1016/j.jamcollsurg.2013.09.006

Palmer, G., Abernathy III, J. H., Swinton, G., Allison, D., Greenstein, J., Shappell, S., & Reeves, S. T. (2013). *Realizing Improved Patient Care through Human-centered Operating Room Design | Anesthesiology | American Society of Anesthesiologists*. https://pubs.asahq.org/anesthesiology/article/119/5/1066/13663/Realizing-Improved-Patient-Care-through-Human

Pantofaru, C., & Takayama, L. (2011). Need finding: A tool for directing robotics research and development. In *RSS 2011 Workshop on perspectives and contributions to robotics from the human sciences*.

Parush, A., Kramer, C., Foster-Hunt, T., Momtahan, K., Hunter, A., & Sohmer, B. (2011). Communication and team situation awareness in the OR: Implications for augmentative information display. *Journal of Biomedical Informatics*, *44*(3), 477–485. https://doi.org/10.1016/j.jbi.2010.04.002

Patnaik, D., & Becker, R. (1999). Needfinding: The Why and How of Uncovering People's Needs. *Design Management Journal (Former Series)*, *10*(2), 37–43. https://doi.org/10.1111/j.1948-7169.1999.tb00250.x

Perry, T. L. M., & Fortuno, T. M. M. B. S. (2021). Effective Collaboration Towards Positive Perioperative Outcomes for the Cardiac Surgery Patient in the Preoperative Phase of Care. *Journal of PeriAnesthesia Nursing*, *36*(4), e15–e16. https://doi.org/10.1016/j.jopan.2021.06.049

Polanyi, M. (1962). Tacit Knowing: Its Bearing on Some Problems of Philosophy. *Reviews of Modern Physics*, *34*(4), 601–616. https://doi.org/10.1103/RevModPhys.34.601

Pons Lelardeux, C., Panzoli, D., Lubrano, V., Minville, V., Lagarrigue, P., & Jessel, J.-P. (2017). Communication system and team situation awareness in a multiplayer real-time learning environment: Application to a virtual operating room. *The Visual Computer*, *33*(4), 489–515. https://doi.org/10.1007/s00371-016-1280-6

Salas, E., Wilson, K. A., Murphy, C. E., King, H., & Salisbury, M. (2008). Communicating, coordinating, and cooperating when lives depend on it: tips for teamwork. *The Joint Commission Journal on Quality and Patient Safety*, *34*(6), 333-341.

Salenger, R., Morton-Bailey, V., Grant, M., Gregory, A., Williams, J. B., & Engelman, D. T. (2020). Cardiac Enhanced Recovery After Surgery: A Guide to Team Building and Successful Implementation. *Seminars in Thoracic and Cardiovascular Surgery*, *32*(2), 187–196. https://doi.org/10.1053/j.semtcvs.2020.02.029

Salerno, N., Dimitrios Papanagnou, M. D., Mahesh, P., Bowers, K. M., Pasichow, S. H., Paradise, S., & Zhang, X. C. (2018). Challenging Hazards Amidst Observational Simulation in the Emergency Department: Advancing Gamification in Simulation Education Through a Novel Resident-led Skills Competition. *Department of Emergency Medicine Faculty Papers*, *10*(11), 3563.

Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., Burroughs, H., & Jinks, C. (2018). Saturation in qualitative research: Exploring its

conceptualization and operationalization. *Quality & Quantity*, *52*(4), 1893–1907. https://doi.org/10.1007/s11135-017-0574-8

Schaffhausen, C. R., & Kowalewski, T. M. (2015). Large-Scale Needfinding: Methods of Increasing User-Generated Needs From Large Populations. *Journal of Mechanical Design*, *137*(7). https://doi.org/10.1115/1.4030161

Schultz, K., Carayon, P., Hundt, A. S., & Springman, S. R. (2005, September). Patient care process and information flow in outpatient surgery. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 49, No. 16, pp. 1469-1474). Sage CA: Los Angeles, CA: SAGE Publications.

Siu, J., Maran, N., & Paterson-Brown, S. (2016). Observation of behavioural markers of non-technical skills in the operating room and their relationship to intra-operative incidents. *The Surgeon*, *14*(3), 119–128. https://doi.org/10.1016/j.surge.2014.06.005

Sobol, M. G., & Lei, D. (1994). Environment, manufacturing technology, and embedded knowledge. *International Journal of Human Factors in Manufacturing*, *4*(2), 167–189. https://doi.org/10.1002/hfm.4530040205

Sonoda, Y., Onozuka, D., & Hagihara, A. (n.d.). *Factors related to teamwork performance and stress of operating room nurses—Sonoda—2018—Journal of Nursing Management—Wiley Online Library*. Retrieved October 4, 2021, from https://onlinelibrary.wiley.com/doi/abs/10.1111/jonm.12522?casa_token=nDOk62iYm70AAAAA:874QVlB5nsUw4N0OGCS-3AeVjr9WXcHAOLU-hXece8fgJuoDI5yyymRHwN07nZdPRUc01TrPaYIetg

Stallard, P., Porter, J., & Grist, R. (2016). Safety, Acceptability, and Use of a Smartphone App, BlueIce, for Young People Who Self-Harm: Protocol for an Open Phase I Trial. *JMIR Research Protocols*, *5*(4), e217. https://doi.org/10.2196/resprot.6525

Tacgin, Z. (2019). From storyboard to practice: My virtual operating room. *Fusion Journal*, *16*, 36–49. https://doi.org/10.3316/informit.032943111810950

Tørring, B., Gittell, J. H., Laursen, M., Rasmussen, B. S., & Sørensen, E. E. (2019). Communication and relationship dynamics in surgical teams in the operating

room: An ethnographic study. *BMC Health Services Research*, *19*(1), 528. https://doi.org/10.1186/s12913-019-4362-0

Umoren, R. A., Poore, J. A., Sweigart, L., Rybas, N., Gossett, E., Johnson, M., Allen, M., Scott, P. J., Truman, B., & Das, R. (2017). TeamSTEPPS Virtual Teams: Interactive Virtual Team Training and Practice for Health Professional Learners. *Creative Nursing*, *23*(3), 184–191. https://doi.org/10.1891/1078-4535.23.3.184

Vegt, N., Visch, V., de Ridder, H., & Vermeeren, A. (2015). Designing Gamification to Guide Competitive and Cooperative Behavior in Teamwork. In T. Reiners & L. C. Wood (Eds.), *Gamification in Education and Business* (pp. 513–533). Springer International Publishing. https://doi.org/10.1007/978-3-319-10208-5_26

Wachs, J. E. (2005). Building the Occupational Health Team: Keys to Successful Interdisciplinary Collaboration. *AAOHN Journal*, *53*(4), 166–171. https://doi.org/10.1177/216507990505300406

Wagner, R. K., & Sternberg, R. J. (n.d.). Tacit knowledge in managerial success. *JOURNAL OF BUSINESS AND PSYCHOLOGY*, 12.

Wahr, J. A., Prager, R. L., Abernathy, J. h., Martinez, E. A., Salas, E., Seifert, P. C., Groom, R. C., Spiess, B. D., Searles, B. E., Sundt, T. M., Sanchez, J. A., Shappell, S. A., Culig, M. H., Lazzara, E. H., Fitzgerald, D. C., Thourani, V. H., Eghtesady, P., Ikonomidis, J. S., England, M. R., … Nussmeier, N. A. (2013). Patient Safety in the Cardiac Operating Room: Human Factors and Teamwork. *Circulation*, *128*(10), 1139–1169. https://doi.org/10.1161/CIR.0b013e3182a38efa

Wheelock, A., Suliman, A., Wharton, R., Babu, E. D., Hull, L., Vincent, C., Sevdalis, N., & Arora, S. (2015). The Impact of Operating Room Distractions on Stress, Workload, and Teamwork. *Annals of Surgery*, *261*(6), 1079–1084. https://doi.org/10.1097/SLA.0000000000001051

Williams, M., & Moser, T. (2019). The Art of Coding and Thematic Exploration in Qualitative Research. *International Management Review*, *15*(1), 45–72.

Winter, S. G., & Nelson, R. R. (1982). *An Evolutionary Theory of Economic Change* (SSRN Scholarly Paper ID 1496211). Social Science Research Network. https://papers.ssrn.com/abstract=1496211

Woringer, M., Dharmayat, K. I., Greenfield, G., Bottle, A., & Ray, K. K. (2019). American Heart Association's Cholesterol CarePlan as a Smartphone-Delivered Web App for Patients Prescribed Cholesterol-Lowering Medication: Protocol for an Observational Feasibility Study. *JMIR Research Protocols*, *8*(1), e9017. https://doi.org/10.2196/resprot.9017

Zhang, M., Ying, J., Amron, S. B., Mahreen, Z., Song, G., Fung, D. S., & Smith, H. (2018). A Smartphone Attention Bias Intervention for Individuals With Addictive Disorders: Protocol for a Feasibility Study. *JMIR Research Protocols*, *7*(11), e11822. https://doi.org/10.2196/11822

APPENDIX A
Stage 1 Interview Questions

1. Introduction (3 mins)

2. General Question (5 mins)
    a. Could you describe your roles and responsibilities in the OR?

    b. What equipment do you interact with the most?

3. Journey Map Tool (10-15 mins)
    a. What is the process?
    b. Who/what do you interact with the most during the process?
        i. Person
        ii. equipment
    c. How do you interact with them?
4. Problems (10-15 mins)
    a. What are the main equipment issues, and how do you troubleshoot them?

    b. What are the main communication issues, and how do you troubleshoot them? (Mishearing teammate, misinterpreting teammate's questions, lack of communication altogether, too much communication?

    c. What are the most common causes of interruptions to your work (e.g., phone calls, pages, nonessential personnel, spilling/dropping items, teaching moments, outside distractions, shift changes, searching activities, equipment alert)?
        i. Impact
        ii. What types of events seem to interrupt your workflow?

d. Could you share some of the stressful event(s) you have experienced in the OR?

5. What if (10 mins)
    a. Process
    b. Equipment
    c. Communication
    d.
6. What is the most ideal OR best communication if there are no limits?

General

Could you describe your roles and responsibilities in the OR?

Could you briefly explain the roles and responsibilities of your teammates in the OR?

Could you share some of the stressful event(s) you have experienced in the OR?

Equipment

What equipment do you interact with the most?

Would different equipment be used by different phases of surgery? used before, during, and after surgery?

How do you troubleshoot when equipment causes issues?

What improvements would you like to see in the frequently used equipment?

Process

What is the process of setting up the equipment?

- What are the difficulties?
- How would you improve the process?

What is the process of monitoring, analyzing, and reporting a patient's status?

Layout

Could you share your thoughts about the physical layout of the OR?

What improvements would you like to see in the OR layout?

Interruptions

What are the most common causes of interruptions to your work (e.g., phone calls, pages, nonessential personnel, spilling/dropping items, teaching moments, outside distractions, shift changes, searching activities, equipment alerts)?

What is the impact of these interruptions on your performance?

What types of events seem to interrupt your workflow?

- Which interruptions are most severe?
- What is the impact?

What action would you take to reduce these interruptions?

What types of events seem to interrupt the surgeon's workflow?

- Which interruptions are most severe?
- What is the impact?

Communication

Which stakeholders do you communicate with the most?

Could you share the types of communication issues have you experienced with the team miscommunication such as Mishearing teammate, misinterpreting teammate's questions, lack of communication altogether, and too much communication?

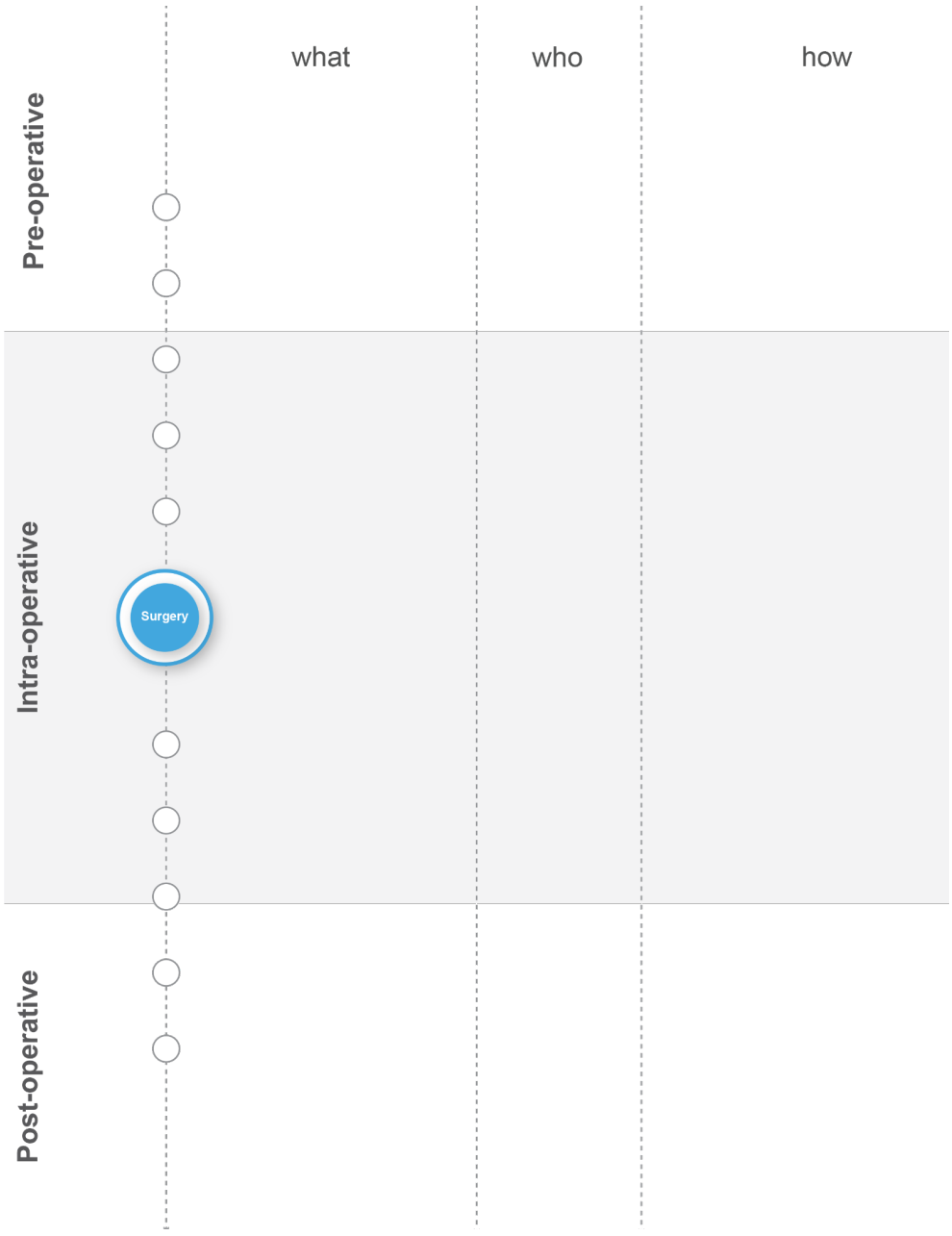
What types of communication issues cause interruptions?

What types of communication issues are most severe?

What could be done to minimize communication issues?

Do you experience any communication issues outside of your team?

APPENDIX B
Journey map template



APPENDIX C
Stage 2 Interview Questions

Content related questions

1. What other setup processes would you like to include in the coaching tools?

2. Could you list the processes most confused by new or circulating staff?

3. What processes are difficult to collaborate with new/circulating staff?

4. What are the processes that require teaching moments frequently?

Feature related questions:

1. Could you think of any other features/functions that could help new/circulating staff get familiar with cOR setup processes?

2. Could you think of additional features/functions to help new/circulating staff collaborate better with cOR team members?

3. Could you think of features/functions to help communication with new staff?

4. Could you think of features/functions that prevent common mistakes during cOR setup?

5. Could you think of features/functions that help share experienced staff's tips and insight?

Overall questions

If you were asked to redesign the prototype, how would you do so?