Serious Games for the Surgical Environment

Addressing Multisensory Communication Modes
for Improved Patient Safety

Submitted By

Caitlin Jordan

Submitted To

OCAD University in partial fulfillment of the requirements for the degree of Master of Design in Inclusive Design

Toronto, Ontario, Canada, April, 2018

Author's Declaration

I hereby declare that I am the sole author of this MRP. This is a true copy of the MRP, including any required final revisions, as accepted by my examiners.

I authorize OCAD University to lend this MRP to other institutions or individuals for the purpose of scholarly research. I understand that my MRP may be made electronically available to the public.

I further authorize OCAD University to reproduce this MRP by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Caitlin Jordan

Abstract

Preventable adverse errors in the operating room account for the third leading cause of death in North America. While process improvements have been made, the larger system of communications and information exchanges amongst surgical team members requires further development. Communication within the operating room must be clearly and efficiently delivered in order to prevent medical errors, mortality or future health complications for the patient. As technical skills are prioritized within the surgical environment, communication is considered a non-technical skill that requires minimal training. Current forms of communication are generally invisible and ambiguous during high-stress situations and can be easily misinterpreted. In order to decrease adverse errors and improve patient safety, the complexities between speech, gaze, touch, gesture and movement must be understood amongst team members must be considered. The design of serious games provides team members with tangible tools for learning and developing strategy for multisensory team communication. These tools ensure the affordances of multisensory communication and information amongst team members can be effectively exchanged during safety-critical events.

Keywords

Multisensory, Cognitive Semiotics, Surgery, Serious Games, Communication, Adverse Errors

Acknowledgments

I would like to acknowledge my brilliant MRP supervisors, Dr. Kate Sellen and Patricia Trbovich, for the incredible support, guidance and expertise provided during this process. It was a pleasure working with, and learning from, you both.

Thank you to Dr. Peter Coppin, not only for the exhilarating introduction to Cognitive Semiotics, but the added opportunity of learning from you over the last two years. You pushed me to be the creator of my own education and curriculum, for which I am eternally grateful.

Thank you to the 2018 INCD cohort (the Saturns) for their unconditional love and support. We started as peers but quickly became a family. I will miss you dearly and hold you in my heart always.

Thank you to Laura Halleran for your genius, jokes and amazing work ethic. You are truly an inspiration to work with and I am beyond thrilled with the prototypes and research we accomplished together this last semester. We communicated! We are resilient!

Most of all, thank you to my beloved partner, Alex. Your strength, support and encouragement push me to be better every day and I could not have done this without you.

To Alex, for your patience and love; To Grace and Roberto, for nourishing my mind and body with food and love; To my friends, for understanding; To my Dad, for always being a phone call away.

Thank you for all your love and support.

Table of Contents

List of Tables

List of Figures and Illustrations

1. Introduction

Surgery is a process of cooperation and teamwork, unfolding through a multitude of tasks in order to ensure success and patient safety. The communication that occurs during a procedure can be both verbal and non-verbal, and while a team with extensive experience in the operating room may prioritize verbal communication during a procedure, subtle and non-verbal communications often readily contribute to the tasks at hand. The surgical environment is an intimate space, with team members standing in close proximity to one another, either side-by-side or face-to-face, with only the patient as a means of separation. Within this context, the controlled environment and positioning of team members ensures meaning can be expressed through body movement, position, proximity and other modes, such as gesture, gaze and touch (Moore, 2011). Particularly during a critical stage of a procedure, non-verbal communication has the ability to transform the outcome. While a team is under extreme duress, the language necessary to communicate with one another is often not sufficient for what needs to be accomplished. Poorly chosen words or misinterpretations can mean the difference between the delivery of a clear communication and an adverse event. The nuances of non-verbal communication have the ability to communicate directly with one, or many, team members simultaneously and therefore require further learning and understanding in the surgical environment.

1.2 Research Question

The challenges in addressing adverse errors in the operating room lie in the varying communications delivered within this environment. As an increased understanding of communication modes and non-technical skills continues to be developed and understood in the field of healthcare, the importance of building upon existing tools becomes increasingly important. How can serious games facilitate knowledge acquisition and learning of communication modes for application in the context of the operating room?

1.3 The Operating Room

For the purposes of this research, the operating room (OR) has been defined broadly in order to encompass general surgery, vascular surgery, laparoscopic surgery, cardiac surgery, neurosurgery and beyond. Surgery is a collaborative activity where individuals trained in varying disciplines work toward a clear goal, performing highly skilled techniques throughout a procedure in order to ensure patient safety. Within this dynamic and changing environment, it is critical that information is continuously shared and clearly delivered in a timely manner (Xiao et al., 2007). As this environment is unpredictable, team members must be responsive in order to prevent miscommunications and to mediate errors.

1.4 Team Members

Team members within the operating room will vary based on the type of surgical procedure being performed and may involve eight to twelve people. Typically, a surgical team will be comprised of three sub-groups of specialties, including surgeons, nurses and anesthesiologists. Within each of the sub-groups, the skill level will vary depending on the years of professional experience of the individual and the position held in the operating room. Each individual present during a procedure has a specific role and performs coordinated team tasks to achieve a common goal. Individual roles further require the acquisition of specialized skills, interdependent work, decision-making and a high cognitive workload (Salas, Cooke, Rosen, 2008). An overview of team member roles and responsibilities can be found in Appendix A: Glossary of Terms.

2. Literature Review

Patient safety has long been a priority within the healthcare industry yet extensive research demonstrates that high rates of incidents continue to occur due to breakdowns in communication (Gawande, Zinner, Studdert, Brennan, 2003; Leonard, Graham, Bonacum, 2004; Sutcliffe, Lewton, Rosenthal, 2004). Such instances can be attributed to medical errors causing between 44,000 – 98,000 deaths in North America each year, resulting in the 3rd leading cause of death and incurring spending losses of US $17 billion to $29 billion dollars

annually (Donaldson, Corrigan, Kohn, 2000; Vicente, 2013; Makary & Daniel, 2016).

2.1 Adverse Errors

Errors are commonplace in the field of healthcare and occur most frequently in the domain of surgical procedures. When errors occur in such high-stress, high-risk environments, concerns are raised, particularly when such instances negatively affect patient outcomes and well-being (Sarker, 2005). Surgical procedures are responsible for more than 47.7% of adverse events in the healthcare system (Strategies, C.R.I.C.O., 2016). The number of adverse events occurring daily in the operating room are roughly 3.0%, with findings that 54% of events are preventable (Thomas, 2001).

Surgical staff are highly trained professionals with years of educational and practical experience. The main motivation of any operating room team is to perform a successful procedure, prioritizing the safety of the patient (Carter, 2003). When adverse errors do occur in this setting, it is not due to poor training or carelessness on behalf of the team. These errors occur due to what are considered softer, non-technical skills, which are not taught or prioritized during medical training. As found by the National CBS Report, of the 7500 surgical procedure malpractice cases analyzed, 26% concerned significant communication failures (Strategies, C.R.I.C.O., 2016). Over 90% of the errors

occur due to verbal communications, with a single communication breakdown found to be the cause (Sarker, 2005). Regardless of team competency and ability, errors continue to be inevitable within this environment). In order for a team to ensure patient safety, non-technical skills must be evaluated in relation to all available modes of communication, including gesture, gaze, sound, touch, body movement and speech and ultimately integrated into training.

2.2 Cognitive Semiotics: A Brief Introduction

Cognitive semiotics can be defined as the study of signs, which are present in everyday life (Van Leeuwen, 2005, Chandler, 2007). Common visual signs include traffic signs, street signs and restaurant signs, but can further encompass words, sounds, images, gestures, body movements and objects (Chandler, 2007). As the field of cognitive semiotics is vast in scope, this analysis is in no way meant to be comprehensive. What is presented is an account of the various communication modes present during surgical procedures, with cognitive semiotics acting as the foundation for understanding multisensory communication.

2.2.1 Multisensory Communication

Communication, in its truest form, is the way in which one person conveys a message to another person, who then perceives it (Norris, 2004). While meaning is conveyed through language, images and texts, additional information can be

conveyed through non-verbal communications, such as posture, gesture, proximity and eye-contact (Moore, 2010). As numerous amounts of sensory information can be perceived rapidly and simultaneously, both the intensity and complexity of a communication exchange, such as the symmetry of the modes in combination, should be assessed. It is therefore important to understand the complexity of interactions between verbal and non-verbal communications and a preliminary understanding of multisensory communication modes is required prior to conducting an analysis of interactions. For the purpose of this project, the multisensory communication modes will be restricted to body movement, gesture, gaze, touch, sound and speech within the context of the operating room. Together, these modes form the basis for a cognitive semiotic system; a system of representation that is neither static nor finite (Norris, 2004). For example, when taking part in a communication exchange, such as a conversation, a number of elements can be observed and assessed; the choice in words, the body language and proximity of one person to another, the length of eye contact or location of the gaze, the sounds heard in the background, the involvement of haptic cues. Each element plays an integral role in the construction of a communication exchange and while humans are intuitively aware of the various modes through which communications can occur, these modes are often taken for granted. Verbal communication and language are considered to be the preferable channels through which meaning and

information are conveyed, with non-verbal communication often considered as supplementary (Kress & Van Leeuwen, 2001; Norris, 2004).

The task of analyzing human movements and non-verbal communications may seem overwhelming, but as these communication modes are restricted to the context of surgical procedures, the taxonomy is not as comprehensive as it may seem. It is important to note that interactions are co-constructed by multiple individuals and are therefore not isolated events. This means that the intentions of one person can be easily misinterpreted by another. Particularly how one person reacts to another, or the level of engagement in a communication exchange. During assessments of communication modes, Norris (2004) notes that analysts should be cautious in assigning meaning to an individual mode. Instead, analysts will take into consideration what has been determined in relation to each communication mode. For instance, a spoken communication can be followed by a head tilt, followed by a change in the posture of the body, followed by a gesture and concluded by another verbal utterance. Thus, communication does not occur through a sole mode, it occurs through a process of interactions and can only be understood in full through an investigation of the different available modes. In order to analyze interactions involving communication, an understanding of how these modes inform one another is required.

Within the context of the operating room, surgical teams indicate levels of engagement with one another through various modes, such as a change in

body position or a slight touch, leading to the completion of a concrete task (Moore, 2011). While the mode of speech is regularly used and evaluated through non-technical skills assessments within this context, such as NOTSS, ANTS and SPLINTS, it is often only one of a number of modes available for use. Other modes are equally relevant to the success of a surgical team yet are not clearly defined, practiced or evaluated in this environment. Many individual modes of communication have been redistributed into different categories related to adverse events, such as situational awareness, teamwork, leadership and decision making. In doing so, an understanding of how individuals and team members can build strategies around communication with one another in this environment remains unclear. Particularly in relation to non-verbal communication, the numerous modes attributed to this area have been approached in a manner which may appear unsystematic in treatment (Moore, 2010). An understanding of multisensory communication is increasingly relevant for a successful procedure and it is important to know how modes of communication are interpreted differently by various surgical specialties and professional roles. If a consistent language and understanding can be developed across surgical professions, the meaning of a communication may cease to be misunderstood or misinterpreted.

2.2.2 Body Movement

Body movements can be described as the ways in which people position the body during an interaction, providing insight to the engagement level of a person (Norris, 2004). The study of body movements looks specifically at form, position and direction in which a person is facing. Body movements can be further evaluated in relation to the bending and straightening of the torso and how the head is raised or lowered (Norris, 2004). These aspects must be considered together and not evaluated individually. It is often assumed that the body being positioned away from an interaction infers disengagement (Dittman, 1987). While this position may signal disengagement in some contexts, it is pertinent that other communicative modes are evaluated before making a final assessment (Norris, 2004). Through observations conducted by Moore (2011), body movements and body alignments have been observed as modes through which meaning is conveyed to other team members in the surgical space. Such observed communications include a change in assumed role and responsibility. Further, the alignment of the body can be presented as a means of negotiating levels of engagement within a specific context. In order to interpret body movements, both the angle and distance must be evaluated. Differences in body movements can be noted depending on the type of surgery being performed, such as laparoscopic surgery or open surgery, the engagement of team members and the level of fatigue during a particular day

(Moore, 2010). During a procedure, the body alignment of team members can infer meaning based on the conditions at hand.

2.2.3 Gesture

Gesture can refer to a movement of the body, or any part of it, and can take many forms, such pointing, hand movements to denote a shape, enactment or modelling items and objects (Kendon, 1997). Kendon (1997) further clarifies gesture in relation to, "actions that are treated as co-participants in interaction as part of what a person meant to say". This includes conventional gestures and gesticulation but does not encompass object manipulation, touch or postures. Gestures have the ability to provide greater meaning or increased specificity to a verbal communication (Muller, 1994 & Kendon, 1997). This mode of communication can be expressive, physical or silent. These aspects ensure that gestures can be adapted into various types of communication exchange. By using a gesture, a literal or abstract idea can be expressed, and a question can be asked or answered. Within the OR, the use of gesture can be demonstrated through the actions communicated by the scrub nurse. The scrub nurse prepares an instrument and holds it out toward the surgeon. This gesture can be followed by a concise verbal communication, a clear statement of instrument name but the scrub nurse does not need to communicate that the tool is now available for use as this is demonstrated by the gesture of holding the tool in the direction of the surgeon. The combination of modes ensures that the

information which is not able to be expressed through verbal communication can be emphasized through a different mode. While gestures occur regularly, the number of gestures used in combination with speech are increased when team members are in view of one another. In some instances, the speaker may use gestures for the sole purpose of an aid, to assist in the formulation of words and to keep the listener engaged during this process (Kendon, 1997 & Freedman, 1977). In order to better understand the purpose and the function and motivation of a gesture during conversation, instances of gesture in various contexts must be compiled and assessed by surgical team members. During this assessment, teams may gain clarity around the contributions that gestures make during an interaction.

2.2.4 Gaze

Gaze is the means through which an observer gathers information during an interaction and is used most frequently when one person is listening, and the act of glancing is imparted (Argyle, 289). As such, gaze contributes to an overall communication exchange by facilitating turn taking and co-participation during conversations (Goodwin, 1981). If eye contact is not exercised during a communication exchange, the communication is often considered incomplete (Kendon, 1964). It has been understood that eye contact increases between individuals when the topic of discussion is cognitively straightforward and less concerned with personal information. Ultimately, gaze can be used to acquire

additional information during a conversation, particularly through eye contact at the end of a conversation to determine how the communication was received. Further uses of eye contact include: signalling to another individual that a conversation or information exchange can proceed, ending a communication exchange and signalling a communication with a new individual through a side glance (Argyle, 1965).

During a procedure, gaze is used to monitor and assess the state of a task or situation. This is demonstrated through an account of a surgical resident assisting the lead surgeon during a paediatric cardiac procedure. The resident describes how gaze is employed to assess all activities and changes in pace during the procedure, for example, "His gaze moved from chest to monitor, chest to monitor, chest to anaesthesiologist, chest to monitor, chest to Deb [team member], chest to the opening OR door, chest to monitor" (Flin, Youngson, Yule, 2015) . This ensures that the resident is able to be prepared for any sudden changes and have immediate knowledge if an issue arises. The resident further describes how the use of gaze allows the ability to be prepared as an individual and on behalf of the lead surgeon, who is focused on the surgical incision and can therefore observe the environmental surroundings. This level of preparation ensures that issues can be immediately prevented instead of responded to after occurring.

2.2.5 Touch

The act of touch provides the unique ability of ensuring that various properties of an object can be encoded simultaneously, and, as the hand, fingers and palm explore the properties of an object through movement, this active exploration enhances overall understanding (Klatzky & Lederman, 1987 & Keehner, 2010). As the hands have a number of different touchpoints, the ability to gage a shape through haptic interaction does not have an equivalent in any other mode of communication, as touch can be felt at many different points and surfaces across the fingers and palms (Klatzky & Lederman, 1987, 1999). By interacting with an item or holding an object, additional information about the shape can be accessed, including weight, texture, warmth, resistance and size (Keehner, 2010).

In order to identify an anatomical structure during a surgical procedure, team members rely heavily on the act of touch for recognition. As the hand or instrument come into contact anatomical structures, this direct interaction provides increased information, such as the location and function of a muscle or tendon (Keehner, 2010). These haptic cues ensure that a structure can be identified in a quick and accurate manner, even if the touch occurs only briefly, also known as a haptic glace (Klatzky & Lederman, 1987, 1999). The ability to actively explore an anatomical structure through haptic cues provides a greater understanding than that of visual cues alone. The act of "seeing" through touch

has been found to be critical during a surgical procedure, as a surgeon will rely on haptic cues to identify, manipulate and navigate through complex anatomical structures (Keehner, 2010). Often, a structure within the body cannot be moved or rotated in order to gain a visual understanding of all sides. Thus, haptic exploration allows the hands or tools of the team member to rotate around the structure, to explore all sides, visible or otherwise. This can be applied to particular structures with anatomical variability due to soft tissue, such as the thorax, abdomen and pelvis. Surgical teams must be able to quickly identify anatomical structures, understand the relationship between them, determine if abnormalities are present and select the appropriate tool to intervene (Keehner, 2010). As these structures may become deformed or displaced through interaction, touch provides appropriate information that vision alone cannot, ensuring team members have the ability to appropriately determine how the surgery will proceed.

2.2.6 Speech

Speech refers to instances in which language is used as a physiological resource; the ability to engage the vocal apparatus and muscles to construct sound (Saussure, 1974). While the human voice has the ability to produce a large variety of sounds and noises, it is used primarily to produce sounds related to speech (Van Leeuwen, 2005). While language encompasses a system of rules and conventions which can be considered independent of the individual use,

the act of speaking can be referred to as an, 'interact', in which an exchange occurs (Halliday, 1985). An exchange can take the form of receiving a response or giving information. There are four possible 'interacts' in speech:

1) Offering information – statements, agreements, acknowledgements
2) Demanding information – questions, answers, disclaimers
3) Offering goods and services – acceptance, offer, rejection
4) Demanding goods and services – command, undertaking, refusal

Yet the act of speech cannot function individually. Sounds produced in order to construct speech typically come in pairs, and function through an initiation and a response (Van Leeuwen, 2005). To further understand verbal communications, the act of speech can be broken into two categories:

1) exchange structure
2) turn-taking

An exchange requires two or more communication moves while turn-taking is the initiation of the move and the initiation of a response (Van Leeuwen, 2005). If a spoken response is not provided, silence can be interpreted as the move or the follow up. In some instances, silence can prompt a new set of exchanges, where an additional question is asked in order to probe for a response. This is described as, 'eliciting', as the answer to the question asked is already known by the person who asks it (Sinclair and Coulthard, 1981). An example of this form

of exchange can be seen below. The provided context is an appointment between a Doctor and patient:

- Initiating move [Doctor] Whereabouts in your chest?
- Response [Patient] On the heart side here.
- Follow up [Doctor] Yes

This example demonstrates both an exchange and turn-taking as well as a means of eliciting a response (Coulthard and Brazil, 1981).

Based on the contextual constraints presented during surgery, team members will call upon different combinations of communication modes in order to re-evaluate the information provided. As such, various modes will not only compensate for insufficient information, but provide further affordances (Keehner, 2010). Each mode has the ability contribute to a complex mental representation yet when a surgical task or skill can be completed by calling upon multiple modalities simultaneously, the outcome will be stronger (Keehner, 2010). If visual cues cannot be adequately relied upon, as a result of weak or obscured information, then data must be acquired using other modes (Ernst & Banks, 2002 & Keehner, 2010). Examples of how communication modes can be assessed during surgery in order to provide an understanding of a task or procedure are outlined in the following section.

2.2.7 Multiple Modalities in Action

During the exchange presented below, Table 1, an attending surgeon (specialist) and a surgical trainee (registrar) perform a particularly difficult procedure, attempting to extract a large tumour from a narrow region of the pelvis (Moore, 2011). As the procedure progresses, the two team members must alternate between the role of assisting and performing the procedure. While the transcript outlines the verbal communication occurring and demonstrates the frustrations in searching for the appropriate words, the majority of communication that occurs is done so non-verbally, as depicted in Figure 1.

Turn	Speaker	Text
1	Specialist	((to Registrar))1 Is it coming?
2	Registrar	It is– ((equivocal intonation)) hmm. Jackie, I'm just gonna move you in deeper. Grab that. Er ah ((exerting considerable force)) there, just there. Oh how annoying. I can feel it.
3	Specialist	Are your fingers down below it?
4	Registrar	Almost like a suction effect at the moment in the pelvis. My fingers are below it.
5	Specialist	Ok well pull on em hard. Pull up on that band. ((several seconds of no dialogue))
6		Naah, this is . . . ((trails off))
7	Registrar	Nup!
8	Specialist	. . . faffing, isn't it?
9	Registrar	It is faffing.
10	Specialist	Oh that's not the word . . . um . . . its all very stiff in here

Table 1. Text of Surgical Episode (Moore, 2011, pp.926).

Within Figure 1, depicted below, the surgical trainee is outlined in red. The frames have been extracted from the filmed footage of the procedure in question and translated into line drawings in order to protect the identity of the surgical team members (Moore, 2011). The first frame demonstrates the trainee assuming the position of the lead surgeon, based on the positioning of the body and head directly over the surgical opening on the patient. In the second and third frame, the trainee is suddenly upright, with both the body and head aligned towards the other team members in order to verbally communicate.

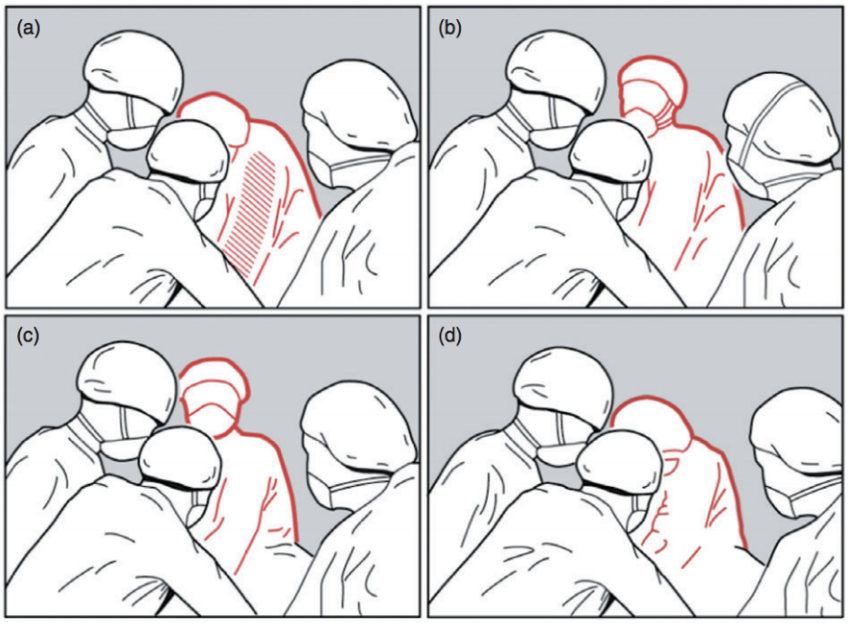

Figure 1. Body alignment constituting a context-holding sequence in surgery (Moore, 2011, pp. 927).

It can be noted in these frames that the trainee continues to anchor the left arm toward the patient and maintaining contact with the body. This gesture and movement indicates to other team members that the trainee is not yet prepared to alternate out of the role of lead surgeon, despite temporarily pausing to communicate through speech. The trainee then returns to the prior position, with head and body positioned over the patient and resumes working, avoiding direct eye contact with all other team members (Moore, 2011). It can also be noted throughout the four frames, that the body alignments of the additional team members do not change, demonstrating that it has been accepted the trainee role will not yet change. Within Figure 2, the trainee continues to be represented by red, with the attending surgeon represented in blue, a medical student represented in green and the scrub nurse represented in black. As the trainee (red) continues to act in the role of lead surgeon, the lead surgeon (blue) can be seen at first close in proximity to the trainee and then slowly, through each frame, distancing the body and head away from the area of focus. Within the third frame, the surgeon faces the trainee with a fixed and direct gaze, signalling that the surgeon has not only disengaged from the role of teacher but is now prepared to assume the role of lead once again.

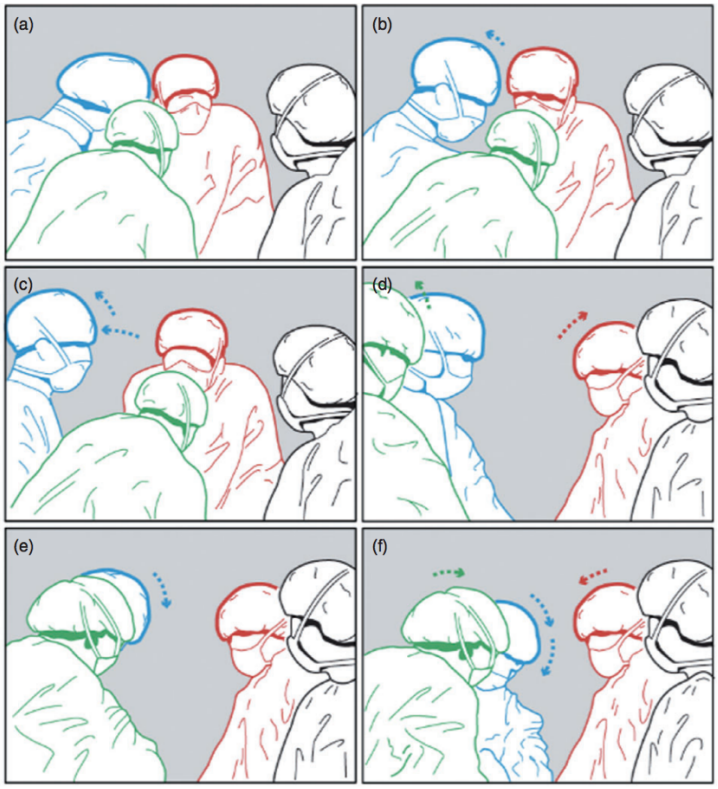

Figure 2. Changes in body alignment constituting a new phase in surgical context (Moore, 2011, pp. 928).

In this instance, gaze is used as a means of contact and communicates that a change in roles is about to occur. This communication is apparent due to the remaining team members positioned around the patient following suit, by not only aligning their bodies with that of the surgeon, but by further disengaging from the joint field of attention, the wound where the registrar is working, and refocusing the gaze towards the surgeon (Moore, 2010). The communication occurs through a sequence of actions, with the surgeon next lowering the head, adjusting body position in order to take over the visual field of attention from the registrar (Moore, 2010). The student correctly interprets the actions of the

surgeon by mirroring the position of the body, head and neck. The student then proceeds to refocus the gaze in the direction of the surgeon, inferring that the change in role has been recognized with procedural assistance focused on them, instead of the trainee (Moore, 2011). These communications occur quickly and are used together in order to strengthen meaning and interpretation. While the positioning of the student (green) and the scrub nurse (black) remain unchanged throughout the first three frames, the positioning changes abruptly in the fourth frame, mimicking that of the surgeon (blue). At this point in the procedure, all team members have become disengaged from the area of focus and the surgeon (blue) can be seen moving the head downwards, and assuming the role of lead surgeon once again. The amount of change that has occurred in head positioning is noted through the arrows demonstrated in the respective colours of the roles (Moore, 2011). The benefits of multisensory communication, as depicted in Figure 1 and Figure 2, demonstrate how efficiently a surgical team can work by employing non-verbal communication modes during a procedure. Had the sequences been constructed solely through verbal communication, the team may have faced a higher cognitive workload, by focusing on the listening to the communications and searching for the verbal communications with which to answer.

Further benefits can are depicted in Figure 3, below, as the images demonstrate how body alignments must be considered in relation to the context of the type of surgical procedure being performed. The first frame (A) is

taken from open surgery, with the scrub nurse (black) positioned around the area of focus on the patient. The second frame (B) is of laparoscopic surgery and it can be noted that the area of focus has changed drastically compared to that of the open surgery. Within the laparoscopic setup, the surgeon (blue) and trainee (red) are now positioned directly beside one another, with the scrub nurse (black) on the opposite side of the table. While all personnel maintain focus directly on the surgical incision within open surgery, the laparoscopic procedure shifts the focus of all personnel away from the patient and with all gazes directed on the monitors.

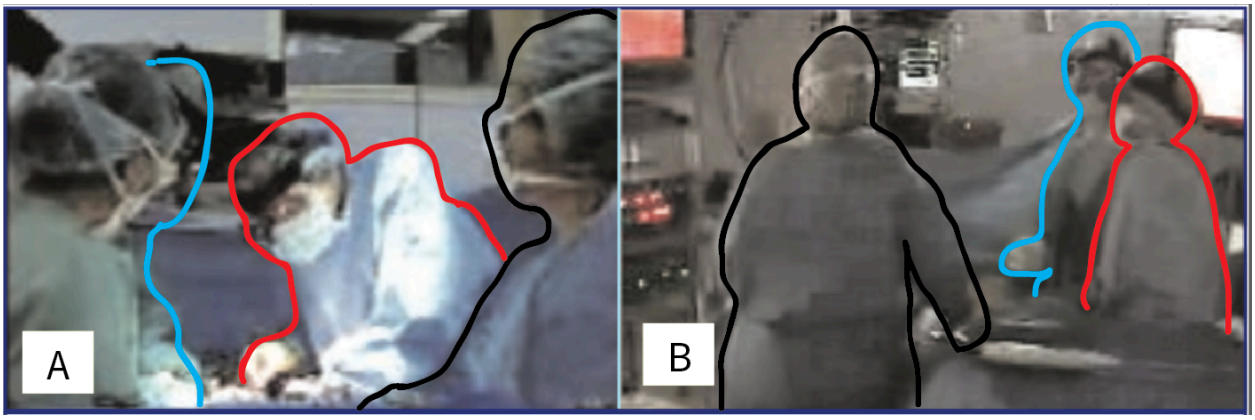

Figure 3. General surgery stance and Laparoscopic surgery stance (Moore, 2010, pp. 31)

Particular attention should be paid to the scrub nurse (black) who maintains an anchoring position with the right arm touching the table, even though the body is turned slightly with the gaze focus away. This is a signal of strong engagement with the procedure and with other team members, also known as the contextual configuration of surgery (Moore, 2010). Such differences in body

position, direction of gaze and placement of personnel within the operating room become critical to the safety of the procedure, especially if these non-verbal communications are misunderstood by team members.

An example of such a miscommunication became apparent during interviews conducted by Moore (2011) with surgical team members. As part of a debrief with surgical staff member, one surgeon described annoyance and discomfort with the lack of engagement on the part of the scrub nurse during the laparoscopic procedure. What emerged during the debrief was a discussion surrounding the two default positions scrub nurses use in relation to open surgery and laparoscopic surgery. The surgeon had not known that different positions were used, based on the type of procedure and had therefore misinterpreted the actions and level of engagement of the scrub nurse. Had this example not been discussed, a tension would have continued between the surgical team members. It was only through the ability of the team to break down the interactions through a debrief session and an analysis of the video footage, that the intentions behind the action were understand and properly interpreted. While this may seem trivial, a misunderstanding of this nature has the potential to produce an adverse event. It has therefore become apparent that no form of communication, whether verbal or non-verbal, is delivered in one, singular form. Instead, communications work together to create a unified action (Moore, 2010).

While surgical teams are aware of the non-verbal and non-technical communications that occur during a surgical procedure, these skills remain difficult to measure and are therefore often neglected or forgotten. As demonstrated by the nuances of the non-verbal communications outlined in Figure 1, Figure 2 and Figure 3, the development of evaluation tools specifically targeting multisensory communication is integral for surgical teams to better understand the complexities and dynamics involved in all forms of communication present within the surgical environment. Not only will a strong understanding of these modes of communications be valuable for identification purposes, it will further provide strategies for how various modes of communication can be integrated into professional practice (Moore, 2011). An environmental scan of existing evaluation tools for non-technical communications in the operating room has been conducted and detailed below.

3. Existing Evaluation Tools for Non-Technical Skills

Team training programs for OR staff have been widely implemented through various forms of guidelines, training manuals and team management strategies (Salas, et al., 1999, 2000, 2008a). Similarly, evaluation tools have been developed for individual assessment through external observations, such as NOTSS and SPLINTS. Each of the aforementioned tools is presented in the form of a checklist and is used to measure individual skills related to teamwork, task

management and decision-making during a procedure. The checklists have been adopted from the NOTECHS behavioural rating system, originating in the field of aviation, and developed for assessing the non-technical skills of pilots (Flin, 2003). Training programs focused on improving surgical team communication have been adapted from human factors principles, as well as existing tools developed for use in the fields of aviation and military services (Hoyert, Kung, Smith, 2005). Particularly within the field of aviation, the introduction of team training programs has seen a notable change to the number of accidents attributed to pilot error. After extensive human factors analysis, communication, coordination and decision-making were deemed responsible for an increase in the number of accidents (Flin, 2003). As pilots had not previously received training in relation to such non-technical skills, programs such as Crew Resource Management (CRM) and Non-Technical Skills for Pilots (NOTECHS) were implemented (Hoyert, Kung, Smith, 2005). The programs have been structured into three phases:

1) Awareness
2) Skills practice and feedback
3) Recurrent Training

By focusing on these phases, aviation teams were able to recognize inconsistencies in communications and build upon new resources for more effective teamwork (Nance, 2004). Due to the success of training programs

targeting non-technical skills in aviation, the framework has been adapted for use in the surgical environment.

3.1 Non-Technical Skills for Surgeons (NOTSS)

Non-Technical Skills for Surgeons (NOTSS) is a competency based training system emerging from the United Kingdom. This development occurred through extensive work with consultant surgeons in the areas of cognitive task analysis, behavioural observations and personal attitudes towards safety (Flin et al., 2006). The previous means of assessing competency in relation to behaviours, values and other non-technical skills was tested through a written examination whereas NOTSS aims to identify the skills that will strengthen patient safety through work-based learning and evaluations. This approach aims to build skills in the realm of cognitive and interpersonal abilities, as well as apply to clinical and surgical situations. The systems further integrates a component of self-reflection into the training, as well as feedback on strengths and weaknesses of performance. Non-technical skills in the realm of surgery are considered to be both cognitive and interpersonal (Flin et al., 2003). Cognitive skills are concerned with areas such as decision making, while interpersonal skills are concerned with teamwork and leadership.

The emergence of this system developed out of a need to addresses the root cause of adverse events. While technical skills are a requirement for completing a procedure, non-technical skills, such as situation awareness,

decision making, teamwork, leadership and communication are typically assumed to be sufficient (Yule et al., 2008). Such non-technical skills have not received the same amount of focus or training as technical skills, therefore, the NOTSS rating system has been developed in order to provide training opportunities and feedback for team members (Flin et al., 2006). A continued awareness and ongoing development of these skills must be further integrated in individual performance.

3.2 NOTSS In Use

NOTSS outlines observable non-technical skills that contribute to a strong surgical practice, based on categorization and a further breakdown of elements through a taxonomy, as listed in Table 2.

Category	Elements
Situation Awareness	• Gathering information • Understanding information • Projecting and anticipating future state
Decision Making	• Considering options • Selecting and communicating option • Implementing and reviewing decisions
Communication and Teamwork	• Exchanging information • Establishing a shared understanding • Co-ordinating team activities
Leadership	• Setting and maintaining standards • Supporting others • Coping with pressure

Table 2. NOTSS Skills Taxonomy (Flin, 2016, pp.3)

The categories and elements are broadly defined in order to cover as many behaviours and skills as possible. A breakdown of strong and weak behaviours attributed to each category are further described in detail in the accompanying NOTSS handbook, with one page dedicated to an overview of communications. The example behaviours act as recommendations and are not meant to be comprehensive, merely acting as a guide for those conducting observations and assessments (Flin et al., 2003).

Hospital ..... **Trainer name** ..... **Date** .....

Trainee name ..... **Operation** .....

Category	Category rating*	Element	Element rating*	Feedback on performance and debriefing notes
Situation Awareness		Gathering information		
		Understanding information		
		Projecting and anticipating future state		
Decision Making		Considering options		
		Selecting and communicating option		
		Implementing and reviewing decisions		
Communication and Teamwork		Exchanging information		
		Establishing a shared understanding		
		Co-ordinating team activities		
Leadership		Setting and maintaining standards		
		Supporting others		
		Coping with pressure		

* **1** Poor; **2** Marginal; **3** Acceptable; **4** Good; **N/A** Not Applicable

1 Poor	Performance endangered or potentially endangered patient safety, serious remediation is required
2 Marginal	Performance indicated cause for concern, considerable improvement is needed
3 Acceptable	Performance was of a satisfactory standard but could be improved
4 Good	Performance was of a consistently high standard, enhancing patient safety; it could be used as a positive example for others
N/A	Not Applicable

Table 3. NOTSS evaluation form (Flin. 2016, pp.13)

The NOTSS system is used by consultant surgeons who assess trainee performance during a surgical procedure. The form outlined below, Table 3, is completed during a period of observation and a debrief occurs with the trainee directly after the procedure has concluded (Flin et al., 2006). In order to conduct NOTSS assessments for surgical team members, consultant surgeons must first become familiar with the NOTSS material and receive training on the process. The consultant surgeon then refers to the evaluation form and rating system in order to provide feedback and a score, as outlined in Table 4, for the team member being reviewed (Flin, 2013).

Rating Label	Description
4 – Good	Performance was of a consistently high standard, enhancing patient safety; it could be used as a positive example for others
3 – Acceptable	Performance was of a satisfactory standard but could be improved
2 – Marginal	Performance indicated cause for concern, considerable improvement is needed
1 – Poor	Performance endangered or potentially endangered patient safety, serious remediation is required
N/A – Not Applicable	Skill was not required or relevant in this case

Table 4 NOTSS System Rating Options (Flin, 2006, pp.12)

3.3 Limitations of NOTSS

NOTSS has seen extensive success in implementation but does face certain limitations, such as time and resource intensive requirements. In order to provide feedback to a trainee, a trained observer must first be selected and receive a formal invitation to conduct surgical observations and a three day period of training ensues (Yule et al., 2009). If an observer with appropriate training cannot be found, one must be trained accordingly using the contents of the system and this person must develop a thorough understanding of NOTSS applications for typical surgical settings. Trainees must further understand the psychometrics involved in rating a performance and spend time practicing observations. Finally, trainees will be subjected to an evaluation process in order to determine if reliable judgements can be made while conducting observations (Flin, 2006).

A further limitation can be found in feedback being provided to a surgical trainee through an external observer. While there are positive aspects to an impartial observer, the observer is assessing only one surgical performance for each trainee. The possibility that the trainee is "performing" for the observation must be factored into the evaluation. Observer insights also differ based on level of training and experience in providing performance feedback to trainees. It has been found that junior level observers are often more harsh in the feedback provided, whereas senior level observers are more forgiving during assessment (Yule et al., 2009). While a debrief does occur between the consultant observer

and trainee immediately after the procedure, there remains a disconnect between the behaviours observed and an understanding of how these behaviours can be improved upon or remedied (Flin, Youngson, Yule, 2015). For example, while the trainee is provided with a list of performance insights and a rating of behaviour, it can be difficult for the trainee to interpret when a communication or behaviour occurred during the procedure as well as the intentions behind it. The trainee must be able to make the connection between the behaviour and the motivating factors in order to make the necessary improvements. Finally, non-technical skills associated with communication can be difficult to observe, as many non-verbal communications can be invisible or difficult to interpret by an observer (Moore, 2011). For example, it is difficult for an observer to assess whether or not the trainee is listening to a team member unless the observer is further evaluating multisensory communications, such as gestures, body movements or gaze. The majority of good and poor behaviours reflected within NOTSS rely specifically on verbal communication exchanges and are not reflective of the nuances involved in surgical communications.

Within the NOTSS handbook, an overview discusses communication, only in relation to teamwork, and focuses primarily on verbal communication, such as clarifications, questions and explanations, without providing recommendations on multisensory modes through which team members may communicate. As minimal information is provided in relation to communication, observers will

focus on assessing verbal communication and may not consider evaluations of other multisensory communication modes necessary.

3.4 SPLINTS

The SPLINTS behavioural rating system was developed in order to evaluate the ways in which scrub nurses are assessed and taught in relation to non-technical skills in the operating room. Within this system, non-technical skills are considered to be, "the cognitive and social skills that compliment technical skills" (Mitchell, 2013). Non-technical skills have been attributed to adverse errors in the operating room, yet are not explicitly or consistently taught in the nursing curriculum. Adverse events are defined within this system as injuries or complications that occur due to issues in patient management as opposed to a issues in patient conditions (Mitchell et al., 2013). The SPLINTS system is similar to the NOTSS evaluation system and focuses on assessing the performance of the individual through the use of a rating system (Mitchell et al., 2012). Within SPLINTS, four elements have been determined for evaluation during performance assessment: teamwork, situation awareness, communication and coping with stress. Within each of these elements is a set of behaviours related to each of the skills (Mitchell, 318). The aim of the SPLINTS system is to develop a comprehensive taxonomy which contains the most critical elements of non-technical skills that ultimately impact patient safety and team reliability (Mitchell, et al., 2013).

Category	Element	Focus group labels*	Good behavioural marker	Poor behavioural marker
Situation awareness	Gathering information	Listening (SA) Watching (SA) Awareness (SA)	• Watches surgical procedure • Collects information from other team members	• Fixates on one task • Fails to listen to instructions
	Recognizing and understanding information	Understanding (SA) Atmosphere (SA) Knowledge (SA)	• Switches between tasks efficiently • Provides correct instrument even when not named/ incorrectly named	• Does not prioritize tasks • Responds late or not at all to change in pace of procedure
	Anticipating	Anticipating (SA) Timing (SA, DM))	• Predicts when plan of procedure is going to change • Times requests appropriately	• Loses track of surgical activity, that is, caught unaware • Asks for items late
Communication and teamwork	Acting assertively	Assertiveness (C)	• Gives clear instructions • Demonstrates leadership qualities	• Fails or slow to communicate requirements
	Exchanging information	Verbal (C) Non-verbal (C) Sharing (TW)	• Provides team with information • Uses non-verbal signals where appropriate	• Makes requests without specifying for whom communication is intended
	Co-ordinating with others	Clarifying (TW) Co-ordinating (TW) Leading (TW) Equipment (DM, TM)	• Suggests alternative options/ equipment • Supports others by providing help and assistance	• Fails to share information about evolving surgical plan • Allows interruptions to disrupt flow of procedure
Task management	Planning and preparing	Planning and preparing (TM) Organizing (TM) Equipment (TM, DM)	• Organizes tasks • Utilizes time during breaks in procedure for other preparatory tasks	• Opens sterile equipment/ supplies indiscriminately • Confuses order of tasks which best promote procedure flow
	Providing and maintaining standards	Maintaining standards (TW) Equipment (TM, DM) Timing (DM, SA)	• Protects sterile field and instruments • Controls volume of music	• Does not adhere to protocols • Does not display effective organization of own workspace
	Coping with pressure	Coping with pressure (MS) Stress in self (MS) Stress in others (MS)	• Does not rise to others' emotional outbursts • Delegates tasks where possible to ease pressure of situation	• Raises voice unnecessarily • 'Freezes' and unable to function effectively

*Skill list given to focus group in brackets.
C, communication; DM, decision making; MS, managing stress; SA situation awareness; TW, teamwork.

Table 5. Results of panel review process (Mitchell, 2013, pp. 321)

Included in Table 5 is an outline of the evaluation form, including examples of appropriate and poor behaviours, in relation to specific categories and defined elements. While SPLINTS is quite similar in nature to the NOTSS system in relation to situation awareness, teamwork and communication, a noticeable difference is the inclusion of a new category; task management. In order to effectively interact with the SPLINTS system, nurses are required to attend a one day training session which entails a three hour introductory period to human factors and a two hour training on the system itself. Training is followed by a one hour practice session, where nurses interact with the tool by observing recorded

video simulations of procedures (Mitchell et al,. 2012). Once nurses have acquired the necessary skills for interacting with SPLINTS, observations are conducted for individual nursing team members using the evaluation form and rating system.

3.5 Limitations of SPLINTS

Limitations occur in the outline of established design requirements within this system. It was determined that only observable skills should receive focus (Mitchell, 2013). While many integral non-technical surgical skills have been incorporated into the system, the observable multisensory skills of gaze, touch, movement and gesture have not been incorporated into the tool. While the SPLINTS system considers a comprehensive list of skills, communication is considered to be inherent in each of the elements outlined in the system and is therefore not always explicitly stated or evaluated in an in-depth manner. For example, the element of situation awareness encompasses listening and watching, both of which are non-verbal communications; sound and gaze. Therefore, a number of valuable communication modes do not have the opportunity to be evaluated and improved upon within the operating room. Unlike NOTSS, SPLINTS incorporates "non-verbal signals" into the category of communication, yet, as details surrounding the modes of non-verbal signals are not explicitly stated, this category can be easily misinterpreted or disregarded. Further limitations occur in the process of training nurses to use the SPLINTS

system. In order to adequately train nurse practitioners to interact with the system, providing training sessions over a longer period of time, has been recommended for uptake (Klamfer et al., 2001). Limitations have been noted by noted by Baker et al. (2001), for the lack of feedback provided to nurses during the training. Individual nurses do not have the opportunity to receive feedback on how well assessments are conducted, which allows for a margin of error. Finally, a disconnect remains between the observer and the individual being observed, as a learning process is not incorporated into the debrief and feedback sessions. Communication is difficult to assess on an individual basis, as it must occur between a minimum of two members, yet the evaluation looks only at one person and does not accurately assess the communications being sent to and from other team members.

3.6 Adaptation of Existing Evaluation Tools

The evaluation tools, NOTSS and SPLINTS, have been developed specifically to evaluate non-technical, communication skills in the operating room are effective but ultimately do not evaluate for a comprehensive analysis of non-verbal communications. Therefore, a framework has been developed in order to shape the design of a new tool for evaluation and to specifically address multisensory communication skills which have been neglected in other tools. Components from each of the previous evaluation tools, including NOTSS and SPLINTS, have been integrated in order to build an adaptable framework

that responds to the needs of verbal and non-verbal communication in the operating room.

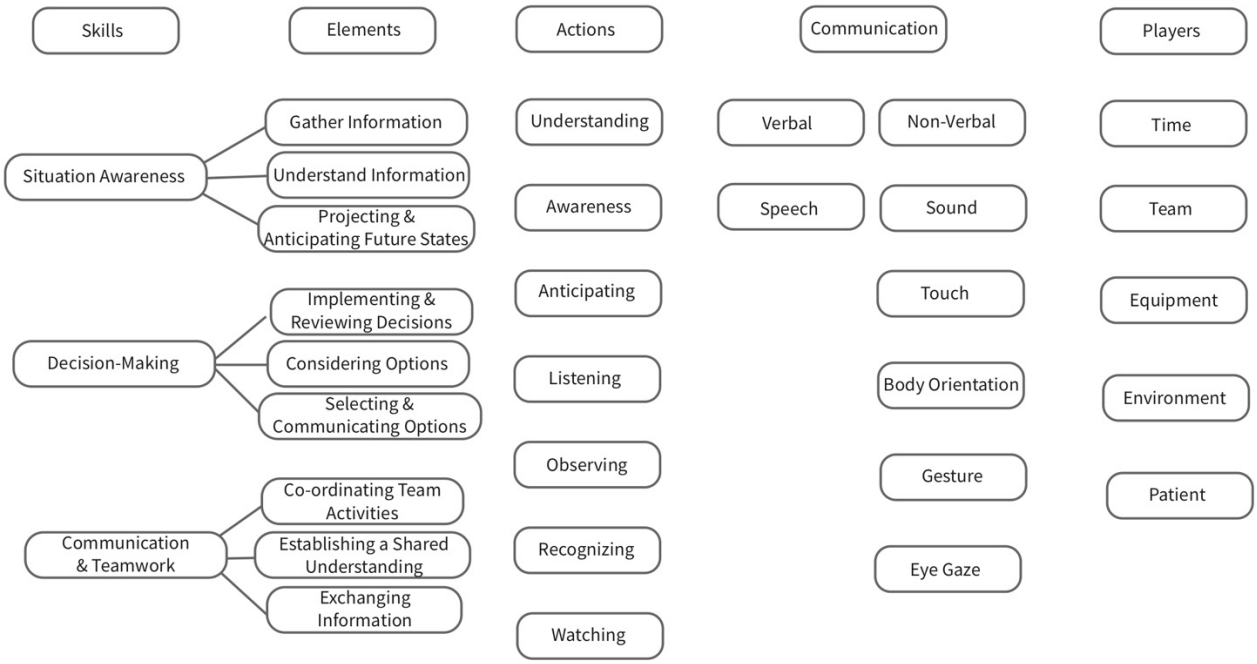

Figure 4. Multisensory Communication Framework (Jordan, 2018)

Within the framework, consideration has been given to the verbal and non-verbal forms of communication that occur within the context of the operating room. As demonstrated by the communication column, verbal communication, such as speech, is only one of numerous modalities which may occur. The remaining modalities are encompassed by numerous non-verbal communications and further broken down by specific and related actions.

4. Games

In order to translate the learning of non-technical communication skills into actionable outcomes in the Operating Room (OR), the design of serious games has been adopted in order to provide surgical trainees and professionals with tangible tools. These tangible tools can be used to understand both the complex dynamics of multisensory communication as well as further learn and apply strategies in real-world surgical procedures.

Games have the ability to create new meaning and understanding in a way that formal and pedagogical settings cannot provide. Whether physical, digital, mobile-based or immersive, games have seen immense success and increase in use over the last decade. Games are also no longer restricted to casual play, and have been incorporated into training programs, learning programs and a number of distinctive fields, including education, health care, public policy and military defense. Due to this re-emergence, game-based learning has been found to be more effective in translating educational material as opposed to traditional and pedagogical techniques (Baby, 2016).

Game designers and educational professionals do not often share the same approach or language when considering developments in this area, thus emerged the development of serious games in order to provide a comprehensive approach for educational game design. Serious games highlight elements that have been previously neglected and provide the opportunity to create new understanding. In order to determine how and why

the use of serious games can contribute to learning the role of non-verbal communications in the operating room, a wider understanding of the importance of games is first outlined.

4.1 Serious Games

Serious games (SG) differ from traditional games as a specific learning objective is incorporated into the mechanics of play. Serious games combine learning, interaction, play, and a challenge for the purpose of teaching or learning a specific skill set. The term SG refers to the transfer of learning (the 'serious' component) to the aspect of entertaining (the 'game' component) and must encapsulate both aspects simultaneously (Arnab, 2015). Serious games are not restricted in classification; development in the genre, game technology, platform and age group can be diverse (Baby, 2016). Within SGs, the player is often not aware of the learning that is occurring while interacting with the game, as the educational components are embedded within the mechanics of the game (Ushaw, 2017). As such, SGs are gaining momentum as tools for learning, training and instruction, presenting an alternative opportunity to enhance educational experiences. Three design requirements must be considered when developing a serious games:

1) cognitive and perceptual models to prepare learners for educational content

2) the incorporation of entertainment factors, such as motivations and storylines
3) interactive features and methods of assessment for both the game and players

Entertainment components of serious game design include two essential factors for consideration; motivation and interactive features. Motivation ensures the learner is educated through the entertainment of the game while further ensuring an interest in the content is developed. This can be done through reinforcement or the concept of blending. Reinforcement ensures the players are rewarded for successfully completing an aspect of the game while blending considers how the educational content is embedded within the game and indistinguishable to the player (Baby, 2016).

For the interactive features, focus is placed on the design of the game, allowing it to operate smoothly and with no glitches. Further incorporated into the design is a storyline or a progression of levels and challenges. Finally, the interactive features must encourage social interaction, impact and teamwork (Baby, 2016). By considering these three design requirements, SGs have the ability to provide a space where experiential learning is supported. This occurs through the attainment of knowledge and subsequent skills built into the mechanics of the game, also known as serious game mechanics (SGMs). In order to develop a serious game, the mechanics must first be considered in order to structure an engaging and comprehensive design.

4.2 Serious Games Mechanics

The SGMs is a tool used to evaluate the effectiveness of the game, from the perspective of learning and game development. SGMs consider how pedagogy, learning and entertainment can be incorporated into aspects of education and gaming.

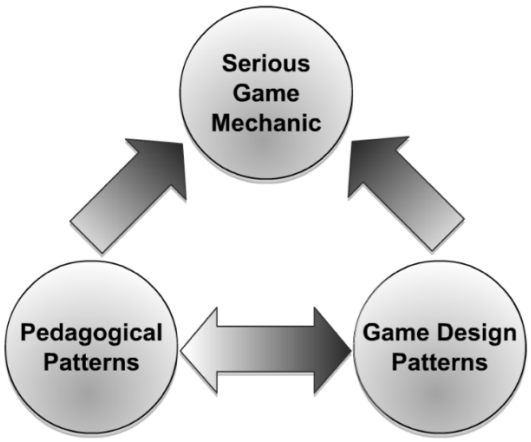

Figure 5. The relationship between Serious Game Mechanics, pedagogy and game design patterns (Arnab, 2015)

Ultimately, SGMs translate pedagogical patterns into comprehensive game mechanics by making design decisions that concretely realize the transition of a learning outcome into a mechanical element of the game (Arnab, 2015). These components can be further broken down into Learning Mechanics and Game Mechanics.

4.2.1 Learning Mechanics and Game Mechanics

Learning Mechanics – Game Mechanics (LM-GM) is a tool that allows for a process of reflection on how educational components and entertainment aspects of the game are interrelated (Arnab, 395). The LM-GM further determine how effective the game can be in terms of translating educational material and learning outcomes into mechanical elements of game design.

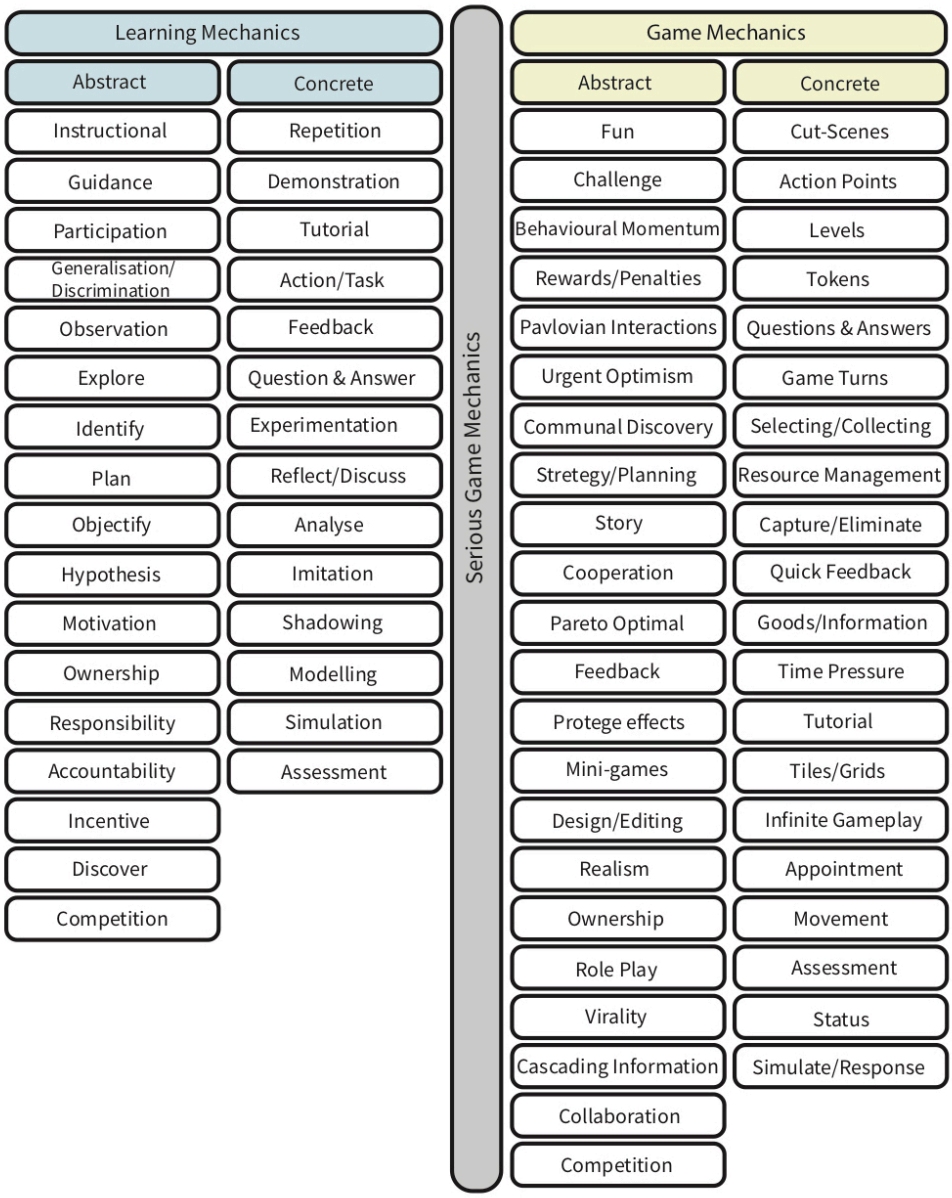

Figure 6. Abstract and concrete elements of the LM-GM framework (Arnab, 2015).

Learning Mechanics (LMs) refer to the operation of learning while Game Mechanics (GMs) refer to the aspect of entertainment. Within the LMs is a strategy and process, encompassed by components such as objectives, tasks, activities and methods. Meanwhile, GMs ensure that players have the ability to make choices and act independently through various actions in the game. This occurs at a level considerably lower than learning mechanics, which operate in the realm of goals, rules and various educational components (Arnab, 2015).

As depicted in Figure 6, the relationship between learning mechanics and game mechanics is demonstrated through a flexible framework. The descriptions provided in each column are potential features to choose from when considering how the mechanics will inform one another. This list has been informed by literature on pedagogy, game education and game mechanics, but is not considered comprehensive (Arnab, 2015). Through Figure 6, the abstract and concrete elements of both the LMs and GMs are presented used to identify and evaluate components of SG analysis, design and specifications. The core components are listed vertically, in the respective LM and GM columns (Arnab, 2015). While the table is static in representation, it should be noted that the process through which the players learn is an ongoing evolution and not fully encapsulated by the framework. The LM-GM model has been incorporated into the design of the SGs for this project in order to provide an analytical tool during the development process.

4.2.2 Serious Games in the Health Care Context

Serious games have the capability of providing alternative means of training and education for medical learners and medical professionals due to the ability of the game to incorporate educational components into the design (Baby, 2016). Particularly within the context of health care, focus is put on the learning outcomes of players, rather than the methods through which this learning is achieved (Ushaw, 2017). Such learning outcomes can be achieved through the five classes of the Benefit Delivery Mechanisms (BDMs), as shown in Table 6. The BDMs demonstrate how LMs and GMs directly correlate to various fields, such as healthcare, education and commercial use. The outlined BDMs

BDM	Health examples	Education examples	Commercial examples
Repetition	Rehabilitation of movement Behavioural change	Verbatim learning	Sports simulation Health and safety training
Exploration	Simulation of cause and effect	Independent discovery Guided discovery	Tourist information Issue awareness
Strategy	Cognitive ability Memory retention	Cognition training Understanding of process	Management simulation Financial simulation
Progress	Progression based therapies Assessment of condition	Trial and error Cumulative knowledge	Gamification Achievements and trophies
Social Interaction	Psychological assessment Social simulations	Team project training	Cooperation simulation Team building exercise

Table 6. The five classes of benefit delivery mechanisms with applications in health, education and commerce (Ushaw, 2017)

include repetition, exploration, strategy, progress, social interaction and these terms are described broadly in order to be applicable to numerous fields and game genres. Repetition focuses on repeating a similar action or sequence in order to memorize definitions, tasks or facts. Strategy is concerned with how the elements of a game are controlled by a player, such as the order in which cards are played. Progress involves a sequence of interactions that lead to a reward or a consequence. Typically, game structure will incorporate different levels or challenges upon which the player can improve. Finally, social interaction ensures that a SG provides a space where the perspectives of multiple players can be incorporated into the game, whether through an action or discussion (Ushaw, 2017).

4.2.3 Metrics Assessment

The following metrics provide a means of comparing the outcomes found in each of the game levels (Baby, 2016). Such metrics include five components:

1) Content validity – the game is evaluated by medical professionals for quality of content
2) Face validity – the game is tested by the relevant players and medical professionals for comparability of game content to real life scenarios
3) Construct validity – the ability to measure the differences in outcomes between novice, intermediate and expert players, demonstrating a significant change in skill level and comprehension

4) Concurrent validity – the way in which current training methods and game outcomes should correlate
5) Predictive validity – the outcomes in the game should be reflected in real world performance outcomes

These metrics will be further discussed in relation to the final iteration of the games prototyped for this project.

4.3 Related Works

Serious games can be represented by physical, synthetic virtual or mixed reality simulations. With the emergence of improved technology, surgical education has moved towards simulation-based training in order to provide students and professionals with skills training modules for highly complex tasks and procedures. Three serious games designed for the healthcare context are outlined below.

4.3.1 Medialis

Medialis is a serious game designed to train surgical teams on decision making skills during a procedure. Incorporated into the game are a series of quizzes referencing ninety-seven real-life surgical cases.

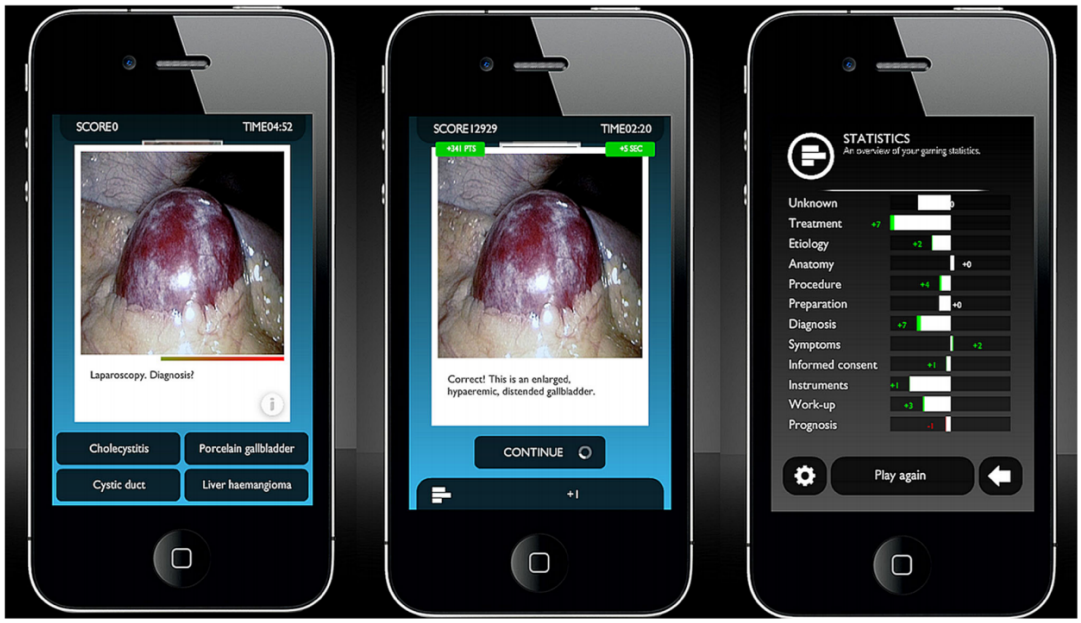

Figure 7. Medialis screen shot – the player is presented with a case (left) with four resolutions. Upon making a choice, the player is presented with feedback (center). Upon completion, the player can review statistics (right) (Graafland, 2014)

Provided for the player is a description of the case, an accompanying image and possible solutions from which to select. The main GMs included in Medialis are time and competition, as players are given ten seconds to solve each case and compete within a network of peers for the highest score (Graafland, 2014).

4.3.2 Blood Management

Another serious game, Blood Management, focuses on halting bleeding during orthopedic surgery through a three level challenge. The first and second levels are beginner modes to ensure the player develops hand-eye coordination skills by halting the flow of fountains. Once this skill has been

achieved, players progress to the third level, where the scenario moves into the orthopedic surgical space and the training mode commences. Within the training mode, players must first follow the appropriate sequence of steps to halt the bleeding on a patient. Next, players enter into a mode with a time constraint and halt the bleeding before the patient dies.

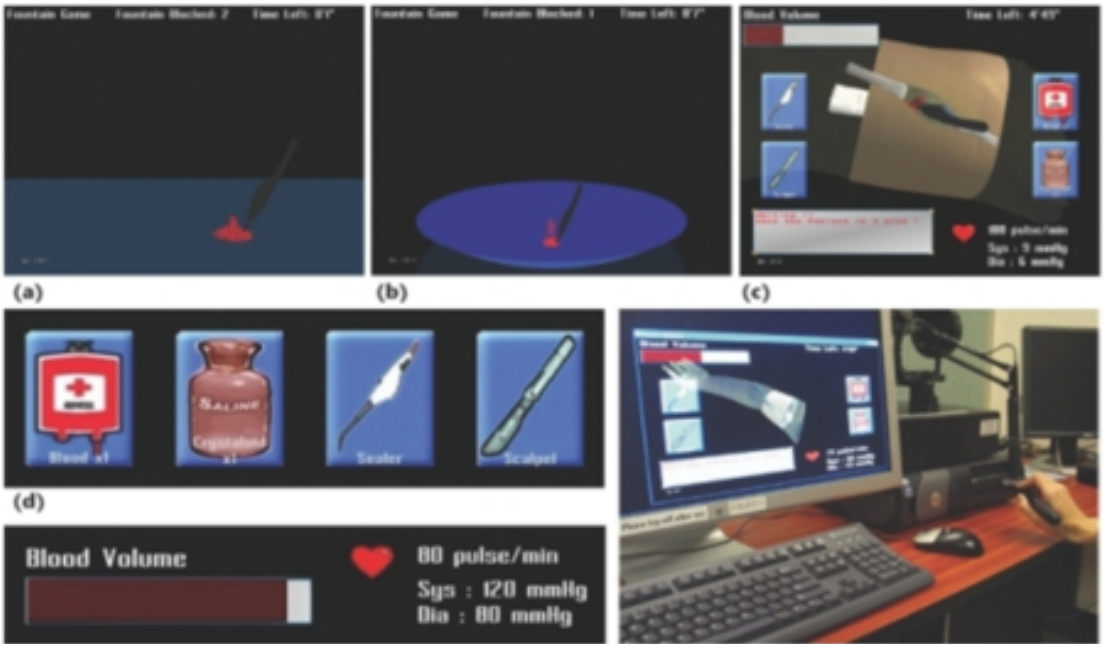

Figure 8. Blood Management screenshots (top, left), Blood Management in use (bottom right) (Qin, 2010).

Finally, after mastering the novice levels, players move into the collaborative mode, and work as a team to complete the same sequence of actions during a simulated surgery. While this serious game focuses on haptic feedback and hand-eye coordination, the general notion of level progression after skill achievement has been incorporated into the overall design of the serious game prototypes for this project (Qin, 2010).

4.3.3 Aller Pour Diagnostiquer

A third game is concerned with Doctor-patient communication and integrates these non-clinical skills into a serious game. While this game is currently under development, the mechanics have been laid out in a web application (Guo, 2014). Players are presented with the four identified steps of a medical consultation between a General Practitioner and a patient and these steps include:

1. greeting the patient and identifying the purpose of the consultation
2. gathering information, either verbally or through a physical examination while listening to the concerns of the patient
3. providing a diagnostic plan and discussing treatment options with the patient
4. ending the session and planning for a follow-up appointment

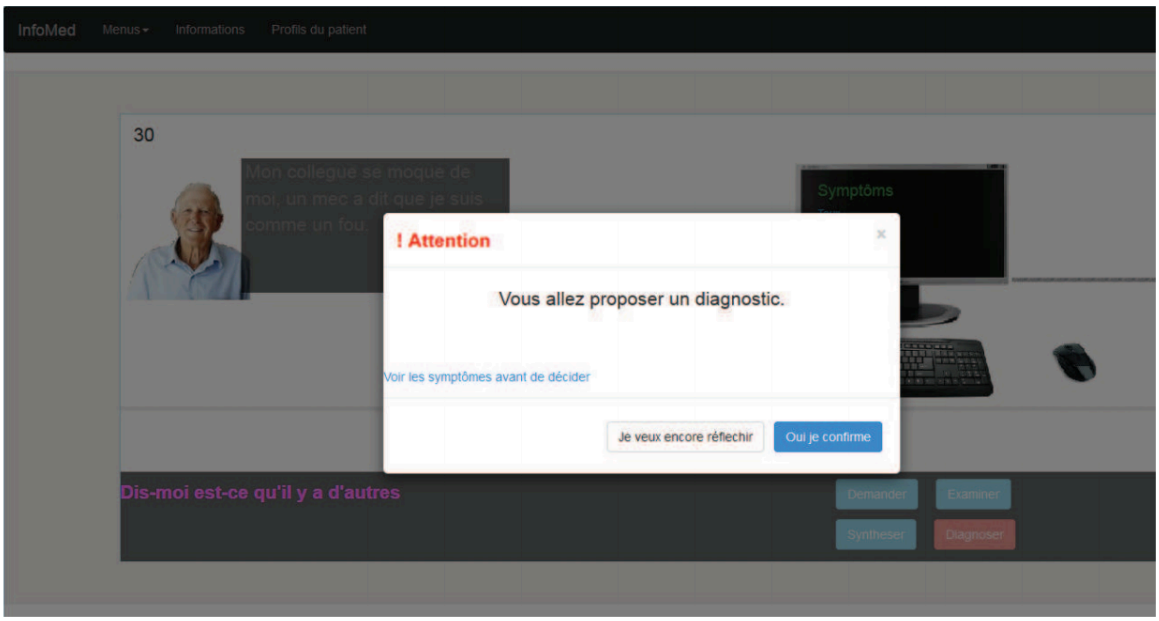

Figure 9. Interfaces of prototype, "Aller Pour Diagnostiquer" (Guo, 2014).

Players are presented with one scenario at a time and a number of possible actions to take. In order to advance to a new scenario, the appropriate action must be selected. If a poor selection is made, the health of the patient is compromised. Each action presents players with an opportunity to practice communication skills and rapport with patients. Upon concluding the game, the player is presented with a summary of the actions played. This summary identifies the appropriate actions made by the player as well as poor actions, with alternative actions provided. The player is also informed of the communication skills acquired during the game and a copy of the results is sent to any relevant superiors for review (Guo, 2014).

The three related serious games outlined above demonstrate the significance of training healthcare professionals on technical skills, psychomotor skills and cognitive skills. Such skills include, depth perception, eye-hand coordination, attention and reasoning during stressful and relevant scenarios. While such skills are highly important and relevant to a surgical procedure, similar training games are not as heavily weighted for non-technical skills, such as communication, during a surgical procedure. An assessment of the current landscape in health games has demonstrated that the majority of games are digital tools. While the benefits and learning outcomes of these games cannot be argued, communication is dynamic and in order to learn the complexities

involved in these skills, a physical approach to serious games has been developed for the purposes of this project.

4.4 Game Components

In selecting board games to act as inspiration for the eventual design of the game prototypes, three games, each sharing similar elements, learning mechanics and game-mechanics were evaluated – Hanabi, Cards Against Humanity and Code Names. In each game, communication is integral to the success of the game. Each game offers a different level of player involvement; Hanabi is co-operative, Code Names is both co-operative and competitive and Cards Against Humanity is strictly competitive. The various game-mechanics allow for an investigation into the affordances and constraints presented within each communication based game. Each game was tested extensively and observations of game play were conducted until a strong understanding of the game mechanics and learning mechanics became apparent. The exploration took place at a board game cafe where an expert was asked to recommend games that involve both strategy and elements of communication.

The first game evaluated is a multiplayer, cooperative game titled, Hanabi. This game came highly recommended as it incorporates communication skills and co-operative aspects of gameplay. The objective of Hanabi is to build the best possible fireworks display by placing tiles on the table in the appropriate order. The tiles are each numbered from one to five and

come in five sets of colours.: red, yellow, blue, green, white. The tiles must be placed in order, starting with one and leading up to five, in the same colour groups. The difficulty with this game comes from the aspect of missing information, as each player is unable to see the tiles possessed and can only view the tiles of the other players. Players therefore have limited information and must work together by giving clues about the numbers or the colours of the tiles. These clues assist team mates to play a tile and complete the fireworks display in each colour. The game ends when all of the tiles have been played.

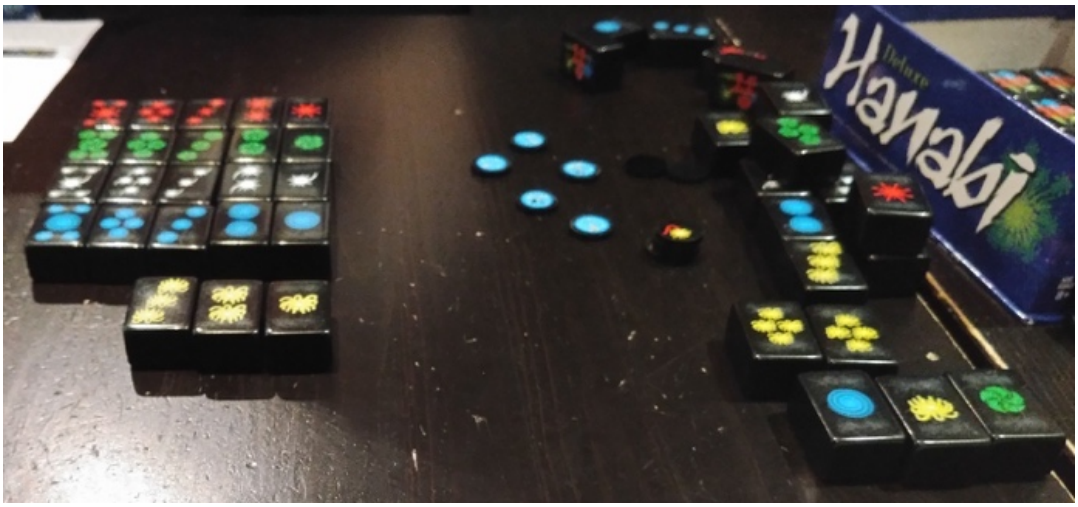

Figure 10. Hanabi board game in play (Jordan, 2018)

After playing the game through once, it became apparent that players would have to determine how others would interpret given clues. Not only does this ensure that players work towards developing a shared mental model at a rapid pace, but must consider all relevant strategies prior to commencing the

game, the required strategy had to be determined prior to commencing the game. This meant that the players must assess the tiles of all other players and determine when clues should be given, and which clues are a priority.

Similar to Hanabi, Code Names is concerned with determining a strategy in order to win the game prior to commencing play. This game was recommended for testing and play as it requires a similar amount of strategy and a specific level of communication. While Hanabi is entirely cooperative, Code Names functions collaboratively in relation to team play while simultaneously being competitive as the teams compete against one another in order to win the game. This competitive card game allows two teams to compete against one another to win the most points possible.

Figure 11. Code Names in play (Jordan, 2018)

Players are divided into two teams: the red team and the blue team. Twenty-five cards are then laid out in a grid on the table, with the words facing up. On the reverse side of the word cards are colours corresponding to the red and blue teams. One person on each team is designated the spymaster and is given a secret map outlining which cards the team must collect. The spymasters then take turns giving one word clues to teammates. The clues must match as many cards as possible on the table, but only those assigned to the designated team colour. As with Hanabi, team members must work together to win the game and provide clues strategically to maximize the number of points received. The Spymaster must consider how the clues on the table will be interpreted by the teammate. The first team to collect all of the assigned cards wins.

Cards Against Humanity is a community-based card game where multiple players compete against one another in order to win. To start the game, each player draws ten white cards. These cards list humorous statements and names of prominent public figures. Players take turns acting as the judge, known as the Card Czar, selecting a black card from the pile and reading it aloud to the group. The remainder of the players will play one white card that best responds to the question asked on the black card.

Figure 12. Cards Against Humanity in play (Jordan, 2018)

The Card Czar shuffles the white cards and selects the response that is either the most suitable or the most humorous. The owner of the selected card wins the round and receives the black card as a reward. The play continues until the players agree to end the game, upon which the person with the most black cards is deemed the winner. The game is simple in design but builds upon dark humour as the underlying theme. There is ultimately no right or wrong answer to any question but players must work to understand the perception of each Card Czar and play a response that will be determined to be the funniest according to individual sense of humour.

4.5 Game Analysis

Upon assessing each of the three games outlined, an analysis was conducted in order to compare game elements and mechanics. Table 7, listed

below, outlines these mechanics in order to determine which elements could be adapted for game development, with a focus on communication skills. Each game has been assessed based on types, objectives, consequences, communications, multisensory elements and skills developed.

GAME	TYPE	GOAL, OBJECTIVE	CHALLENGE	CONSEQUENCES	COMMUNICATION	MULTISENSORY	SKILLS DEVELOPED
Hanabi	Cooperative Card Game Multi-player Strategy	Work together for common goal Achieve highest score before time runs out	Build the best fireworks display possible by playing tiles in order of colour and number	Pay close attention to given clues or risk losing the game	Communication is restricted Communication occurswith intention and strategy	Provided clues are as important the information not provided	Critical Thinking Problem Solving Memory Logic Deductive Reasoning Inductive Reasoning
Cards Against Humanity	Competitive Card Game Humorous	To win as many black cards as possible Play white cards in response to black card hypothetical	Anticipate how the Card Czar will respond to cards played	Playing without strategy ensures players will repeatedly lose rounds	The majority of communications occur during Card Czar discussion of white card responses.	Players observe responses of Card Czar by listening to comments and watching for facial reactions	Develop Awareness Anticipate Memory Strategic Thicking Problem Solving
Code Names	Cooperative Team Play Table Top Word Game	For all players to retrieve all field agents on their team Give verbal clues to teammate	Avoid selecting the word cards assigned to the opposing team or the assassin	Providing clues that lead to the wrong word selection can assist the opposing team or lose the game	Communication is restricted to one word per team each turn	Information communicated is equally as important as the information omitted Players cannot give non-verbal clues	Time Management Strategic Thinking Word Association Concept Identification Deduction Concept Identification

Table 7. Analysis of Hanabi, Code Names and Cards Against Humanity

Through this analysis, it became apparent that strategy surrounding communication, whether explicitly or implicitly stated within a game, was integral to build into the team or individual outcome. The analysis of the board games further allowed for the commencement of prototyping game designs.

5. Methods

This research project is an extension of an in-class assignment within the Inclusive Design program at OCAD University. The class was based on Cognitive Semiotics and concerned with assessing the semiotics of the surgical environment, including, but not limited to, gaze, touch, body movements, gestures, sounds and speech as ways of conveying various forms or meaning. The original assignment was designed with the assistance of surgical professionals and trainees at St. Michael's Hospital in Toronto, ON. After conducting interviews with surgical staff members and observing a laparoscopic procedure, a number of co-design sessions were facilitated. It became apparent that numerous forms of communication were relied upon within the dynamic space of the operating room. The focus of the assignment then shifted towards multisensory modes of communication that occur in the operating room amongst team members. The initial study and findings were validated by surgical team members. The next iteration of this assignment is the core of this Major Research Project.

In traditional design research, the act of designing and conducting research may occur through separate forms of knowledge generation. As this form of research can be theory driven with a focus on the testing of a hypothesis, the role of designer and researcher are often independent of one another (Sanders, 2014). The researcher may provide a secondary person, the

designer, with a hypothesis and a set of restrictions to be built out into a tangible item or tool. The tool would then be built by the designer and returned to the researcher for user testing. Thus, knowledge is siloed and restricted to its respective fields and the prototyping and designing of artifacts occurs only after the research has concluded (Stapper, 2014).

The research engaged within this project is classified as *research through design,* in which the act of prototyping not only provides the design team with insights into the testing of an initial hypothesis, it further allows for rapid evaluation of evolving ideas and concepts, as well as the ability to continuously improve upon the original idea (Sanders, 2014). Throughout this process, the act of designing is integral to the generation of knowledge and is conducted by an individual who assumes the role of both designer and researcher.

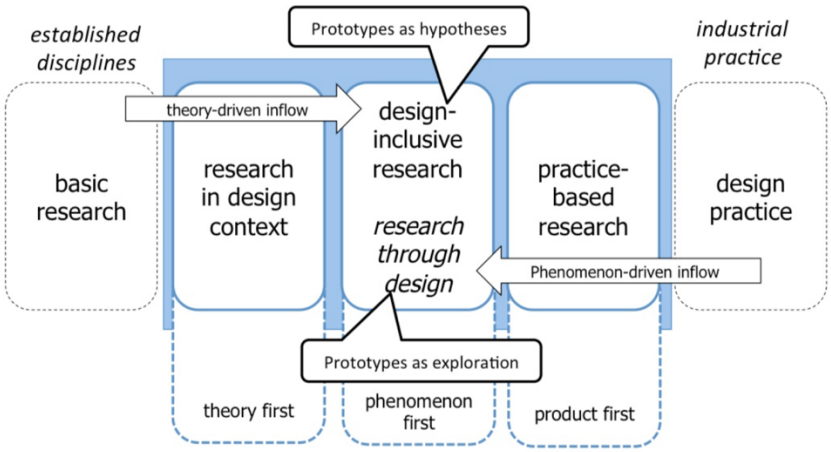

Figure 13. Types of prototyping research (Sanders, 2014)

This form of research can ultimately be considered exploratory in nature as the goal is to gain knowledge through the exploration of a phenomenon, which may or may not result in the outcome of a prototype. The act of designing has been engaged during the entire process of both research and design for the purpose of this project. This aspect of iterative prototyping has allowed for early concepts to be realized into material form, tested by the design team and re-worked once again for future applications. The design process engaged within this project has explored the ways in which individual players can access various types of information in relation to the surgical context and will be discussed in the next section of this work.

5.1 Prototypes

The initial development and design of the games was done with the intent of exploring the intangible notions of communication and resiliency skills within the context of the operating room. Iterations evaluated the weight of predetermined roles for each player, how communication modes could be translated into actionable outcomes and how learning could be engaged throughout the process.

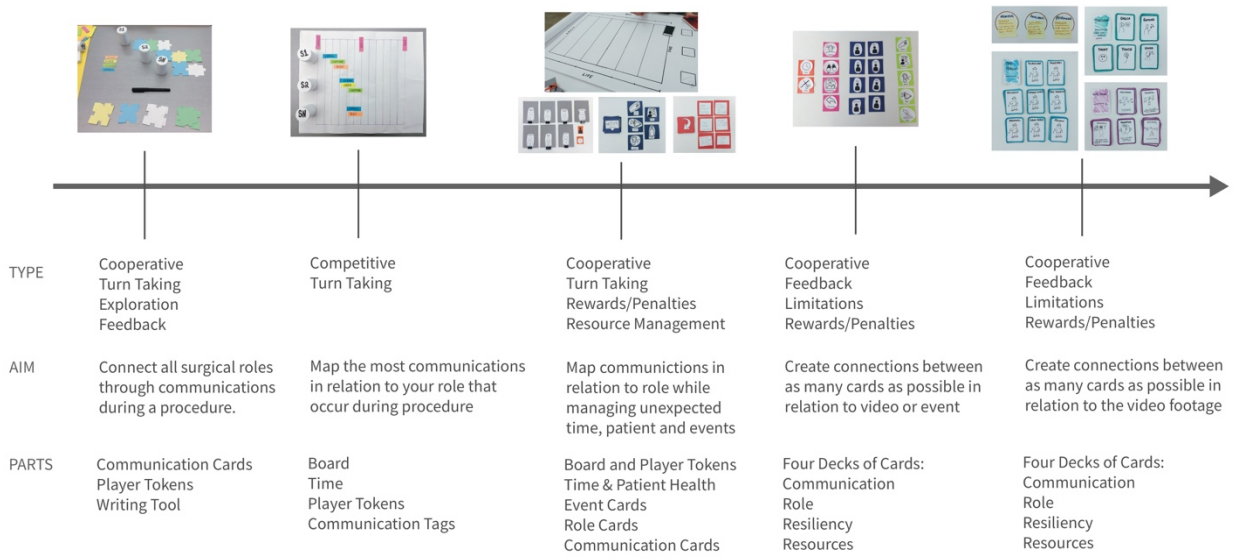

Figure 14. Prototyping timeline – card game (Jordan, 2018).

The first three iterations of the card game focused on collecting data on communication styles and perception of time from workshop participants who would have experience working or conducting observations in the OR. The intention was to determine the critical content occurring during events and tasks, provide players the opportunity to review the types of communications selected for an interaction and to understand the perception of players invoking different communication styles. Ultimately, these prototypes aimed to:

1. provide participants with an adaptable tool
2. utilize operating room scenarios that would allow for the opportunity to build shared mental models
3. collaborate outside of the high-stress environment of the OR

4. visualize work processes
5. understand alternative viewpoints in relation to roles and responsibilities

These iterations built upon concepts of the Hanabi game by providing players with a role card and a limitation in terms of the types of communications that each player could not use. While these limitations were known by the individual player, they were not known by the remainder of the players, adding a level of difficulty to play and prompting a level of communication surrounding which interactions could be played by each role. This iteration further developed the game mechanics by establishing elements of play. The game was built for two to five players in order to provide a team environment without being overwhelmed by the number of players. This game was designed to be cooperative, with all players working together in order to respond to the Event Cards while maintaining awareness of the time and patient health factors and working together to play Communication Cards. Ultimately, the mechanics of this game proved to be overly complex in terms of the limitations imposed upon players as well as the multiple demanding factors of time and patient health. The game continued to be ineffective in relaying why communications occurred at certain moments, and the static game board proved to be equally ineffective in demonstrating the passing of time during a procedure.

The fourth and fifth iterations moved in a different direction, focusing specifically on the use of cards and removing the element of the board, time and patient health, which were ultimately deemed unnecessary. These iterations incorporated the element of resiliency into the cards with elements focusing on learning, anticipating, monitoring and responding.

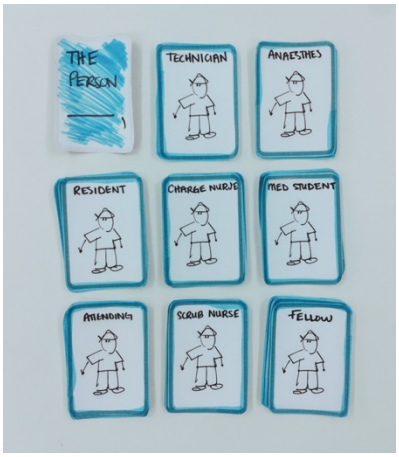

Figure 15. The role cards

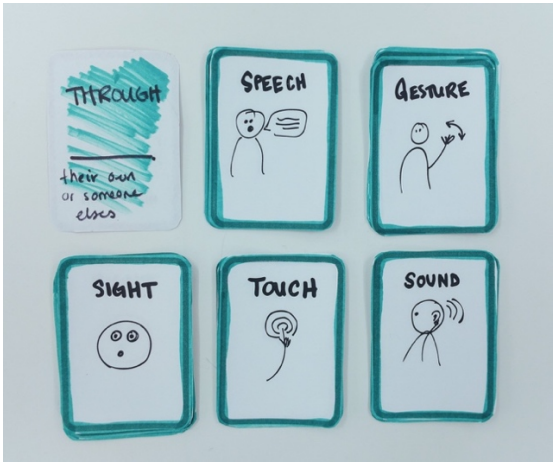

Figure 16. *T*he communication cards

It was determined that an aspect of communication was missing in the previous iterations of the games and a focus on resiliency provided an opportunity for an actionable outcome and an intention behind the communication. In order to interact with the cards, a scenario would be provided, such as, "Make surgical incision", prompting players to respond by playing a role, a resilience and a communication card. Players would have the ability to compare responses and discuss the difference in perception or interpretation of how the scenario could

be responded to. The limitation with these iterations came from the lack of objective with the game.

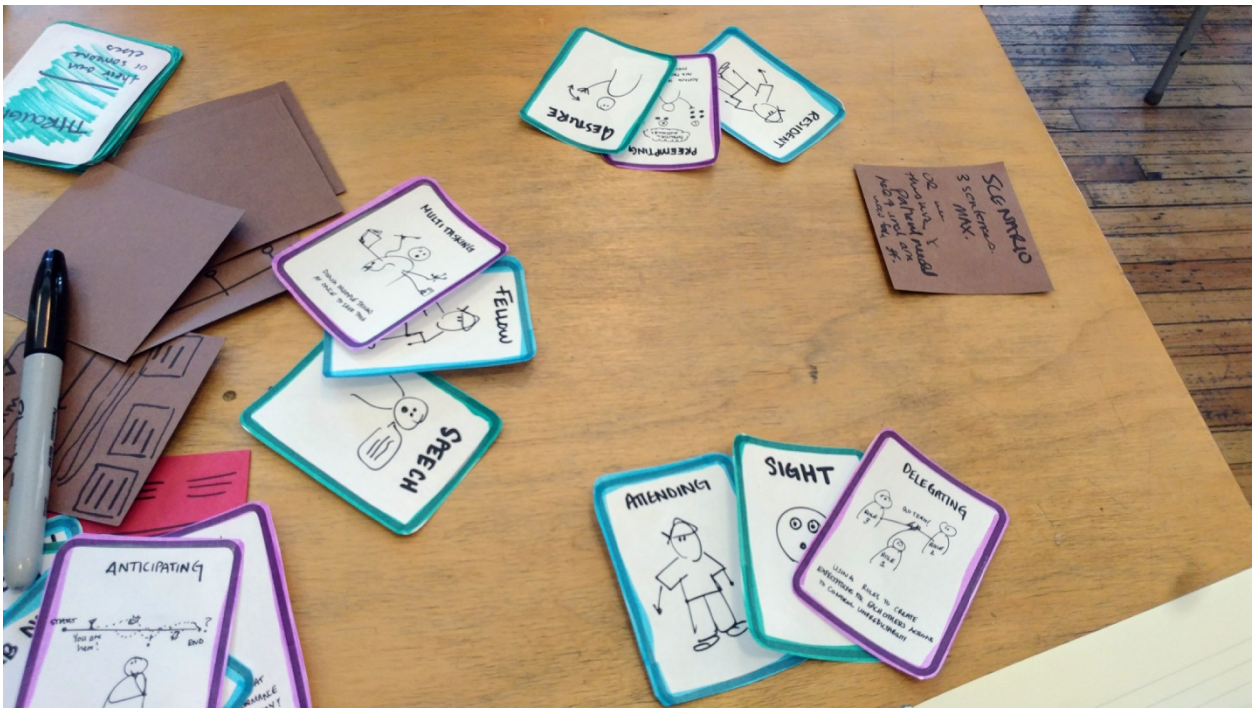

Figure 17. Card game prototype in use

The final iterations were designed to work in response to a video debrief of a surgical procedure, such as the ten minute compiled report of threats and resilience captured through the Black Box recorder at St. Michael's Hospital. The cards would be face up on the table in full view for all of the players. The video would stop at a random point in the procedure and the players would take turns predicting the outcomes by selecting one role card, one communication card and one resilience card. The selected cards would be discussed and the video

would resume playing to determine whether the player was accurate in the selection of cards and outcomes.

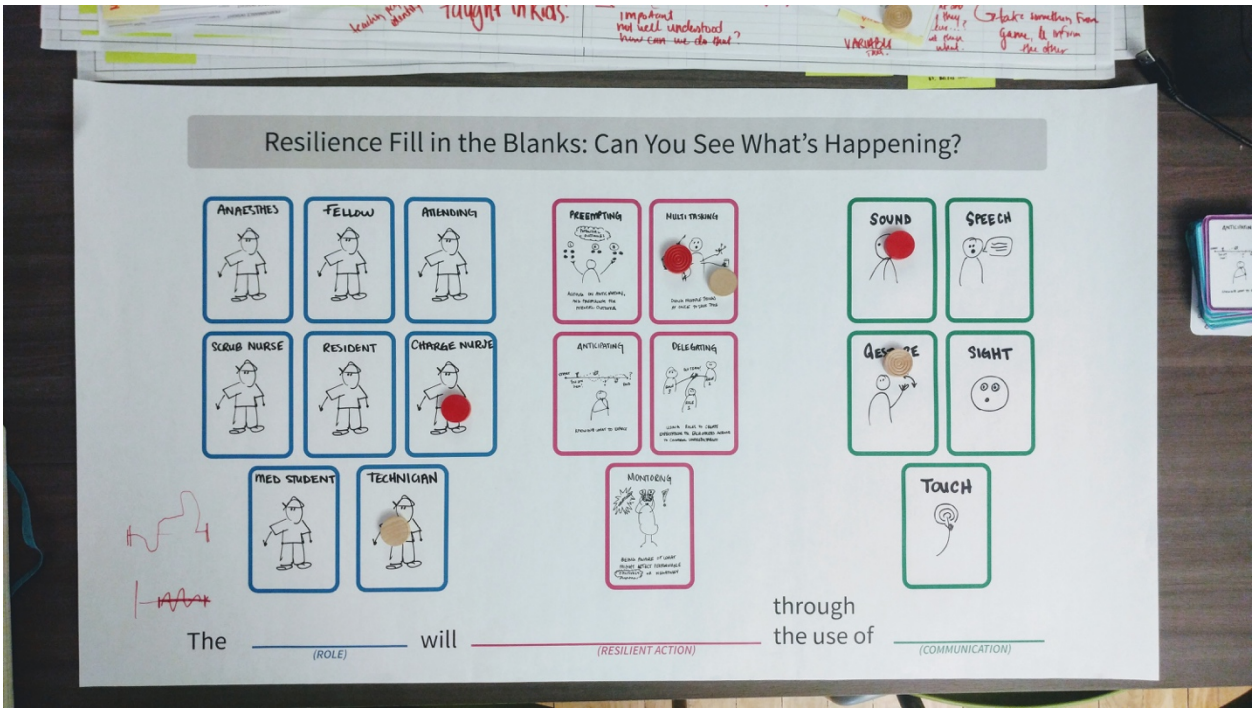

Figure 25. Early game board design

The final iterations ultimately pushed the game into two different directions; a card game to initially understand the dynamics of communication and resilience, as well as a secondary board game to gain insights into strategies in relation to communication and performance during a procedure .

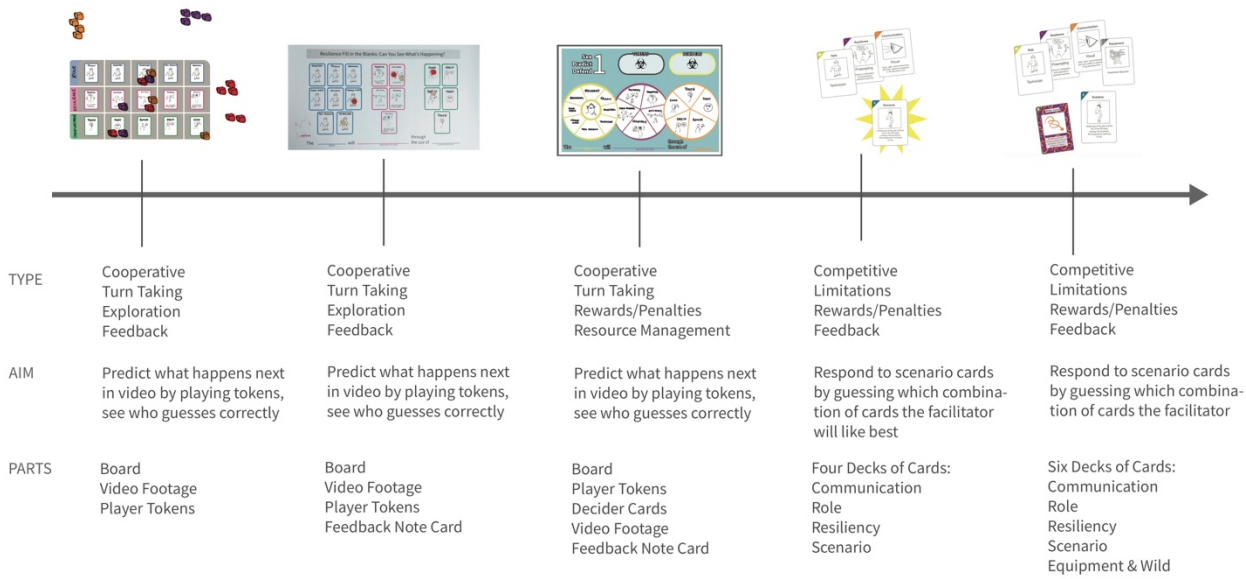

Figure 18. Prototyping timeline – board game (Jordan, 2018).

5.2 The Current Prototypes

The first part of the current prototype is a competitive card game designed to assist operating room staff in understanding the dynamics of communication and resiliency. As both communication and resiliency (see Appendix B: A Brief Introduction to Resiliency) are non-technical skills, this game focuses on making these invisible skills tangible and demonstrating the value in their use. The objective within this game is for players to compete against one another in order to acquire the most points. This game focuses on introducing the concepts of resiliency and the various communication modes that can be conveyed in response to a scenario. The game can be played by novices, intermediates and experts, with a variety of challenging decks to integrate into the game.

Each player begins by drawing three cards from the following decks: Communication, Resilience and Role. Next, the players will determine who is the first facilitator of the game. The person with the smallest hands will be the first facilitator, also known as the Team Lead.

Figure 19. Overview of card decks for final prototype

The Team Lead will draw one Scenario Card (blue) from the deck and read it aloud to the group. Each player must then select one Communication Card (orange), one Resilience Card (purple) and one Role Card (green) from their hand that best responds to the Scenario Card and play the cards face down so answers are anonymous. The Team Lead reviews all responses out loud and,

based on personal sense of humour and perception, determines which responses best address the Scenario Card.

Figure 20. Cards in play – players responding to the scenario card

The winner of the round receives the Scenario Card as a prize and the game continues, with the player to the left of the Team Lead assuming the position of facilitator for the next round.

Figure 21. The winner of the round receives the Scenario Card as a prize

Once players have mastered the novice deck, more challenging Scenario Cards can be added into the game. Or, if players are feeling creative, blank scenario cards have been incorporated into the deck for an increased challenge. The blank cards provide players with the opportunity to and new scenarios into the games.

Figure 22. Blank Scenario Cards for players to create

The intermediate level offers an additional deck and allows players to include Equipment Cards. The game functions similarly to the novice version, with players responding to Scenario Cards, only now players have the ability to incorporating the type of equipment being used into each response.

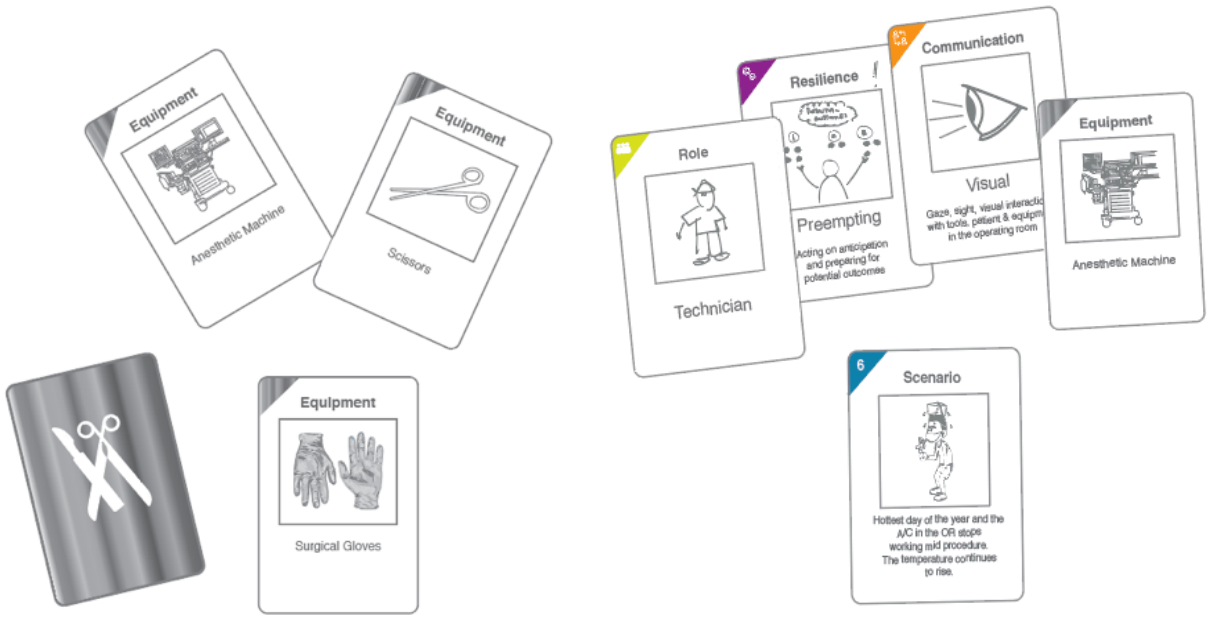

Figure 23. Equipment Cards added to the game for experienced players

Finally, the expert level introduces Wild Cards into the game for an increased challenge for players. The Wild Cards will lengthen the game by forcing players to discard or trade with other players. The Wild Card is drawn by the Team Lead after selecting the winner of the Scenario Card. The action of the Wild Card must be responded to prior to a new Team Lead assuming the position of facilitator.

Figure 24. Wild Cards, front and back

The second part of the prototype is a game board, created as a follow-up to the competitive card game and designed to interact specifically with a curated video report during a debriefing session. This aspect of the prototype focuses on gaining insights into communication and resilience strategies in relation to performance reviews.

Team members are provided with a different set of coloured tokens and a game board displays all roles, communications and resiliencies in full view for the OR team to respond to during a video debriefing session. The team watches the video until it is stopped at a random point, such as after an action has occurred or prior to a new action occurring. Team members must then determine what the outcome will be by placing their tokens on the board.

Players add one token to a role, one token to a communication and one token to a resilience and must defend the selection as plausible and valid in relation to the video clip.

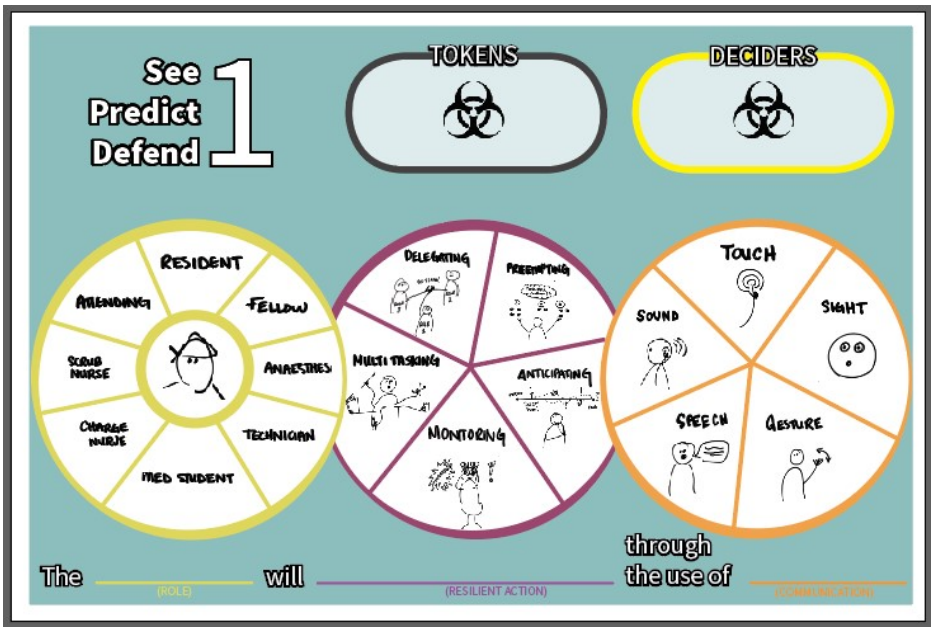

Figure 26. Refined game boar

The board focuses on training team members on the skills available to use and to provide an increased understanding of how to employ in response to an event. In order to further facilitate learning, a cue card is provided to each team member, for the purpose of note taking and keeping track of predictions throughout the debriefing session. The initial game board has been further refined to reflect the colour choices used in the card version.

The new direction of the board game went through a number of quick iterations but ultimately focused on supporting the debrief session of filmed surgical procedures.

5.3 Design Requirements

The games have been designed specifically for surgical team members and while players may differ in terms of professional roles undertaken within the OR, there is no one role that is given preferential treatment within these games. Similarly, the games have been designed to be flexible in order to be used by various surgical specialties. The roles are interchangeable and if focus on a certain role is required, the games have the ability to support this through the removal of unnecessary cards.

The design of the cards and game board is clean and simple to avoid overstimulation. The bold colours were chosen to reflect the playfulness of the game and simple icons were used on each card in order to provide players with access to both visual and text-based information.

In order to avoid assumptions in relation to professional roles attributed to certain genders, gender-neutral drawings and language have been used in order to describe the scenarios.

The games have been designed to be analogue in order to provide team members with tangible tools to interact with during a team debriefing session. The analogue board game facilitates interaction amongst a small group, where players have the chance to not only learn from one another but learn how team members process information and approach problem solving. This assists with the development of a shared mental model and encourages players to understand different approaches taken by other roles. This lose structure further

provides a safe environment through which team members can learn without consequence.

The games have been further designed to incorporate feedback mechanisms in order to provide players with the opportunity to assess individual play as well as the actions of other players. The opportunity for players to evaluate problems, actions and solutions is available after completing a turn or a round. Feedback is provided through the ability of players to identify how many scenario cards the other players have won, as well as what types of responses are being generated for wins.

Finally, humour and satire have been incorporated into the design of both the card game and board game in order to provide players with a playful outlet. The content for the scenario cards was specifically influenced by medical humour blogs, such as Gomer Blog, targeting medical students who have been found to succeed when learning incorporates satire.

5.4 Prototype Mechanics

A game is considered to be a competitive activity, with a defined setting and rules which constrain play (Baby, 2016). Within the prototypes games, the aspect of learning and the understanding of new concepts does not solely evolve from the content of the game. The learning occurs through the process of engaging with other players and building skills or strategy in relation to the content. In order to receive the maximum benefits of the games, the various

levels can be incorporated into a structured setting, such as the Black Box debriefing sessions with team members, in order to enhance learning and comprehension.

Three levels have been incorporated into the games in order to provide players with incremental learning objectives; novice, intermediate and expert. The games have been developed as organized learning strategies in order to improve overall competency of team members in relation to communication skills. The game levels provide team members with the ability to navigate tasks from the perspective of various team members and ultimately gain an understanding of the importance of each role within the surgical environment.

Level 1: The first level introduces minimal constraints through basic challenges and unlimited gameplay. The actions that can be taken by a player in this level are only limited by the cards provided. This introductory card game provides team members with an overview of multisensory communication modes and resiliency that can be relied upon during a surgical procedure. Team members have the ability to react to these new concepts through provided scenarios. The learning is accelerated through the competitive aspect of the game as players compete to win, and do so through an accelerated and thorough understanding of the game concepts. Players are encouraged to pay close attention to the reaction of the facilitator while assessing the responses to

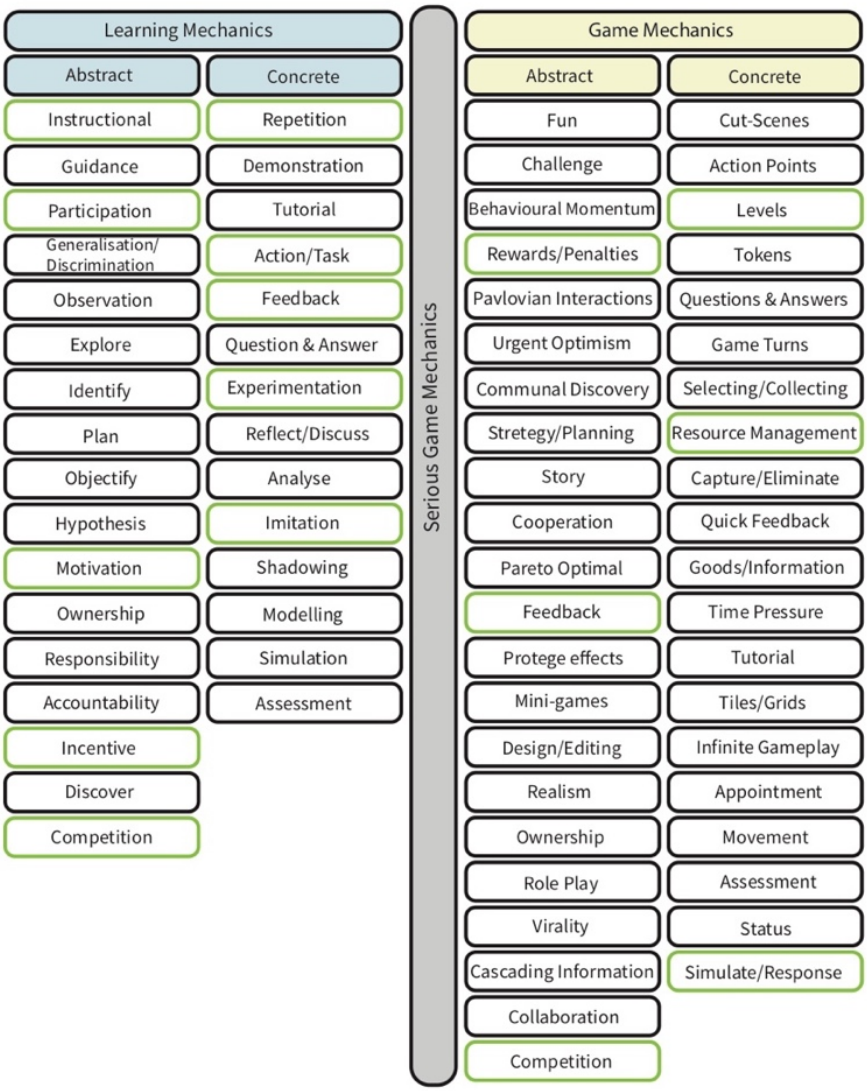

Figure 27. Card game mechanics, LM-GM for Level 1 and 2

each scenario. If players choose to ignore how assessments occur, the risk of losing the game increases. The element of competition has been embedded into Level 1 and Level 2 in order to challenge players to learn. These levels allow multiple players to compete against one another, ensuring play is driven by the motivation to win.

Level 2: The second level tests the skills acquired during the first level by introducing more complex challenges with added consequences. This intermediate level provides team members with an increased challenge by introducing new cards to the game. In doing so, team members work towards skill building by considering numerous aspects of the surgical environment, such as role, communication, resiliency and equipment. The simulated environment further allows players to practice responding to extreme scenarios without fear of consequence.

Level 3: The expert level builds upon the concepts introduced in Level 1 and Level 2 through the incorporation of a board game. The board game supports team debrief sessions and works toward building strategy around communication and resiliency by providing team members with a collaborative game space to learn, which is reflective of the actual surgical environment. Team members are further challenged as video recorded procedures now act as the scenarios to which players must respond. Instead of competing against one another, the board game ensures players are able to learn how to anticipate future obstacles by working through edge-case scenarios and developing effective solutions. In doing so, team members are able to develop a shared mental model and build strategy for effective team performances. Level 3 provides players with real-time feedback on professional performance, an act that rarely occurs during surgical procedures. This form of feedback is

delivered to the players immediately through discussion and table talk occurs. The external resource of the video footage provides players with an additional source of feedback.

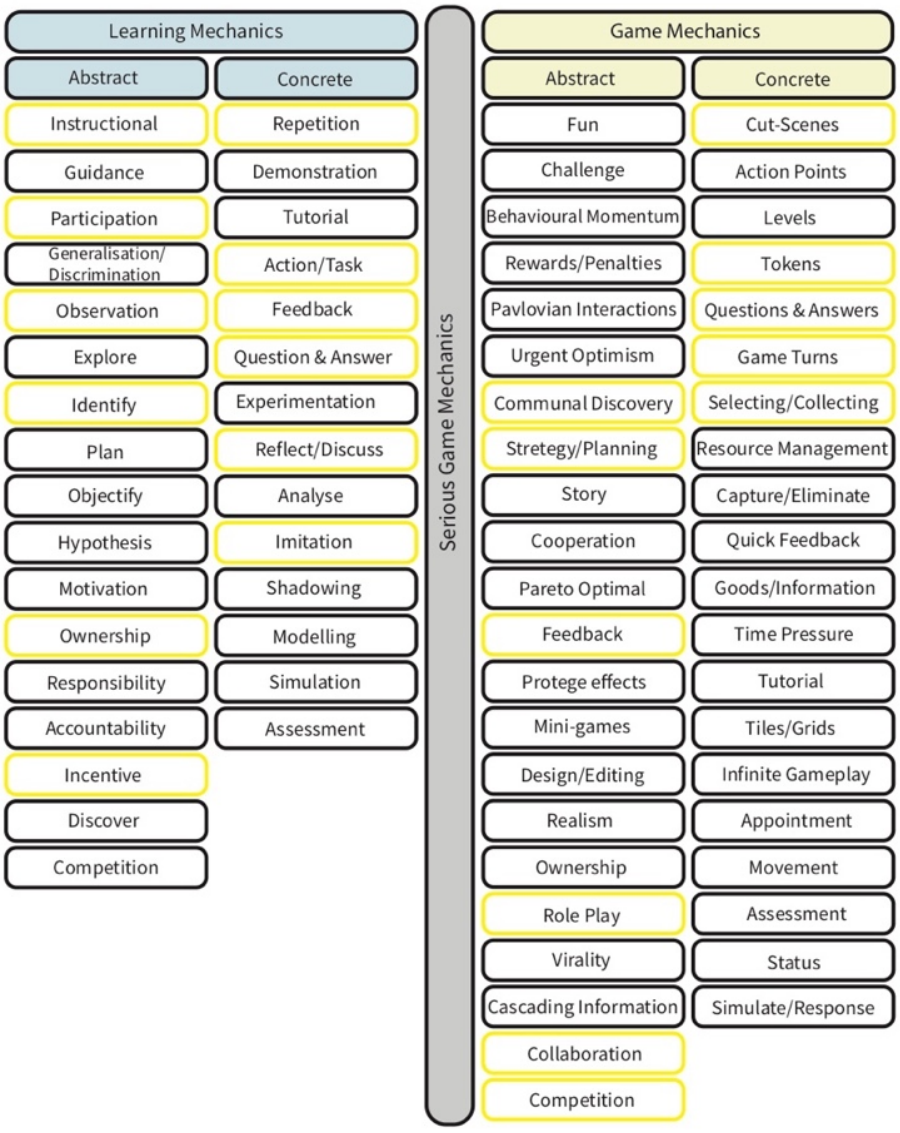

Figure 28. Game board mechanics, LM-GM for Level 3

6. Discussion

The undertaking of designing a serious game has been highly challenging, particularly in forcing required elements of communication into game-mechanics. Further, communicating the core work of this research can be equally challenging as there are two goals embedded within the work:

1) research on modes of communication and multisensory interactions
2) translating communication modes into actionable learning outcomes through serious games design for surgical team members.

6.1 Reflection of the Framework

The creation of the framework allowed for specific elements to be distinguished as the core aspects of communication within the research and to evaluate which elements were not relevant to the scope of the project. The framework has also allowed for the developed prototype to be properly positioned for future work. Particularly, the framework serves as a conceptual area of exploration through which the concrete, prototyped games are anchored. The combination of the prototype and framework within this research support one another through both rationale and evidence. The development of the framework may have the capacity to support further exploratory research in the area of communication modes within the context of the surgical environment.

6.2 Reflection on the Prototypes

For the purpose of this project, the developed prototypes have the ability to be both a product and a tool through which to generate new knowledge and insights. Both of the game prototypes are considered to be finalized within the scope of this project and can be further developed in future iterations.

While the games can be played as is, further development is required in order to test the assumed learning outcomes of players. It is currently difficult to be assess the quality and functionality of the game whilst in development, without the expertise of the end users, the surgical team members. The game has yet to be played by members of the surgical team but it has been observed and tested by Black Box coordinators and surgical analysts from St. Michael's Hospital in Toronto. The medium fidelity, paper-based prototype was presented to a lead laparoscopic surgeon, a surgical team coordinator and a surgical analyst for feedback and evaluation, upon which the current iterations were approved for moving forward. Testing is also required in order to evaluate whether players are able to determine how the game is to be played based on the instruction manual alone. It has yet to be determined whether or not the game-mechanics will allow for effective learning and be an engaging game. Specifically in relation to the third level of the game, user testing is required in order to determine if the game functions in accordance with both video footage of the surgical procedure and the debrief session.

As the current games are focused on providing players with a fundamental understanding of the modes of communication and aspects of resiliency, there is space for additional developments in relation to only communication or only resiliency. Such a development, in terms of communication modes, could be envisioned in the form of the combinations of communication modes required in order to complete the various, lower-level actions encompassed within the higher-level action of the procedure itself. It could be interesting to evaluate how players determine entire sequences of communications, which sequences are given more value or and which sequences are used most frequently.

As the concepts of the games are unknown to surgical team members, players will not experience gaps in learning. All players will learn at the same rate and progress together, regardless of professional experience and surgical discipline. The game does not require training and can be played independently by team members, with minimal commercial cost. The games are also multidisciplinary, incorporating all major roles into play and team members are pushed to consider how various roles would respond to a scenario. This form of learning through role rotation is known as cross-training and provides team members with the ability to assess a scenario from the perspective of peers (Gaba et al., 2005).

6.3 Limitations

The limitations of this study are two-fold due to time constraints related to REB approval and the inability to coordinate user testing with medical professionals in such a short window of time. It was therefore not possible to demonstrate the usability of the games in relation to improved learning and comprehension. It was also not possible to evaluate the impressions of medical professionals as they interacted with the various elements of the game. These limitations will be resolved within future research and prototyping.

6.4 Future Research

The effectiveness of the games requires testing with various surgical team members and will aim to evaluate player reaction and learning. Testing will aim to evaluate the content, functionality and learning outcomes of the games, in relation to surgical team members. In order to assess the comprehension and applicability of these elements for both medical learners and medical professionals, pre-game and post-game surveys and semi-structured interviews will be administered to those participating in usability testing. Surveys and interviews will aim to assess awareness of communication modes and resiliency prior to playing the games and evaluate comprehension after players have interacted with the various game components.

6.5 Conclusion

This game is introduced as a teaching tool, with the specific intentions of educating medical students and medical professionals on communication modes and resiliency in the operating room. In the context of this game, the teaching and learning is achieved through the act of simulation. The game simulates real-world scenarios that correspond to surgical procedure in the operating room. After playing a number of rounds, the new concepts being introduced should have the potential to be transferred to real world. Players should have the ability to recognize combinations of response cards as being strong or weak and will receive immediate feedback from the facilitator as to how the responses affect the outcome of the game. This ensures that players understand which communication modes can be of value within a specific context. While a simulation can take on numerous forms, a balance was sought between reality, simplicity and fun. The scenarios aimed to provide a humorous lesson, both general to the context of surgery but specific to the personnel. Not only does an analogue game increase team interaction in the same space, it ensures that players have tangible tools with which to interact.

The games developed are centered around the topics of communication modes and resiliency in the operating room. The content is delivered in the form of different levels (novice, intermediate and expert) in order to introduce one topic at a time and provide players with time to develop skills and strategy in relation to the concepts.

The intention of the games is to provide a space where various personnel with multidisciplinary backgrounds can interact with one another outside of the Operating Room. Not only is there a wide array of educational and professional experience in the same space, but teams have the added ability of learning from peers in a manner that is less rigid in nature. For example, medical students have the ability to learn in the same flexible environment as an attending surgeon and will have the opportunity to build rapport with one another while contributing to the discussion surrounding the game play. This form of interaction is rare within the medical profession as many personnel are siloed and do not often cross paths outside of the OR. This game also has the ability to level the playing field. These non-technical, invisible skills are not well known and have not yet been introduced comprehensively within professional training or the educational curriculum. Therefore, regardless of professional experience, all team members are relatively well aligned in relation to learning ability, as, in this space, each team member is a novice learner. The various team members then experience learning as a group, providing the opportunity to increase team morale and familiarity.

Within the surgical environment, certain types of communications can be pronounced during interactions and heavily relied upon during communication. In instances where verbal communication cannot be used during a procedure, alternative system could be developed in order to offer examples for

replacements. Such a system of specialized gestures, movements, gazes, haptic cues and so forth, could be of particular use for team members in order to coordinate specific tasks, responsibilities or roles. While meaning can be conveyed through various non-verbal modes within the operating room, the possibility of miscommunication can lead to an adverse event during a procedure. Thus, it is integral that differences between non-verbal communications be understood as well as the meanings that are conveyed in order to avoid potential miscues, misunderstandings and adverse errors.

7. References

Argyle, M., & Dean, J. (1965). Eye-contact, distance and affiliation. *Sociometry*, 289-304.

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., Freitas, S., Louchart, S., ... & De Gloria, A. (2015). Mapping learning and game mechanics for serious games analysis. *British Journal of Educational Technology*, *46*(2), 391-411.

Baby, B., Srivastav, V., Singh, R., Suri, A., & Banerjee, S. (2016, March). Serious Games: An overview of the game designing factors and their application in surgical skills training. In *Computing for Sustainable Global Development (INDIACom), 2016 3rd International Conference on* (pp. 2564-2569). IEEE.

Carter, D. (2003). The surgeon as a risk factor. *BMJ*. 326, p.832-3.

Chandler, D. (2007). *Semiotics: the basics*. Routledge.

Cope, A. C., Mavroveli, S., Bezemer, J., Hanna, G. B., & Kneebone, R. (2015). Making meaning from sensory cues: A qualitative investigation of postgraduate learning in the operating room. *Academic Medicine*, *90*(8), 1125-1131.

Coulthard, M. and Brazil, D. (1981) 'Exchange Structure' in M. Coulthard and M. Montgomery, eds. *Studies in Discourse Analysis*, London, Routledge and Kegan Paul

Crossley, J., Marriott, J., Purdie, H., & Beard, J. D. (2011). Prospective

observational study to evaluate NOTSS (Non-Technical Skills for Surgeons) for assessing trainees' non-technical performance in the operating theatre. *British Journal of Surgery*, *98*(7), 1010-1020.

Donaldson, M. S., Corrigan, J. M., & Kohn, L. T. (Eds.). (2000). *To err is human: building a safer health system* (Vol. 6). National Academies Press.

Ernst, M. O., & Banks, M. S. (2002). Humans Integrate Visual and Haptic Information in a Statistically Optimal Fashion. *Nature 415,* 429-433.

Flin, R., Martin, L., Goeters, K. M., Hörmann, H. J., Amalberti, R., Valot, C., & Nijhuis, H. (2003). Development of the NOTECHS (non-technical skills) system for assessing pilots' CRM skills. *Submitted to Human Factors and Aerospace Safety*.

Flin, R., Yule, S., Paterson-Brown, S., Rowley, D., & Maran, N. (2006). The non-technical Skills for Surgeons (NOTSS) system handbook v1. 2. *University of Aberdeen, Scotland*.

Flin, R. (2013). Non-technical skills for anaesthetists, surgeons and scrub practitioners (ANTS, NOTSS and SPLINTS). *The Healthcare Foundation*, 1-9.

Flin, R., Youngson, G. G., & Yule, S. (Eds.). (2015). *Enhancing surgical performance: A primer in non-technical skills*. CRC Press.

Gaba DM, Howard SK, Fish KJ, Smith BE, Sowb YA. Simulation-based training in anesthesia crisis resource management (ACRM): a decade of experience. Simulat Gaming. 2001;32(175):175-93.

Gawande, A. A., Zinner, M. J., Studdert, D. M., & Brennan, T. A. (2003). Analysis of

errors reported by surgeons at three teaching hospitals. *Surgery*, *133*(6), 614-621.

Gee, J. P. (2005, June). Good video games and good learning in Phi Kappa Phi Forum, 85(2), pp. 33 – 37.

Graafland, M., Vollebergh, M. F., Lagarde, S. M., van Haperen, M., Bemelman, W. A., & Schijven, M. P. (2014). A serious game can be a valid method to train clinical decision-making in surgery. *World journal of surgery*, *38*(12), 3056-3062.

Guo, J., Singer, N., & Bastide, R. (2014, May). Design of a serious game in training non-clinical skills for professionals in health care area. In *Serious Games and Applications for Health (SeGAH), 2014 IEEE 3rd International Conference on*(pp. 1-6). IEEE.

Habermas, J. (1984) *The Theory of Communicative Action*, vol. 1, *Reason and the Rationalization of Society*, trans. by T. McCarthy, Boston, MA: Beacon Press.

Halliday, M.A.K. (1985) *An Introduction to Functional Grammar*, London, Arnold

Hoyert, D. L., Kung, H. C., & Smith, B. L. (2005). Deaths: preliminary data for 2003. *National vital statistics reports*, *53*(15), 1-48.

Keehner, M., & Lowe, R. (2010, March). Seeing with the Hands and with the Eyes: The Contributions of Haptic Cues to Anatomical Shape Recognition in Surgery. In *AAAI Spring Symposium: Cognitive Shape Processing*.

Kendon, A. (1964). The distribution of visual attention in two-person

encounters. *Re-port to Dept. of Scientific and Industrial Research, London.(1967)"Some functions of gaze direction in social interaction Acta Psychologica*, *26*, 1971.

Kendon, A. (1997). Gesture. *Annual review of anthropology*, *26*(1), 109-128.

Klatzky, R. L., & Lederman, S. J. (1987). The intelligent hand. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 21, pp. 121-151). San Diego: Academic Press.

Klatzky, R.L. & Lederman, S.J. (1999). The haptic glance: A route to rapid object identification and manipulation. In D. Gopher & A. Koriats (Eds.) *Attention and Performance XVII. Cognitive regulations of performance: Interaction of theory and application.* (pp. 165-196). Mahwah, NJ: Erlbaum

Kress, G. and Van Leeuwen, T. (2001) *Multimodal Discourse: the Modes and Media of Contemporary Communication*, London: Edward Arnold.

Leonard, M., Graham, S., & Bonacum, D. (2004). The human factor: the critical importance of effective teamwork and communication in providing safe care. *BMJ Quality & Safety*, *13*(suppl 1), i85-i90.

Makary, M. A., & Daniel, M. (2016). Medical error-the third leading cause of death in the US. *BMJ: British Medical Journal (Online)*, *353*.

Mitchell, L., Flin, R., Yule, S., Mitchell, J., Coutts, K., & Youngson, G. (2012). Evaluation of the Scrub Practitioners' List of Intraoperative Non-Technical Skills (SPLINTS) system. *International Journal of Nursing Studies*, 49, 201-211

Mitchell, L., Flin, R., Yule, S., Mitchell, J., Coutts, K., & Youngson, G. (2013).

Development of a behavioural marker system for scrub practitioners' non-technical skills (SPLINTS system). *Journal of evaluation in clinical practice*, *19*(2), 317-323.

Moore, A. R., Butt, D., Ellis-Clarke, J., & Cartmill, J. (2010). Linguistic analysis of verbal and non-verbal communication in the operating room. *ANZ journal of surgery*, *80*(12), 925-929.

Moore, A. R (2011). Surgical teams in action: a contextually motivated view of interpersonal engagement and body alignment. *Baldry/Montagna (eds)*.

Nance, J. J. (2004). Admitting imperfection: revelations from the cockpit for the world of medicine. *The patient safety handbook 1st ed. Boston: Jones & Bartlett*, 187-203.

Norris, S. (2004). *Analyzing multimodal interaction: A methodological framework*. Routledge.

Qin, J., Chui, Y. P., Pang, W. M., Choi, K. S., & Heng, P. A. (2010). Learning blood management in orthopedic surgery through gameplay. *IEEE computer graphics and applications*, *30*(2), 45-57.

Salas, E., Rozell, D., Mullen, B., & Driskell, J. E. (1999). The effect of team building on performance: An integration. *Small group research*, *30*(3), 309-329.

Salas, E., Rhodenizer, L., & Bowers, C. A. (2000). The design and delivery of crew resource management training: exploiting available resources. *Human factors*, *42*(3), 490-511.

Salas, E., Cooke, N. J., & Rosen, M. A. (2008a). On teams, teamwork, and team

performance: Discoveries and developments. *Human factors*, *50*(3), 540-547.

Salas, E., DiazGranados, D., Weaver, S. J., & King, H. (2008b). Does team training work? Principles for health care. *Academic Emergency Medicine*, *15*(11), 1002-1009.

Sanders, E. B. N., & Stappers, P. J. (2014). Probes, toolkits and prototypes: three approaches to making in codesigning. *CoDesign*, *10*(1), 5-14.

Sarker, K. S., Vincent, C. (2005). Errors in surgery. *International Journal of Surgery*, 3, p. 75-81. DOI:10.1016/j.ijsu.2005.04.003

Saussure, F. de (1974 [1916]) *Course in General Linguistics*, London, Peter Owen

Stappers, PJ, Sleeswijk Visser, F, & Keller, AI (2014) The role of prototypes and frameworks for structuring explorations by research through design. In: Rodgers, P & Yee, J. (Eds) The Routledge Companion to Design Research. Taylor & Francis. ISBN 978-0415706070, 163-174

Strategies, C.R.I.C.O. (2016). Malpractice risks in communication failures: 2015 annual benchmarking report. *Cambridge, MA. Available at https://www. rmf.harvard.edu/cbsreport*.

Sutcliffe, K. M., Lewton, E., & Rosenthal, M. M. (2004). Communication failures: an insidious contributor to medical mishaps. *Academic Medicine*, *79*(2), 186-194.

Thomas EJ, Brennan TA. (2001). Errors and adverse events in medicine: an overview. In: Vincent CA, editor. Clinical risk management. Enhancing patient safety. London: BMJ Publications.

Ushaw, G., Eyre, J., & Morgan, G. (2017, April). A paradigm for the development of serious games for health as benefit delivery systems. In *Serious Games and Applications for Health (SeGAH), 2017 IEEE 5th International Conference on*(pp. 1-8). IEEE.

Van Leeuwen, T. (2005). *Introducing social semiotics*. Psychology Press.

Vicente, K. J. (2013). *The human factor: Revolutionizing the way people live with technology*. Routledge.

Xiao, Y., Schimpff, S., Mackenzie, C., Merrell, R., Entin, E., Voigt, R., Jarrell, B. (2007). Video Technology to Advance Safety in the Operating Room and Perioperative Environment Surgical Innovation. *Sage Publication*. Vol 14 (1), p. 52-61, DOI: 10.1177/1553350607299777

Yule, S., Flin, R., Maran, N., Rowley, D., Youngson, G., & Paterson-Brown, S. (2008). Surgeons' non-technical skills in the operating room: reliability testing of the NOTSS behavior rating system. *World journal of surgery*, *32*(4), 548-556.

Yule, S., Rowley, D., Flin, R., Maran, N., Youngson, G., Duncan, J., & Paterson-Brown, S. (2009). Experience matters: comparing novice and expert ratings of non-technical skills using the NOTSS system. *ANZ journal of surgery*, *79*(3), 154-160.

8. Appendix A: Glossary of Terms

Glossary of Terms

Anesthesiologist

A physician specializing in anesthesiology and related areas who is board certified and legally qualified to administer anesthetics.

Anesthetic

A drug or gas that causes insensitivity to pain (p. 41 – Oxford), administered before a surgical operation

Attending Surgeon

A surgical member of the attending staff of a hospital. The attending surgeon has completed their medical residency and practices as a surgeon. Their duties include supervising fellows, residents, medical students, and other practitioners.

Circular Nurse

A certified nurse who is a member of the surgical team and responsible for all non-sterile activity in the operating room. Their responsibilities include coordinating patient support, tool retrieval, assistance to the surgical team, identifying potential environmental hazards, maintenance of communications, and an advocate for the patient.

Communication Mode

Considered a verbal or non-verbal means of conducting a communication exchange between two or more team members.

Fellow

A board-qualified specialist pursuing any range of subspecialty training post-medical school. During surgery, a fellow is considered to be in a more senior position than the resident and trained to execute a small portion of the procedure.

General Surgery

The treatment of injury, disease or deformity through an operative surgery.

Intraoperative

An event or action occurring during a surgical operation.

Laparoscopic Surgery

A minimally invasive endoscopic examination of the abdomen.

Operating Room

Also known as the operating theatre or the OR, a room within the hospital that is equipped for the performance of surgical operations.

Resident

A physician who holds a medical degree and is licensed to practice medicine. The duration of a residency is roughly three years in length, following four years of medical school.

Respiratory Therapist

A specialized healthcare practitioner trained in pulmonary medicine. Their role in the surgical space includes supporting intensive care units, emergency departments and trauma resuscitations. They are responsible for stabilizing, treating and managing patients transported by air or ground ambulance. This role can also be referred to as a technician.

Scrub Nurse

A surgical nurse in the operating room who is responsible for the sterilization and coordination of surgical tools and instruments. The scrub nurse scrubs in for each procedure and is considered sterile.

Simulation

Real-world processes or systems that require simulation in order to understand the limitations. Simulation first requires the development of a model in order to understand the key characteristics, behaviours and functions of the systems or processes.

Surgeon

A medical practitioner qualified to practise surgery (p. 1302 – Oxford)

Surgery

The branch of medicine concerned with treatment of bodily injuries or disorders by incision or manipulation (p. 1302 – Oxford)

Surgical Resident

A medical graduate enrolled in a specialized, hospital-based training program who practises under supervision while completing board certification in a chosen surgical speciality

Registrar

A middle ranking hospital doctor undergoing training as a specialist (p. 1084 – Oxford)

UHN

The University Health Network is a medical research organization located in Toronto, Ontario, Canada. It is the largest research organization in North America.

Vascular Surgery

A surgical subspecialty that manages diseases of the vascular system, arteries and veins through medical therapy, minimally invasive catheter procedures and surgical reconstructions.

9. Appendix B: A Brief Introduction to Resiliency

As adverse errors and patient safety are discussed in relation to multisensory communication within this MRP, the game prototypes have further incorporated resiliency as a core component into both the Learning Mechanics and Game Mechanics. The game prototypes have been a joint venture between two design researchers and, for the purpose of interests and scope, all aspects of resiliency have been explored and researched by Laura Halleran while all aspect of multisensory communication have been discussed in this MRP by Cait Jordan.

Resiliency is integral to healthcare training and performance improvement within the operating room. As defined by Hollnagel, resiliency is considered to be, "the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions"[1].
In order to understand the benefits of resiliency, Hollnagel discusses the four, interdependent, cornerstones: monitoring, anticipating, learning, responding[2].
By assessing daily routines and determining how workarounds and stress management occur, surgical team members have already begun to determine strategies for resiliency, yet, as with modes of communication, it is considerably challenging to comprehend such intangible concepts. Resiliency has therefore

been integrated into the design of the serious games as a means through which communication modes can be expressed.

References:

1. Hollnagel E, Braithwaite J, Wears RL. Resilient Health Care. Hollnagel E, Braithwaite J, Wears RL, editors. Surrey: Ashgate Publishing Limited; 2013. 297 p.
2. Hollnagel E. Prologue: the scope of resilience engineering. Resil Eng Pract A Guideb [Internet]. 2011;xxix–xxxix. Available from: http://www.gowerpublishing.com/pdf/SamplePages/Resilience_Engineering_in_Practice_Prol.pdf