Creating Effective Learning Platform

for Neonatal Resuscitation Knowledge and Skills Retention through Serious Game Design

Dongjun (Chloe) Li
MDes, University of Alberta

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Dongjun (Chloe) Li

Supervisor: Robert Lederer

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Abstract

Birth is a magical moment for a newborn baby when they go from dependent support in the womb to breathing independently. These are significant physiological changes in every newborn babies' life. Nevertheless, approximately 10%-15% of babies need help at birth. To improve neonatal survival, healthcare professionals (HCPs) may need to perform neonatal resuscitation. This medical emergency requires rapid, knowledgeable, and skillful responses. To be successful it requires frequent simulation-based education to improve their knowledge and skills during neonatal resuscitation. However, the current educational approaches are resource-intensive and have prohibited HCPs to practice frequently. There is a need for an accessible alternative learning platform offering HCPs to improve their cognitive, psychomotor and communication skills.

This study focused on designing a serious game as a learning alternative supporting neonatal resuscitation training. The study's overarching aim is to form a structural framework to guide serious game design and investigate design practices to offer HCPs an accessible and immersive learning environment. User research is achieved by reviewing HCP's interview scripts and eye-tracking video of neonatal resuscitation and the observation of neonatal resuscitation in the Neonatal Intensive Care Unit (NICU). The user research analyzes neonatal resuscitation's human factors, including teamwork and team communication, psychological, cognitive state, the design and organization of the equipment and environment. The study developed a framework by integrating experiential learning and the core elements for serious game design, including immersion and engagement, fidelity, emotion, entertainment, game difficulty, and feedback. This research's primary outcome takes the form of a prototype called the VR RETAIN (the Virtual Reality REsuscitation TrAINing for Healthcare Professionals) —an interactive VR game-based learning platform to support neonatal resuscitation training. The VR RETAIN adopted the proposed serious design framework to guide the design process. During the play, HCPs could improve their knowledge by going through the learning cycle of experiencing scenarios, reflecting on their performance, concluding their knowledge understanding and testing modifications in a new scenario.

This study explores the use of a serious game for developing better medical education. For the future development of the serious game, there is a need for an interdisciplinary team from the fields of design, medicine, education, and computer science.

Keywords:
Neonatal Resuscitation
Serious Game
User Experience Design
Medical Education
Experiential Learning

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Acronyms

AAP: the American Academy of Pediatrics

AHA: the American Heart Association

AI: Artificial intelligence

AR: Augmented reality

COVID-19: Coronavirus disease 2019

CPAP: Continuous positive airway pressure

ECG: Electrocardiogram

HALO: High Acuity, Low Occurrence

HCPs: Healthcare professionals

NICU: Neonatal Intensive Care Unit

NRP: Neonatal Resuscitation Program

PEEP: Positive end-expiratory pressure

PIP: Peak inspiratory pressure

PPV: Positive-pressure ventilation

RETAIN: REsuscitation TrAINing for Healthcare Professionals

SBME: Simulation-based medical education

VR: Virtual reality

VR RETAIN: Virtual Reality REsuscitation TrAINing for Healthcare Professionals

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Chapter 1 Introduction

The birth of babies is a crucial occasion for every life. When babies transition from intrauterine to extrauterine life, they need to complete the conversion from placental gas exchange to pulmonary respiration (Perlman et al., 2015). However, there are 10% of newborn babies unable to breathe spontaneously. If these babies are not getting interventions to establish breathing immediately after birth, it will result in birth asphyxia.

Neonatal resuscitation is a set of interventions to support babies' transition at birth and has been a significant focus to reduce neonatal mortality and morbidity (Weiner, Zaichkin, & Kattwinkel, 2016). The most common neonatal resuscitation interventions include drying, pure stimulation, suction, and respiratory support. Less than 1% of babies require more advanced interventions, including endotracheal intubation, chest compressions, and medications. In 1985, the American Academy of Pediatrics (AAP) and the American Heart Association (AHA) reached a joint agreement to develop a training program to improve neonatal resuscitation called Neonatal Resuscitation Program (NRP).

Neonatal resuscitation is High Acuity, Low Occurrence (HALO) event requiring both high levels of technical and non-technical competency to make a decision and execute operation effectively and quickly. Deficiencies while performing neonatal resuscitation could result in fatal errors and poor patient outcomes. A sentinel report from 2004 reviewed the cause of perinatal death or permanent disability (The Joint Commission, 2004).Among the 47 cases, 72% identified the root cause of perinatal death or permanent disability as poor communication skills and teamwork; 47% cause as HCPs' competency, and 40% cause from the deficiencies in orientation and training process. To address this issue, the neonatal resuscitation guidelines recommend simulation-based medical education (SBME) (Perlman et al., 2015). SBME has been identified as a highly effective instructional strategy for the acquisition and retention of skills required to competently perform in dynamic, high-pressure, high-consequence environments such as the NICU (Anderson & Warren, 2011).

While studies have reported that SBME activities have reduced neonatal morbidity and mortality in real-life clinical situations (Mduma et al., 2019). The SBME is both financial and human-capital intensive requiring equipment, manikins, and experienced instructors trained in simulation education. Consequently, healthcare facilities have to provide enough simulation opportunities for HCPs (Mileder, Urlesberger, Szyld, Roehr, & Schmölzer, 2014).The optimal frequency of simulation training is crucial for maintaining neonatal resuscitation knowledge and skills. Studies have shown that with maternity care professionals who have attended simulation training, they have demonstrated that they retain knowledge. However, alarming loss of significant skill performance occurs three months after training for resuscitation (Marshall, 2014). This issue is amplified for the HCPs who work in remote and rural delivery centers with fewer simulation resources and fewer deliveries a year. The insufficient simulation training has a further negative impact on HCPs' confidence and belief in the effectiveness of an intervention that may result in delayed initiation of resuscitation or ineffective performance. Based on this situation and as the current simulation training is time-intensive and cost-intensive, an accessible alternative training method is needed for HCPs to practice their knowledge and skills.

Serious games designed for a serious purpose, such as educational training other than pure entertainment, are growing rapidly as an accessible alternative in academic research. Serious games use active, experiential, or problem-based learning to motivate learners to develop their skills enjoyably. Moreover, compared to the traditional simulation, game-based simulation enables learners to experience situations that are difficult (even impossible) to achieve in real life due to factors such as cost, time, and safety concerns (Kurt Squire & Henry Jenkins, 2003). Therefore, game-based simulation has been increasingly used as a supplemental teaching tool in SBME, including neonatal resuscitation training. Many medical education areas, including surgery, emergency medicine, and anesthesiology, have introduced serious games as SBME and reported a positive outcome on HCPs' performance (Ghoman et al., 2020).

Serious games foster Higher-Order thinking for HCPs by providing them an enjoyable

active learning experience of dealing with the high emergency clinical situation. To create a real-world situation for learners to explore and learn, knowledge and technology are integrated with various visualized ways. Current serious games include tabletop games, computer games, and virtual reality (VR) and augmented reality (AR) games. For this thesis, all games, including board games, tabletop games, video games, web games, screen-based simulators, tabletop simulators, VR games, and artificial intelligence (AI) games. Depending on each type of the game's, a targeted learners' performance can be improved. For instance, a serious table-top game could improve learners' communication skills as they sit around a table and communicate with each other. A computer game could help learners to reflect their performance and address their weaknesses without an instructor monitoring aside by providing an artificial intelligence feedback system. VR games could get the learners immersed in a virtual and interactive environment. The learning is achieved by experiencing engaging content. In this thesis, the proposed strategy is to design a serious VR game to improve the performance of HCPs in neonatal resuscitation, especially for intermediate and advanced learners, by providing a high immersive, engaging learning environment and a practical evaluation and feedback system.

This thesis focuses on applying game elements into formal contexts for learning practice, specifically in the medical education field.

Chapter 1 includes a general background of neonatal resuscitation and simulation-based medical education. As neonatal resuscitation plays a crucial role in supporting babies' transition at birth and reducing neonatal mortality and morbidity, sufficient neonatal resuscitation training is imperative. However, the current simulation training is time-intensive and cost-intensive to support a HCPs' need for high training frequency. The study discusses the opportunities for using game-based simulation as an accessible supplemental teaching tool in SBME to acquire and retain knowledge and skills.

Chapter 2 describes a detailed introduction of neonatal resuscitation, including its background, technical steps and human factors such as teamwork requirements. The experiential learning theory consists of a four-stage learning cycle (concrete experience, reflective observation, abstract conceptualization and active

experimentation) and four separate learning styles (accommodating, diverging, converging, assimilating). Analysis of the limitations of the current learning method for neonatal resuscitation and game-based learning needs along with qualitative analysis of several existing games for neonatal resuscitation training.

Chapter 3, through reviewing interview scripts and the eye-tracking videos, and observing the process of neonatal resuscitation, I analyzed the human factors of neonatal resuscitation from the teamwork and team communication to psychological, cognitive state, the design and organization of the equipment and environment in NICU. An HCP's journey map on neonatal resuscitation was developed based on the analysis discussed above. The map presents a detailed neonatal resuscitation process showing the problem or user pain points during the process and the potential design opportunities for problem-solving.

Chapter 4, from a designer's perspective, an analytical synthesis of the core elements for serious game design, including immersion and engagement, fidelity, emotion, entertainment, game difficulty, and feedback. This chapter's focus is on interweaving these core elements into the design process to create an immersive, engaging learning environment to optimize the learning outcome. Subsequently, a serious game design framework is proposed. The framework presents the relationship between the described elements and integrates them within the experiential learning cycle. The framework aims to provide structural guidance for serious game design, especially the games relevancy to simulation training.

Chapter 5, I provide an overview of the integrative design process of the VR RETAIN. The proposed framework is adopted as a principle to guide the VR RETAIN design process. This chapter discusses the core design process and how neonatal resuscitation training is integrated with and activated by core game mechanics, rules, game objects, game feedback and the game environment design. The initial design prototype of the game, including the game environment rendering and interface, is presented.

Chapter 6 discusses the limitations of this study and the potential directions of future design and concludes the serious design's research efforts at this time.

Chapter 2 Neonatal Practices

2.1 Introduction of Neonatal Resuscitation

2.1.1 Background

Most newborn babies successfully make this transition from fetal to neonatal life without help. Nevertheless, an estimated 10%-15% of babies worldwide need interventions to breathe at birth. Studies demonstrated that approximately 85% of babies born at term would initiate spontaneous respirations within 10 to 30 seconds of birth, an additional 10% will respond to drying and stimulation, 3% will initiate respirations after positive-pressure ventilation (PPV), 2% will be intubated to support respiratory function, and 0.1% will need chest compressions and/or epinephrine to achieve this transition (Perlman et al., 2015). Although most babies do not require intervention to start breathing spontaneously, there is still a large number of births worldwide where infants meet HALO situations and need to be helped at birth.

Neonatal resuscitation, broadly defined as support for successful transition at birth, has been a significant focus on all efforts to improve neonatal survival (Weiner et al., 2016). Neonatal resuscitation is a highly stressful medical emergency requiring rapid, knowledgeable, and skillful responses based on the understanding of the complex scenarios. Globally there has been an increase in a skilled birth attendant presence over the past 20 years. Medical errors by these healthcare providers remain common and are responsible for more than 40% of neonatal mortality (Pathirana et al., 2016). Health care providers who attend deliveries and treat the babies in the NICU must be well prepared. Their presence to perform resuscitation is a cornerstone of neonatal resuscitation. To improve outcomes, neonatal resuscitation guidelines recommend SBME for HCPs to improve knowledge, skills, and teamwork performance (Perlman et al., 2015).

2.1.2 Neonatal Resuscitation Steps

The current SBME programs, such as the Neonatal Resuscitation Program, provide standardized education and algorithms to guide HCPs in neonatal resuscitation

(Weiner et al., 2016). It helps HCPs learn the cognitive, technical, and teamwork skills needed to resuscitate and stabilize newborn babies. To achieve this goal, the NRP published the Textbook of Neonatal Resuscitation based on current practice, rational conjecture, and an informal consensus among experts. In the 7th edition (latest version) of the textbook the NRP Flow Diagram (see Figure 2.1.1.1) describes the steps to evaluate and resuscitate a newborn. It is divided into five parts starting with preparing the resuscitation and initial assessment and care. Each diamond in the flow chart gives evidance to HCPs to proceed to the further resuscitation steps or staying/ going back to routine care. As too many interventions can be harmful to a newborn baby, HCPs must assess the baby's situation carefully and try to avoid unnecessary intervention steps as much as possible. The detailed explanation of the NRP Flow Diagram given by the textbook is stated below:

> *"Initial Assessment: Determine if the newborn can remain with the mother or should be moved to a radiant warmer for further evaluation." (p.8)*

> *"Airway (A): Perform the initial steps to establish an open Airway and support spontaneous respiration." (p.8)*

> *"Breathing (B): Positive-pressure ventilation is provided to assist Breathing for babies with apnea or bradycardia. Other interventions (continuous positive airway pressure [CPAP] or oxygen) may be appropriate if the baby has labored breathing or low oxygen saturation." (p.8)*

> *"Circulation (C): If severe bradycardia persists despite assisted ventilation, Circulation is supported by performing chest compressions coordinated with PPV." (p.10)*

> *"Drug (D): If severe bradycardia persists despite assisted ventilation and coordinated compressions, the Drug epinephrine is administered as PPV and chest compressions continue." (p.10)*

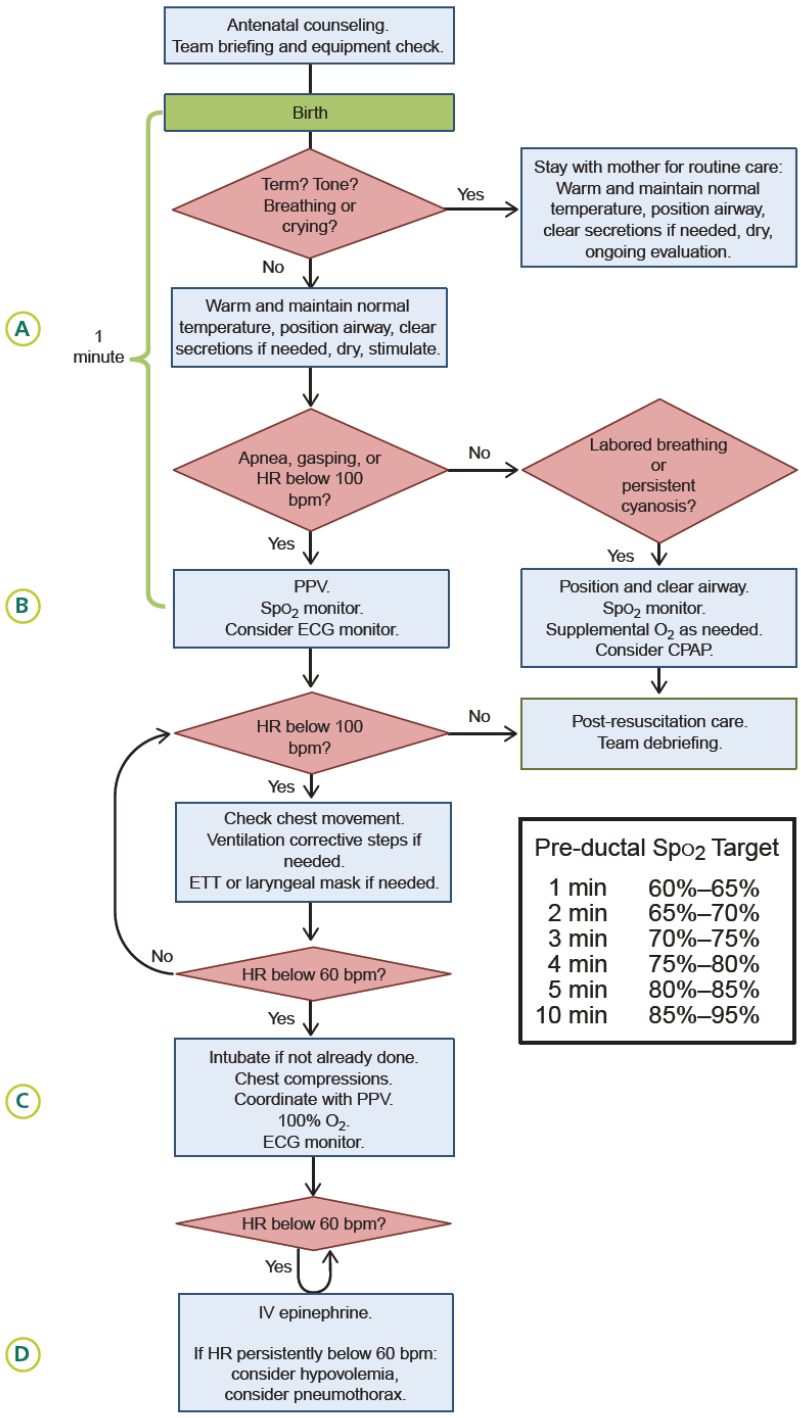

Figure 2.1.1.1 The NRP Flow Diagram

Source: (Weiner et al., 2016)

Unlike the focus on the restitution of cardiac operation for adult resuscitation, most newborns requiring resuscitation have a healthy heart, and the focus is the ventilation of the lungs. The fetus's lungs are filled with liquid and instead of taking oxygen from the lungs, the fetus receives oxygen-rich blood from the mother's placenta. After birth, when the baby takes its first breaths, its lung fills with air, and the blood flow is redirected to start passing through the lungs to be oxygenated. Then, the baby can use their lungs for gas exchange. Although in most circumstances, this healthy initial transition occurs within a few minutes of birth, there are still many babies who failed to initiate this respiratory effort independently. Thus, the core of neonatal resuscitation is to helping babies to establish adequate respiratory physiology.

2.1.3 Human Factors in Neonatal Resuscitation

Apart from technical factors, non-technical factors such as decision making, teamwork also play a crucial role in neonatal resuscitation. Studies in high resource settings have demonstrated that deficiencies in non-technical skills were the reasons for the majority of fatal errors and poor patient outcomes (Ghoman et al., 2020; Pathirana et al., 2016; Rall, Manser, Guggenberger, Gaba, & Unertl, 2001). Neonatal resuscitation is a highly stressful medical emergency. HCPs must perform multiple procedures rapidly and effectively. Any delay in decision making or team communication can result in a severe problem. Even for the experienced HCPs who have sufficient knowledge and skills to perform a successful resuscitation, each person's skills may not be used optimally due to some non-technical issues such as ineffective team communication. Therefore, improving non-technical performance is essential for reducing neonatal mortality and morbidity in high and low resource settings.

Neonatal resuscitation should be a team activity that involves a minimum of two persons who work together. Depending on the complexity of the scenario, the team members could be more than five persons. Breakdowns in teamwork can decrease the quality of neonatal resuscitation.

Before a babies' birth, the first steps in preparing for resuscitation is a team pre-briefing which includes (Weiner et al., 2016):

- Assign each team member's role and tasks
- Review the clinical situation and the action plan
- Assess perinatal risk factors.
- Identify a team leader.
- Delegate tasks.
- Identify who will document events as they occur.
- Determine what supplies and equipment will be needed.
- Identify how to call for additional help.

Team pre-brief is very important for achieving a successful neonatal resuscitation. Based on the interviews with the HCPs at the Royal Alexandra Hospital and the video recordings, the resuscitation team does not execute team pre-briefing very often. This issue can be caused by many reasons, such as time pressure. A more detailed analysis will be discussed in Chapter 3.

Sequentially, during the resuscitation, as the team goes through the NRP Flow Diagram, every team member must maintain a shared mental model to ensure that interventions are performed in the correct sequence with the correct technique. The components of such a shared mental model include situational awareness, using available information, information sharing and delegating workload optimally. The Textbook of Neonatal Resuscitation lists ten essential NRP behavioral skills (see Figure 2.1.2.1) adapted from the Center for Advanced Pediatric and Perinatal Education, Lucile Packard Children's Hospital at Stanford University (Weiner et al., 2016). This list provides an overview of vital behavioral skills and their use in neonatal resuscitation.

Behavior	Examples
Know your environment.	• Perform an equipment check before the baby is delivered. • Know the location of resuscitation equipment and how to access it. • Know how to call for help and who is available.
Use available information.	• Know the prenatal and intrapartum history, including maternal complications, maternal medications, and other risk factors.
Anticipate and plan.	• Perform a pre-resuscitation team briefing to ensure all team members know the clinical situation. • Assign roles and responsibilities. • Discuss an action plan in the event of complications.
Clearly identify a team leader.	• Identify the team leader before the birth. • Effective leaders – Clearly articulate goals. – Delegate tasks as appropriate while monitoring the distribution of workload. – Include other team members in assessment and planning. – Think "out loud." – Maintain situational awareness. – Hand over leadership to another team member if he must become involved in a procedure.
Communicate effectively.	• Call team members by name. • Share information actively. • Inform your team if you identify a problem, error, or patient safety concern. • Order medications by name, dose, and route. • Use concise, clear language. • Use closed-loop communication. • Verify information. • Ensure that changes in information or assessments are shared with all team members. • Include family members in communication as appropriate.
Delegate workload optimally.	• Do not duplicate work or use more resources than necessary. • Change task assignments depending on skill sets and what is required at the moment. • Do not allow one person to become overloaded with tasks. • Do not allow the team to become fixated on a single task.
Allocate attention wisely.	• Maintain situational awareness by scanning and reassessing the clinical situation frequently. • Monitor each other's skill performance to ensure patient safety.
Use available resources.	• Know what personnel are available. • Know what additional or special supplies are available and how to access them.
Call for additional help when needed.	• Anticipate the need for additional team members based on risk factors and the progress of the resuscitation. • Call for additional help in a timely manner. • Know how you will call for additional help and the process for getting the right kind of assistance.
Maintain professional behavior.	• Use respectful verbal and nonverbal communication. • Actively seek and offer assistance. • Support and promote teamwork. • Respect and value your team.

Figure 2.1.2.1 Neonatal Resuscitation Program Vital Behavioral Skills

Source: (Weiner, Zaichkin, Kattwinkel, American Academy of Pediatrics, & American Heart Association, 2016)

After the resuscitation is completed, a quick team debriefing with reflection, audit, and feedback will help the team to be prepared for the next medical emergency. There are two types of debriefing: technical performance debriefing and critical incident stress debriefing (Yamada, N. K., Kamlin, & Halamek, 2018). Technical performance debriefing is used to evaluate the healthcare team's technical performance, such as the operation of intubation. Critical incident debriefing aims to provide non-technical support in psychology, cognition, and team member behavior. The crucial part of debriefing is not finding a significant problem after every resuscitation but to go through each resuscitation to identify a series of small gaps in every element, and thus make significant improvements on the NRP performance.

2.2 Medical Education

2.2.1 Experiential Learning Theories

Learning is a complex process that people need to acquire, retain, and recall knowledge, behaviors, and skills. How humans learn is sophisticated and successful learning is multifaceted with biological, behavioral, and contextual elements (Morrison, 2015). Many theories explain how humans learn, and each has its own merits

Among the learning theories, Kolb's experiential learning theory has been used widely as a theoretical framework for learning and teaching in medical education (Kaufman & Mann, 2010) and conducting simulation-based learning instruction (Clapper, 2010). Kolb's experiential learning theory is a learning theory proposed by David A. Kolb, published in 1984 (Kolb, David A., 1984). In experiential learning theory, Kolb defines learning as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience" (Kolb, 1984, p. 41). The theory focuses on two models: a four-stage cycle of learning and four separate learning styles.

The learning cycle comprised of four phases (see Figure 2.2.1.1):

1) Concrete Experience: Concrete learning where the learners involved in an experience such as a simulation.

2) Reflective Observation: Reflect on the performance where the learners reflect from experience.
3) Abstract Conceptualization: Where the learners generate their thoughts into more abstract models, create principles and conclusions.
4) Active Experimentation: The learners utilize the information that they have learned to guide the subsequent practice, which is a new cycle of learning.

Kolb's Experiential Learning Theory has been applied to train and teach HCPs in many medical fields over several decades (Kaufman & Mann, 2010). It serves as a well-established model with an experiential basis, which can be used to guide simulation-based medical education, including learning neonatal resuscitation. When learners are trying to learn new knowledge or skills, they perceive things passively as they may not know what they do not know. Accounting for the learners baseline knowledge and personal experience, this process could be achieved by attending lectures, reading a textbook, and doing a simulation. Second, after the perception happens, the learners come to the reflective phase. They become aware of their learning situation, knowing what they have learned and what they need to learn. For instance, this phase could be a debrief phase in simulation. After the simulation, learners understand more deeply how their knowledge and skills can be applied in a simulation or an authentic environment and the deficiency of their performance. Third, based on the awareness of their performance, the learners begin to abstract the concepts of refining their knowledge and skills for future simulation or an actual procedure. Lastly, to ensure the transferal of knowledge and skill, the newly acquired and purposefully refined knowledge and skills should be deliberately applied to future practice. Kolb stated that learning is a continually recurring cycle. Each time the learners complete one learning cycle, learning occurs at a higher, more sophisticated level.

As Kolb pointed out that learning is a cycle that occurs over time with the constant refinement of already existing knowledge and psychomotor skills. This learning cycle states the idea that the more often the learners reflect on a learning experience, the more opportunities they should make incremental improvements. Learners must experience each phase of Kolb's cycle to acquire knowledge. Nevertheless, they may

not choose to execute each phase equally. During the process of learning, learners tend to spend more time on one or two phases based on their individual learning preferences (Lisko & O'dell, 2010).

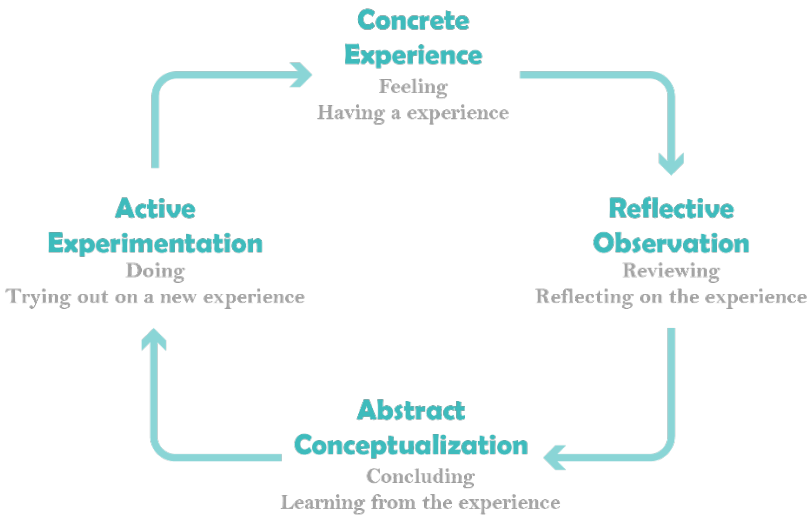

Figure 2.2.1.1 Kolb's experiential learning cycle (Kolb, 1984)

It is essential to recognize the preference of individual learning styles for each learner to achieve optimal learning, in addition to providing a model for experiential learning, Kolb proposed four learning styles (Kolb, Alice & Kolb, 2005). According to Kolb, learners acquire knowledge by perceiving and transforming experience. Learners can either perceive information from the practical experience they have been involved in without thinking deeply through it or information by conceptualizing abstract knowledge. After the information is perceived, learners need to transform the information to achieve learning outcomes. This transformation process can be achieved either through hands-on doing or observation. Subsequently, the learning process consisted of perception and transformation placed as two axes generate four dimensions of four learning styles: accommodating, diverging, converging, and assimilating (see Figure 2.2.1.2). Kolb specified the four learning styles to determine the extension of learning for an individual.

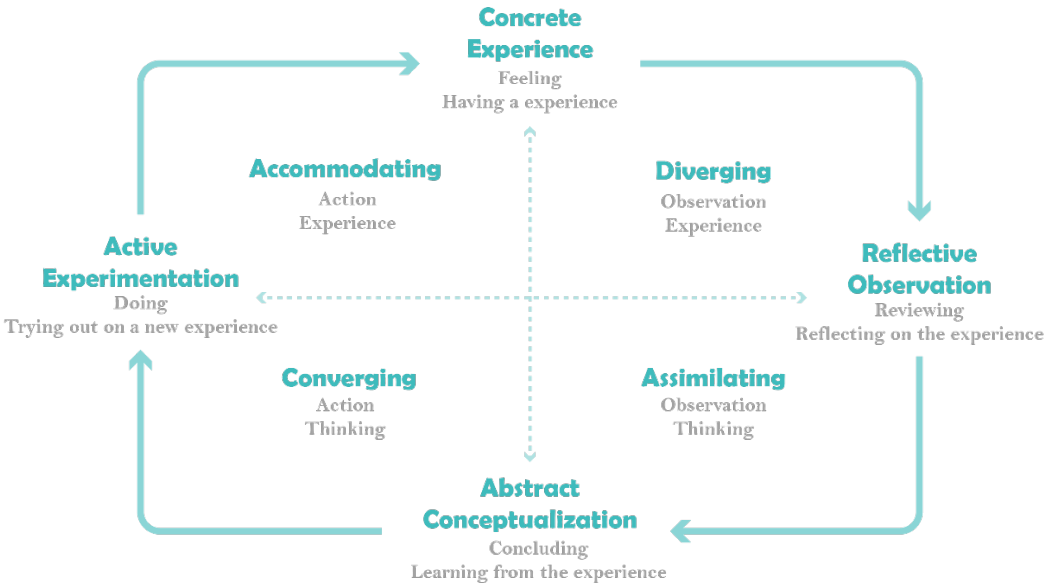

Figure 2.2.1.2 Kolb's learning Styles (Kolb & Kolb, 2005)

Kolb pointed out that the most effective learning style is at the intersection of the four dimensions of this model, with equivalent utilization of all four styles in the form of a learning cycle using concrete experience, reflective observation, abstract conceptualization, and active experimentation. Most learners are skewed toward 1 or 2 quadrants based on their basic knowledge, personal experiences, and needs on their position (Kolb, Alice Y. & Kolb, 2005). For example, for HCPs, studies (Ahmed, Wojcik, Ananthanarayanan, Mulder, & Mirza, 2019) have shown that both fellows and faculty who have gained a baseline knowledge showed a preference for assimilating and diverging styles. The contrast was the residents who showed a diametrically different learning style. The dominant style of residents is "learn by doing" accommodating and converging versus assimilating and diverging. The variance of learning styles between residents and fellows/faculty does not mean that learning styles are mutually exclusive. Instead, there is a considerable overlap of characteristics of adjacent learning styles in Kolb's diagram. These learning styles can occur at the same time during the learning process, and all are contributing.

Using all four styles equally to educate students and modifying teaching and learning methods based on learning style could be useful in improving learning (Naisirzadeh,

Heidarzadeh, Shirazi, & R, 2014). Studies have demonstrated that the learning outcomes could be higher achieved if learning was matched with the predominant learning style of the learner (Birch, Sankey, & Gardner, 2010; Pashler, McDaniel, Rohrer, & Bjork, 2008). Learners must be able to access multiple learning methods that match with their learning styles and thus optimally potentiate and benefit learning outcomes.

2.2.2 Learning Methods for Neonatal Resuscitation

In the past, learning methods were limited to lectures, coaching, and self-study. Much of the knowledge acquisition depended on lectures. The development of technology has provided multiple methods for 21st-century learners to acquire knowledge and practice skills. Technology is being integrated into healthcare industries that are characterized by high risk to human life. Integrating simulation into an instructional modality has changed the way that clinical learning and the practice of clinical knowledge, skills, and teamwork are occurring.

Simulation is a reliable tool for training HCPs to improve treatment outcomes, which includes several modalities that have in common the reproduction of specific characteristics of clinical reality. Simulation training describes training that occurs in highly realistic environments using real human actors or realistic human-patient simulators (Halamek, 2008). As a representation of experiential learning, simulation training allows HCPs to affect, to different degrees, the course of the educational experience through verbal or physical interaction with the simulated components or patients. When embedded appropriately, simulation immerses HCPs into a realistic environment that replicates with the key visual, auditory, and tactile cues that prompt HCPs to practice and refine skills that they would encounter in real clinical situations. Through simulation training, HCPs could decrease medical errors or their likelihood to harm a patient from the lack of exposure to specific clinical skills.

Compared to simulation training, the traditional training methods in neonatal resuscitation have certain limitations. The traditional training methods consist of relatively passive exercises in classroom settings followed by observation of experienced HCPs resuscitating babies and the assumption of graduated

responsibility for the care of newborns in the real clinical environment (Halamek, 2008). Activities in classroom settings include reading textbooks, attending lectures, small group discussions, and taking oral and written examinations. In the classroom, the settings are isolated from the distractions, team member cues, and the stress of the actual environment. Such an environment may provide opportunities to learn knowledge and skills but cannot provide the challenges in treating real patients adequately. Besides, NRP needs to ensure that HCPs have high level interpersonal and communication skills so that they can work coordinately as a team. Developing these communication skills is difficult and cannot be gained by merely attending a lecture. Learners traditionally have been educated in silos with little or no interaction with others.

Additionally, making space in the curriculum for such training is challenging, primarily as it must compete for time with high priority courses that provide training in core medical knowledge and techniques (Lujan & DiCarlo, 2006). Learners with limited experience would place a patient at some degree of risk. Moreover, the pace of actions in real situations is too fast for learners to think and transfer experience into knowledge. Also, learners are unable to experience all the different variety of clinical cases as it is entirely dependent on the randomness of the cases that present themselves there, especially for low-frequency, high-risk events such as neonatal resuscitation which do not occur with regular frequency.

To make up for deficiencies in traditional training, simulation serves as an alternative training method providing an opportunity for preparing HCPs with tailored scenarios that can review the occurrence of rare events. Simulation training has several advantages over traditional training methods. These advantages include but not limited to:

- Active learning
- No direct risk to patients
- Providing the opportunity for repetitive practice at the learner's own pace
- Increasing learners' self-confidence

- Providing the opportunity for practicing teamwork
- Providing uncommon, critical scenarios rarely happened in real life
- Reflective learning by team debriefing and video feedback

Based on the stated advantages, simulation has been used as an instructional modality in neonatal resuscitation, changing how HCPs learn and practice their clinical knowledge, skills, and abilities that are required to be competent and to ensure a babies' safety. Simulation can duplicate the real clinical situation, fully interactively immerse HCPs, and provide immediate feedback. Such an immersive environment facilitates active learning and involves HCPs in cognition, decision-making, and situational awareness in actual neonatal resuscitation. Through simulation training, HCPs will be better prepared and need less supervision when entering the real NICU, resulting in improved babies' safety and faculty productivity.

Despite the benefit of simulated training in neonatal resuscitation, there are some issues with this training. The current simulation training method is prohibitive in its use of time, funding, and is personnel intensive. It requires expensive mannequin simulators and numerous other simulation equipment that ensure regular maintenance costs. During the simulation, a qualified practitioner/instructor must take time away from their clinical responsibilities to supervise learners to perform neonatal resuscitation smoothly, which is an additional cost. It can be difficult for the practitioner/instructor to observe and record every act that a trainee is performing in real-time. The practitioner/instructor can give feedback when the learner asks a question or commits an obvious or serious error, but he/she may sometimes miss to notice tiny errors.

As described above, the high cost of preparing and running a simulation is a barrier for HCPs to access and to partake in simulation training. This problem may leave many HCPs dangerously underprepared to care for their small patients safely. Limited access to simulation training means that many HCPs neither receive nor adequately maintain their neonatal resuscitation knowledge and skills.

Although a HCP may feel competent in neonatal resuscitation after simulation training,

after three months, they will experience a decay in the knowledge and skills developed during the training (Levitt et al., 1996; Patel, Posencheg, & Ades, 2012). HCPs need to be recertified every two years based on the requirement of NRP. However, their knowledge and skill decay can often start immediately after initial training (Patel et al., 2012). The HCPs exacerbate this situation in rural hospitals with relatively fewer simulation resource capabilities and lower birth attendance rates (Marshall, 2014). With fewer opportunities to practice neonatal resuscitation skills, HCPs face increasing challenges in maintaining a broad range of competencies in the context of isolated clinical practice and a dispersed patient population. With the loss of intervention skills, the unprepared healthcare team can lose their confidence and effectiveness during the neonatal resuscitation, which may result in fatal errors and poor patient outcomes.

NRP suggests that healthcare providers engage in more frequent refresher simulation sessions to maintain their knowledge and skills. However, since the current simulation methods are both financially and human-capital intensive, this becomes impractical for HCPs to practice frequently. Insufficient practice can result in severe consequences, such as decision-making deficiencies and medical errors or deviations from the resuscitation algorithm. This problem restricts their medical education to providing a mainly theoretical understanding of clinical knowledge, rather than being able to leverage the advantages of real-world learning offered by simulation training. Therefore, other alternative simulation approaches are needed to maintain HCPs' clinical knowledge and skills.

Serious game simulation (e.g., tabletop game, digital game) can serve as an alternative simulation approach to fit the existing gaps in healthcare education by providing a relatively low-cost enjoyable experiential learning experience, in order to motivate HCPs to practice and maintain their knowledge and skills. The idea of using game elements for learning purposes was proposed early by Clark Abt in 1970 and further published in a book entitled serious game (Abt, 1970). In this book Abt defined "serious game":

> *"Games may be played seriously or casually. We are concerned with serious games in the sense that these games have an explicit and carefully thought-*

> *out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining" (p.9)*

Based on Abt's theory, the serious game consists of two factors, learning and playing. The learning factor determines the learning objectives such as learning clinical knowledge, teamwork competence and coping with stress. The playing factor focuses on the enjoyable interaction created in the intrinsic motivation for gameplay. Although learning and playing appear to be the opposite of each other, they have some common characters: challenges, time-intensive, and interactive processing that require cognitive effort and willingness to acquire new knowledge or skills (Ke, Shute, Clark, & Erlebacher, 2018). Playing games is a well-established method. During the game playing, the learners learn the game rules first, and then by using strategies to complete several tasks, they increase their competence for game success.

With its inherent entertainment factor, the serious game can significantly enhance HCPs' learning outcomes and motivation (Bonde et al., 2014). Many healthcare areas, including surgery, emergency medicine, and anesthesiology, have applied serious game as a simulation training approach to improve HCPs' psychomotor and technical skills and have reported positive outcomes (Ghoman et al., 2020). Serious game simulation can foster HCPs' Higher-Order Thinking, such as decision making, the ability to evaluate intervention performance during HALO events through enabling active-learning experiences. Besides, compared to the traditional simulation with a high-cost resource setting, serious game simulation usually requires less equipment and consumes fewer human resources. This low-cost feature unlocks the limited simulation opportunities for HCPs to refresh their knowledge and skills. Hence, serious game simulations are increasingly used as supplemental teaching tools in healthcare education.

2.3 Current Development Effort and Applications

There are numerous forms of serious game platforms, including board games, tabletop games, computer games, mobile games, and VR/AR game. Each type of serious game

can target different learning objectives. Platform differences may significantly impact a learner's performance based on various facets of the platforms. For example, a tabletop game could be used for training learners' teamwork and communication skill. The form of the tabletop game may provide a realistic environment for learners sitting around the table and communicating with each other. While a mobile game, for instance, enables the learner to take advantage of their fragmented time to memorize knowledge and practice skill, since the mobile game is more accessible for learners to play anytime and anywhere.

Though there is a rapid growth of serious games in the healthcare education field, the application of serious games in neonatology is still lacking. Following is a review of the existing serious games for neonatal resuscitation.

2.3.1 The NRP eSim

The eSim (Laerdal Medical, Stavanger, Norway, and American Academy of Pediatrics, Itasca, Illinois, USA) is a computer serious game added to the 2015 NRP provider curriculum (Ghoman et al., 2020; Weiner et al., 2016). In this game, a learner could practice resuscitating a newborn baby following the NRP diagram with a screen-based 3D environment of the baby, and 2D equipment and action selection. The eSim is designed for the learner who takes on the role as a team leader during the resuscitation. At the beginning of the game, the learner is provided the information of the baby, such as the baby's gestation, so that they could assess the risk and prepare for the birth. Then the learner needs to select and adjust supplies based on the baby's situation (see Figure 2.3.1.1). After completing the equipment check, with the arrival of the baby, the learner could drag or click the equipment and action icons provided on the screen to resuscitate the baby (see Figure 2.3.1.2). When the baby is stabilized, the learner could choose the baby either stay with the mother or transfer to post-resuscitation care. Following the end of the resuscitation, the learner receives feedback on their performance with a final score, a debrief, and a time-stamped list of the decisions he/she made (see Figure 2.3.1.3).

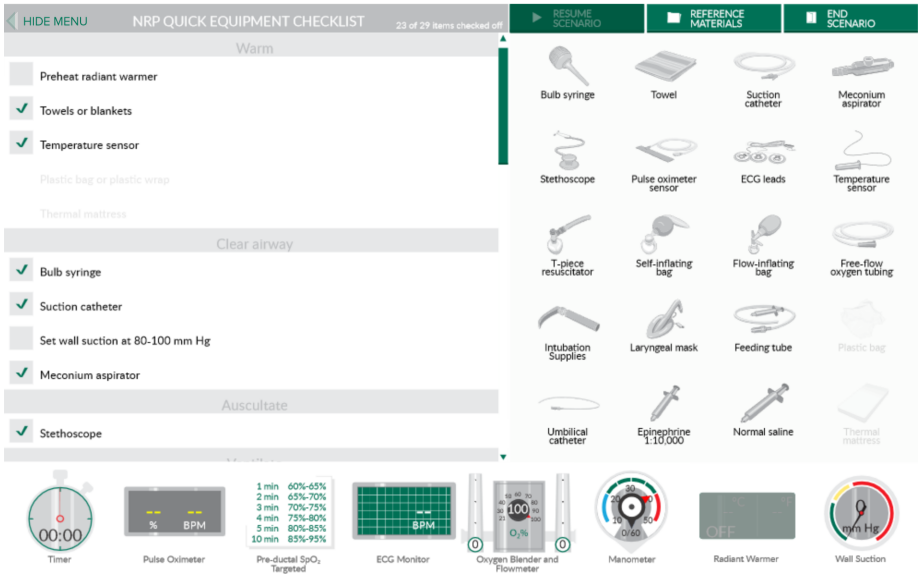

Figure 2.3.1.1 The interface of equipment checking in the eSim

Source: (American Academy of Pediatrics, 2020)

Figure 2.3.1.2 The interface of neonatal resuscitation in the eSim

Source: (American Academy of Pediatrics, 2020)

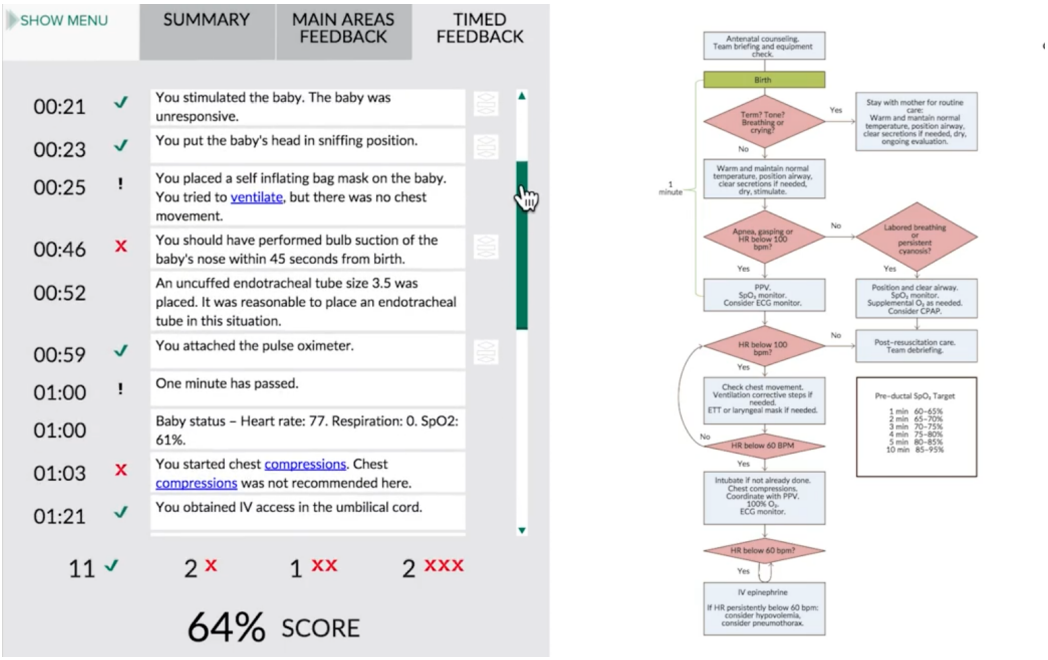

Figure 2.3.1.3 The interface of summary and feedback in the eSim

Source: (American Academy of Pediatrics, 2020)

Based on my playing experience, there are some noticeable design points and design opportunities that could improve the eSim:

If the learner has made any mistakes in the equipment checking phase, he/she would not be able to access to the next phase (the resuscitation phase) until they readjust the equipment to the recommended settings showed in the interface. The way that the system alerts the learners of their mistakes in the early stages saves playing time for them. If the learners choose the inappropriate equipment set in the very early stages, then there is no need to continue the game as the following operation could not save the baby effectively under a wrong equipment setting. However, a learner may fail to learn from mistakes due to the right answer being given so easy and straightforward to them as shown on the interface. This problem may occur due to the default equipment setting as well. During the equipment checking phase, most equipment has been selected by default. This default setting does not give a chance to the learner practicing his/her equipment checking competency, as they could simply rely on the default setting and skim over it. An alternative way to avoid this unwarranted situation happening could be providing the answer for equipment setting to the learner more

implicitly or have them type in setting parameters for the equipment used. For instance, when they adjust a wrong equipment setting, instead of providing the right answer immediately, the game may give limited prompts to learners and let them find the right answer. In this way, the learners would be conscientious and responsible for their decision making, and they would be forced to find and memorize the knowledge.

eSim presents a high immersive simulated environment for the learner. During the resuscitation, the learner receives responses from the baby though watching the baby's skin tone changes and chest movement. Meanwhile, once the ECG leads are attached to the baby, the learner can sense the heart rate changes by listening to the sound rhythm from the ECG monitor. When the heart rate sounds slow, it may cause anxiety and fear for the learner, especially for the novice, which contributes to the poor performance. Therefore, the high-fidelity configuration and challenging level of the game may not fit the novices' competency and hence reduce the game engagement. The difficulty and fidelity level of the serious game should be designed based on the targeted learners' personal experience and competency.

There is a critical area that remains to be addressed to improve the eSim. When a learner has difficulty in resuscitating the baby, no cue helps them to make a further decision. If the learner could not identify the baby's status and give the correct intervention steps to the baby, then they could only listen to the baby's heart rate getting slower until stopped, with no prompts for changing this situation. The no prompt setting may cause more substantial anxiety and frustration for the learner, which significantly decreases the learner's interest in game playing. With the baby's heartbeats getting slower and slower, to avoid seeing the death of the baby, the learner may quit the game in advance instead of continuing to finish. Furthermore, once the learner ends game playing in the middle, he/she would not receive the feedback from the game indicating his/her errors and be provided with the correct steps for playing next time. The opportunities for sustaining the play interest and motivating the play engagement could be offering options for the learner to call for help. After experiencing a hard time during the simulation and getting the answers later, the learner's memory would be imprinted and may retain the knowledge longer.

2.3.2 The RETAIN Game Platform

The RETAIN (Resuscitation TrAINing for Healthcare Professionals) game platform (RETAIN Labs Medical, Edmonton, Alberta, Canada) currently has two versions of serious gaming for neonatal resuscitation: a tabletop simulator and a web-based simulator. Both simulators provide learners with a series of evidence-based scenarios with different complexity levels. During playing, learners perform neonatal resuscitation using cards and game pieces that represent equipment, supplies, and actions.

The RETAIN tabletop simulator can be played individually or with up to four learners in an interdisciplinary team. The players can choose roles including nurse, respiratory therapist, trainee, nurse practitioner, midwife, and consultant. A facilitator, who does not participate, monitors the game, giving instructions if applicable. The face side of the cards presents the name and category of the item. On the reverse side are instructions and further information. The RETAIN tabletop simulator also contains pre-brief and debrief cards (e.g., What did you learn?) for communicating with others and allowing the learners to evaluate themselves. The tabletop simulator has reference tables, timers, and monitors that can be adjusted by the instructor according to the various scenarios and the learners' performance. At the beginning of the game, the team assigns roles and checks equipment with the prompts from the pre-brief cards. Then the team chooses equipment pieces and informative action cards to perform neonatal resuscitation. Meanwhile, according to the intervention from the team, the facilitator updates the baby's status based on the evidence-based scenarios booklet and records the team's performance. At the end of the game, the team asks questions on the debrief cards to reflect their performance and get feedback from the facilitator.

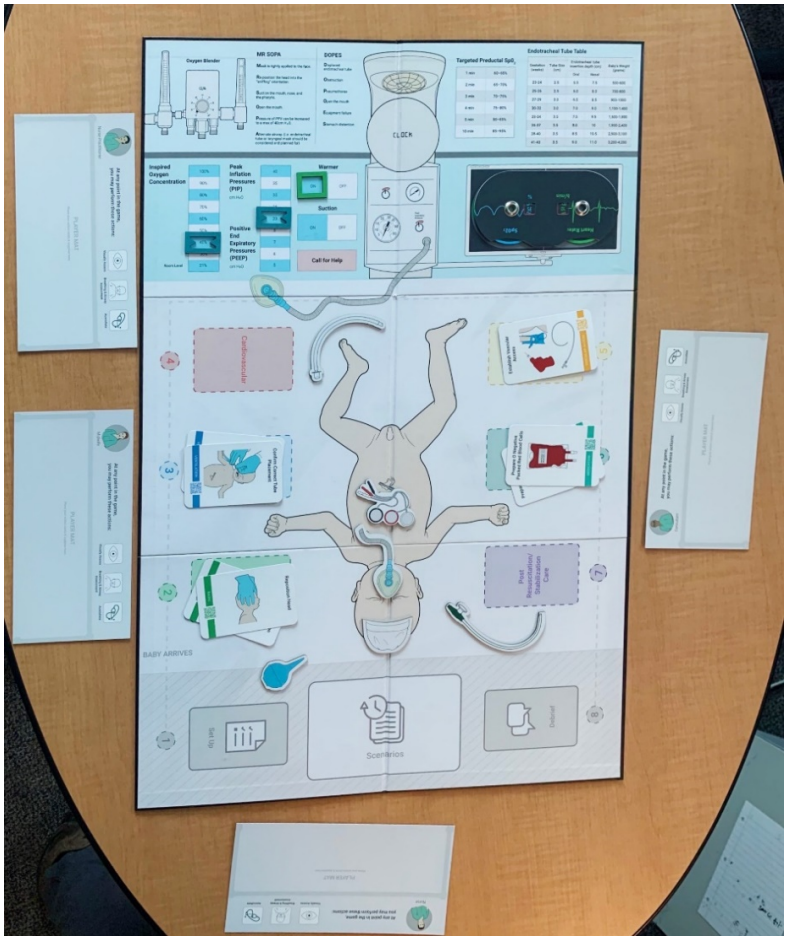

Figure 2.3.2.1 The RETAIN (REsuscitation TrAINing for healthcare professionals) neonatal resuscitation tabletop simulator

The RETAIN web-based simulator is designed to be played individually. During the game, the learner assumes the role of the team leader who directs the resuscitation team. The learner is prompted by a non-learner character (NPC), that speaks for the team. All the equipment, supplies, and actions are presented on the screen in menu selections. Once the game starts, the guide introduces the scenario and updates the status of the infant continuously. Then the learner chooses the team, equipment, and actions from the menu to resuscitate the baby. The baby's skin tone and the parameters of monitors (e.g., heart rate) change according to the selections the learner makes, and what order they are made. After the game finishes, the learner receives a score based on adherence to the NRP algorithm and successful stabilization of the baby and time-stamped list of his/her actions.

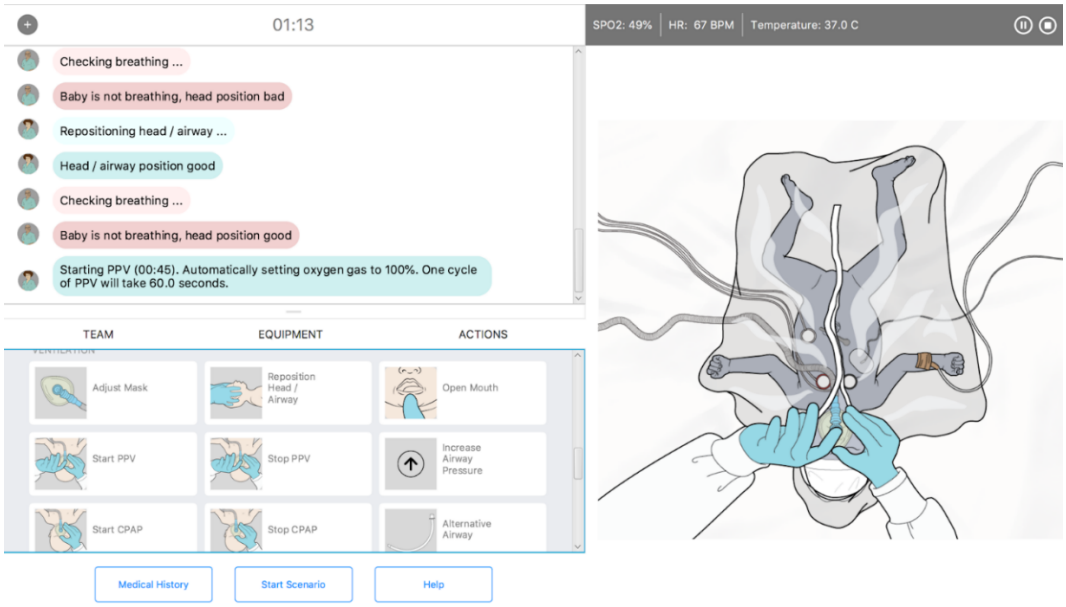

Figure 2.3.2.2 The RETAIN (REsuscitation TrAINing for healthcare professionals) neonatal resuscitation web-based simulator

Source: (Centre for the Studies of Asphyxia and Resuscitation, 2020b)

The current RETAIN tabletop simulator enables the learners to communicate and cooperate actively. Both the tabletop simulator and the web-based simulator help the users to learn and maintain knowledge of the fundamental algorithms of neonatal resuscitation in a low-cost and accessible way. In addition to this benefit, the web-based simulator can pick scenarios based on the learners' experience and respond to a learner's every action immediately. For example, if a learner did an incorrect action, the monitors could be changed to show the negative consequence(s). However, some parts could be improved in the RETAIN game platform.

Practical evaluation and feedback remain to be improved in both simulators. In the tabletop simulator, it is hard for the instructor to observe and record a learners' every action and adjust the monitors at the same time. Usually, the instructor gives guides when the learner asks a question or commits an obvious or severe error, but the instructor may sometimes fail to notice smaller errors. For example, during the initial care of a baby, the instructor may fail to notice that the pulse oximeter is attached to the wrong position of the baby, as there are many operations simultaneously

happening on the baby. In the web-based simulator, the learner receives a time-stamped list of actions as feedback when he/she finishes the game. This list does not indicate which action is wrong or done at the wrong time. Thus, in both games, effective evaluation and feedback remain to be improved for helping the learner to identify what went well and what remains to be improved next time. As the RETAIN game platform is still developing, this situation might be changed in the future.

Although both simulators provide a series of scenarios for beginners to advanced learners, the actual user interaction is only appropriate for novices. For example, action cards are currently presented with instructions and additional information that are not needed or should not be provided to experienced learners. Alternatively, when performing resuscitation, the learner simply chooses equipment or actions from existing options. For example, the cards would indicate the exact amount of ventilation pressure increment is 5 to 10 cm H_2O. These instructions are always visible and therefore act as prompts reminding learners what could be done during resuscitation. The beginners could be benefited from the instructions to go through the intervention steps. However, there is a higher requirement of knowledge and skills maintenance for the experienced learner to be well-prepare for real resuscitation. In the delivery room, except for the reminder from the colleague, there are no prompts visable to tell HCPs the detailed intervention steps. The HCPs must make decisions without much help from the environment.

Besides, the delivery room is a stressful environment where every decision must be made quickly. The RETAIN game platform can provide a fun and relatively less stressful approach for novices to get started with neonatal resuscitation. Without being highly anxious, learners can focus on acquiring clinical skills and knowledge. The experienced learners could benefit from the current RETAIN game as well by maintaining the necessary knowledge and skill. However, to get the improvement of the intervention competence further, more challenge is required in training. When the learners go to a real delivery room, having excellent cognitive and communication skills and the ability to make rational decisions in a stressful environment is essential.

Hence, it appears that there is a gap between the current RETAIN game and real-life resuscitation practice. A transitional simulator may be needed after learners play the tabletop and computer games, but before they do resuscitation in real clinical situations.

As a member of RETAIN Labs Medical, this research aims to contribute to the larger RETAIN game platform by dealing with the existing shortcomings of the current RETAIN game platform. This study presents a transitional RETAIN game which would provide learners with a more effective evaluation and feedback system, and a more appropriate and realistic learning environment, especially for intermediate and advanced learners. The new RETAIN game is achieved by virtual reality will be discussed in detail in Chapter 5.

Chapter 3 Neonatal Resuscitation Process Analysis

The work with various institutions and persons was done under the ethics application already in existence of Dr. Georg Schmölzer and Emily Zehnder. I reviewed Emily Zehnder's interview scripts with HCPs. I observed 32 neonatal resuscitation cases by attending deliveries in the Royal Alexander Hospital and watching the eye-tracking video of HCPs' Performance. The eye-tracking technology could reflect infrared light to track HCP's pupillary movement and show the movement in the eye-tracking video from their viewpoint. Within the ethics application and because of Alberta Health regulations, I was not able to take with me any recordings and images. I was allowed to watch them and used them for analysis but could not put them into my document.

3.1 Overview of Neonatal Resuscitation and Clinical Core Facets

Approximately 10% of babies require resuscitation at birth. Training HCPs is crucial for their acquisition and retention of knowledge and skills in neonatal resuscitation and in order to reduce neonatal mortality and morbidity. To improve the learning outcomes, the NRP introduced the NRP Flow Diagram that describes the steps to evaluate and resuscitate a baby. The NRP Flow Diagram includes the following elements of neonatal resuscitation: preparation for resuscitation, initial steps for newborn care, establish effective an airway for breathing, compressions, and medication. Although studies provide moderate-quality evidence supporting the efficacy of the NRP Flow Diagram in improving neonatal outcomes (Weiner et al., 2016), there are still some design opportunities that remain to be improved in neonatal resuscitation. Following is a HCPs' journey map on neonatal resuscitation that I developed.

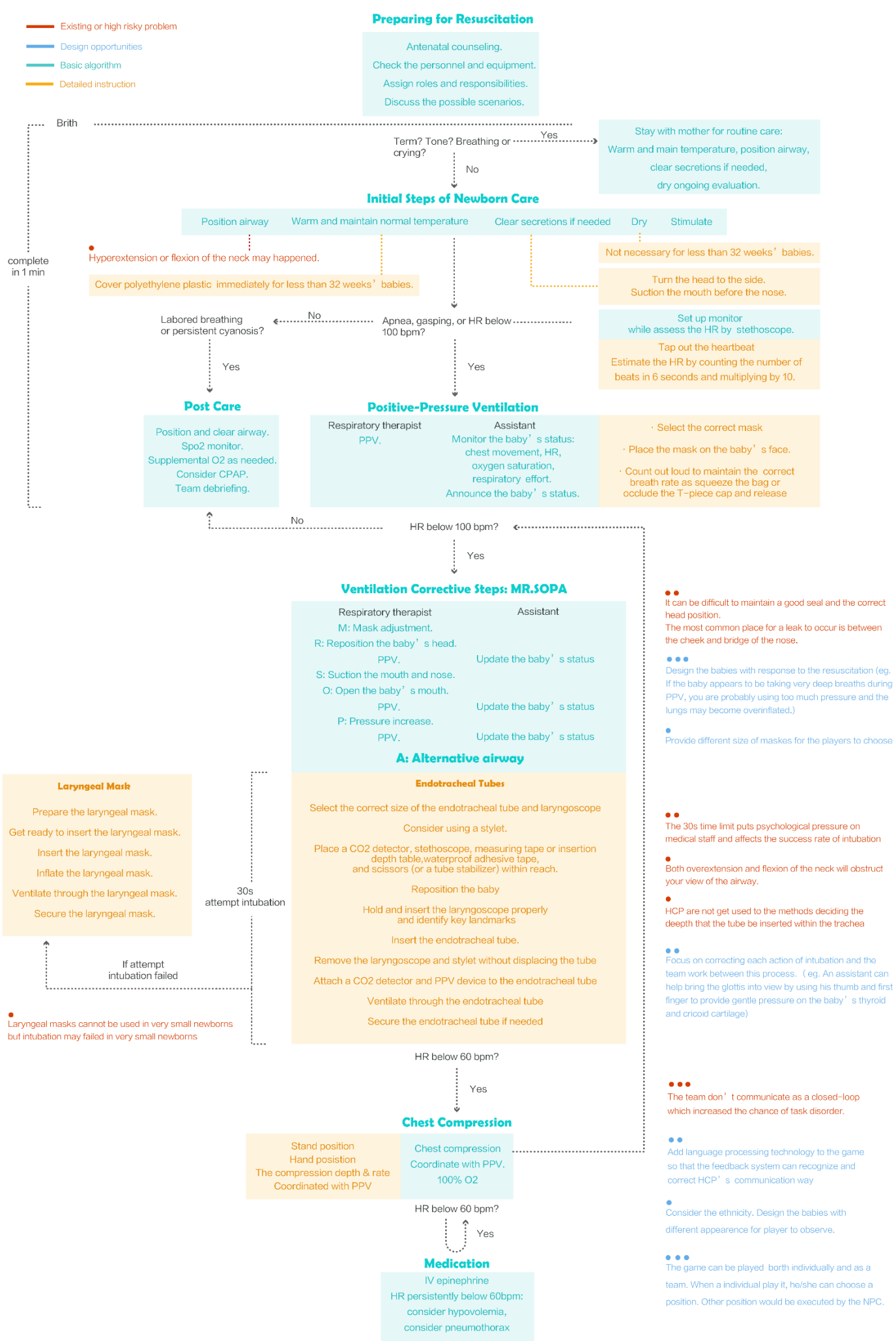

Figure 2.3.2.1 The Neonatal Resuscitation Journey Map

This journey map was created based on the NRP Flow Diagram and the video recording of neonatal resuscitation performance in the Royal Alexandra Hospital. It gives an overview of the neonatal resuscitation process from preparing the resuscitation to medication. The blue blocks show the essential neonatal resuscitation steps. While the yellow blocks contain more detailed procedures and time rules for the essential steps, during the resuscitation, HCPs must ensure that they have adequately performed the steps of each block before moving on to the next block. Evaluation questions are presented at the end of each block to determine whether moving on to the next steps. The journey map also points out some high-risk problems as examples that may occur during the intervention, and the design opportunities to solve the problems. Overall, the high-risk problems can be divided into two domains: technical problems and human factor problems.

There are numerous types of clinical errors in resuscitation, such as failure to hold the mask correctly to keep a good seal on the baby's cheek.

Following is a list of resuscitation knowledge that HCPs should follow with the bolded keywords that require more attention to avoid error occurring. This list would also be used as a part of the guideline for game design.

- Prepare polyethylene plastic for the babies less than 32 weeks gestation.
- Maintain the baby's body temperature between 36.5°C-37.5°C.
- Give appropriate oxygen gas mixture (initially 21% for greater than or equal to 35weeks', 21%-30% for less than 35weeks').
- Give appropriate gas flows (starts between 10L/min).
- Position the head in a correct sniffing position (not hyperextension neither flexion).
- Solution mouth before the nose.
- Gently rub the babies' back, trunk, or extremities to provide stimulation.
- Tap out the accurate heartbeat.
- Given free-flow oxygen without holding the flow-inflating bag and T-piece resuscitator tightly.

- Hold the mask tightly and keep a good seal for PPV and CPAP.
- Select the correct size of the masks that just cover the baby's nose and mouth, but not eyes.
- Attach pulse oximeter on the right hand or waist.
- Breaths are given at a rate of 40/min to 60/min.
- Start with a PIP of 20 to 25 cm H2O.
- Start with a PEEP of 5 cm H2O.
- Keep announcing the baby's vital signs.
- Increase pressure in 5 to 10 cm H2O increments, maximum 40 cm H2O.
- Select the correct size of endotracheal tube for intubation (size 2.5 for below 28 weeks, 3.0 for 28-34 weeks, 3.5 for greater than 34 weeks).
- Select the appropriate laryngoscope blade (No. 1 for term newborns, No. 0 blade for preterm newborns, No. 00 blade for extremely preterm newborns).
- Hold the laryngoscope blade by the left hand and insert it into the baby's mouth. Lift, instead of rotating, the laryngoscope to expose the larynx.
- Identify the key landmarks for intubation, which is the vocal cords appear as thin vertical stripes in the shape of an inverted letter "V."
- The 30s allowed for an intubation attempt.
- Insert the endotracheal tube with correct depth based on the baby's gestation and weight.
- Be able to listen and identify the breath sounds in both axillae and over the stomach.
- Be able to secure the endotracheal tube by tape.
- Listen to the chest to ensure the tube did not move after the securing.
- Stand at the head of the warmer to give chest compression once intubation is completed, and the tube is secure.
- Administer chest compressions by placing thumbs on the sternum below an imaginary line connecting the baby's nipples. Encircle the torso with hands. Support the back with fingers.
- Give compression rate 90/min with three compressions and one breath every 2 seconds.
- Count out the rhythm of chest compression: "One-and-Two-and-Three-and-

Breathe-and ...".

- Check the heart rate after 60 seconds of compressions and ventilation rate 0.5 to 1 mL/kg dose for the endotracheal route.

The human factors could be divided into three domains: communication and teamwork factors, cognition factors, and physical factors (Law, 2019). The communication and teamwork factors address the optimization of how HCPs could work as teams to accomplish their duties safely and communicate efficiently. Cognition factors related to how HCPs perceive the baby's condition and environment situation, control their emotions and make a decision accordingly. Physical factors include some external aspects such as the ergonomic design of equipment and the layout of the resuscitation environment. All three domains have a significant influence on neonatal resuscitation. Having difficulties in any of these domains could cause poor resuscitation performance and increased neonatal mortality and morbidity. Thus, it is vital to analyze these factors for designing game mechanics. The factors of the three domains are discussed in the following sections.

3.2 Communication and Teamwork Factors Analysis

Proficiency in communication and teamwork skills is essential for HCPs to perform neonatal resuscitation. The Joint Commission (2004) identified that the primary root cause of perinatal death or permanent disability is poor communication skills and teamwork (The Joint Commission, 2004). Other studies also asserted that lack of communication is a leading cause of preventable errors that result in reduced patient outcomes (Denham et al., 2008; Poore, Cullen, & Schaar, 2014). Consequently, beyond individual performance, it is essential to optimize teamwork abilities between HCPs to perform neonatal resuscitation successfully.

During the resuscitation, the team must maintain good teamwork behaviors to ensure smooth procedural protocols. These teamwork behaviors include (Thomas et al., 2007; Yamada, Nicole K. & Halamek, 2015):

- Assign and know each team member's role and tasks clearly (according to individual experience and capabilities)
- Ask questions to any team member related to resuscitation, such as the baby's status, the assessment, and treatment plans.
- Share information to other team members such as maternal history, their treatment intentions, and the baby's status
- Assert opinions related to the resuscitation operation
- Communicate with each other concisely and clearly. For example, order medication by name does, and route.
- Verify the information that is communicated

Although many studies have provided similar critical teamwork behavioral skills for HCPs to follow (Katakam, Trickey, & Thomas, 2012; Thomas et al., 2007; Weiner et al., 2016; Williams, Lasky, Dannemiller, Andrei, & Thomas, 2010), an appropriate standardized method for HCPs to communicate efficiently and is still lacking, to help HCPs communicate effectively. The NRP program recommended that HCPs use closed-loop communication as a technique that ensures the instructions are heard and understood (Weiner et al., 2016). Closed-loop communication has initially been used in military radio transmissions based on verbal feedback to ensure proper team understanding of a meaningful message (Salik & Ashurst, 2019). Closed-loop communication has a three-step process. First, the transmitter gives a message directly to the specific receiver with his/her name and speak clearly. Then, the receiver accepts the message and repeats the message back to the transmitter seeking clarification and confirmation. Lastly, the original transmitter confirms the message has been transmitted correctly and thereby closing the loop. In neonatal resuscitation, there should be one more step that the receiver completes the command in the message and reports back to the original transmitter for intubation order (Weiner et al., 2016),

> *Sandy: "Robert, I need a 3.5-mm endotracheal tube, with a stylet, and a laryngoscope with a size-1 blade. Tell me when they're ready."*
> *Robert: "You want a 3.5-mm endotracheal tube, with a stylet, and a laryngoscope with a size-1 blade."*

Sandy: "Correct."
Once the equipment is ready,
Robert: "Sandy, a 3.5-mm endotracheal tube, with a stylet, and size-1 laryngoscope are ready now." (p.11, p.12)

Using closed-loop communication could help HCPs avoid medical errors due to deficiencies in verbal communication from language impediments, interruptions, misunderstandings, and hesitation to speak up against authority. However, based on the observation of neonatal resuscitation video recording, HCPs often do not communicate with each other in a closed-loop form. The repetition of the medication requests could be prone to misunderstanding. For instance, there are many ambiguous messages such as "Can someone increase the pressure?" The information is unclear in this message. The transmitter did not speak to a specific person and did not speak a precise amount or what pressure they wanted to increase. The receiver is unclear, and this could result that no one responded to the order, or the order is duplicated by two HCP, or the wrong pressure is increased. Furthermore, if the task was not done, it could have a severe negative impact on the patient treatment outcome. In the example above, after the transmitter asked the question, there is no one response to her question for 30 seconds until she asks the question directly to a specific receiver with their name attached. Then the receiver confirmed her question with the pressure increase. The operation of increasing pressure is delayed for 30 seconds because of the unclear communication.

Although not communicating in a closed-loop may result in unclear communication and possibly follow with a misunderstanding of medication orders, for example, and hence poor patient outcomes, there are some barriers for HCPs to use closed-loop communication. First, to make sure there is no misunderstanding in communication, there are many repetitions of the message between transmitter and receiver for confirmation. However, in the time-crunched medical emergency environment, complications may increase due to too much-verbalized information. Excessive communication is likely to lead to task overload and decreased operating efficiency. When a team member received a command, instead of performing the command

immediately, he/she repeats the command back to the transmitter, asking for confirmation. It takes a longer time by using closed-loop communication than the existing communication process, which is receiving the order and directly executing it. Furthermore, if another team member also wants to share vital information at the same time, he/she has to wait while this closed-loop communication finishes. In the resuscitation, even a few seconds are critical to saving a baby's life. Because it is time-consuming and potentially increases in workload, closed-loop communication has its shortcoming for individuals to use in neonatal resuscitation.

For communicating clearly, it is significant to speak the receiver's name directly when giving a medical order. No directly naming receiver can confuse team communication. However, from the observation of the resuscitation video recording, HCPs do not say the receiver's name often. According to the HCPs in the Royal Alexandra Hospital, team members are always changing in NICU. Team members may not be familiar with each other. It always occurs that the team meets first when preparing to resuscitate a baby. Thus, due to being unfamiliar with other team members, it may be hard for HCPs to remember and say the name of others under pressure. Even though they recall names, it may distract their attention from their tasks. An alternative method to solve this problem could be to say a team members' role or wear signs with the designation such as team leader, respiratory therapist. There may be more than one team member who has the same team role, such as a nurse. For these team roles, HCPs could call their roles with their tasks such as a cardio nurse, drug nurse, and so on. However, it might take a while for HCPs to get used to calling others by their team roles, and many pieces of training are required. It is unrealistic to think that this issue can be solved through communication alone. Team members must know each other so that they can commit to working cohesively, and each team member performs a suitable task based on their experience, which can rely on the organization of the local hospital policy.

Besides verbal medication ordering, the resuscitation team communication also focuses on sharing the vital signs information, such as verbalizing the baby's heart rate and the sounds of breath after auscultation. Sharing the vital signs information helps each team member to maintain situational awareness in real-time. However, HCPs did

not consistently share information as observed from the video recordings. This issue occurs more often on the intubator. In some video recordings, the intubator moves their line of sight between the monitor and the baby frequently but does not share the information from the monitor and the baby frequently. Furthermore, some team members do not share the completed tasks and their intentions, such as attaching the pulse oximeter.

There are many factors, which could cause the infrequency of information sharing. Neonatal resuscitation is a high-stress and time-intensive medical emergency. During the resuscitation, team members' attention is focused on their hands-on tasks, perception of the baby's condition, and further decision making. They need to receive and analyze multiple bits of information and utilize the information for decision making while working as a team under the time pressure. Doing multitasking at the same time makes it harder to pay attention and to keep sharing information with team members. Besides, a study (Thomas et al., 2006) found that HCPs share less information about their assertions, evaluation of plans, and intentions. It is assumed that sharing assertion, evaluation, and intention is required more in complicated situations, such as intubation. In some more routine cases, many resuscitation processes are standardized, such as drying and attaching sensors. For the standardized routine care, it requires less exchange of information from HCPs, especially sharing intention, assertion, and teaching.

Other communication and teamwork issues observed in the video recording, including varied and ineffective talk. There are many meaningless phrases during the intervention, such as "the baby is so cute." or talking to the baby, "You are really working there, honey." The unconstructive speech could distract HCPs' attention from their tasks, interfere with information sharing, and thereby increase the chances for errors to occur. This issue reveals that the language used in resuscitation should be standardized.

Besides communicating precisely and concisely, resuscitation teamwork also requires that each team member performs manual tasks coordinately. A resuscitation team is

not just a group of people working together, but a team sharing the same mental model, helping each other appropriately, and achieving the collective goal. Every team member has a responsibility to give a hand to assist others to finish their tasks when they need it. Being able to percept the right time and coordinate with others smoothly is the key to improving teamwork quality. There is some uncoordinated teamwork performances remaining to be improved, as seen in the video recordings. For example, a HCP standing on the left side of a baby was attaching the pulse oximeter on the baby's right hand. While the other two HCPs were standing on the right side of the baby, one was auscultating the baby's chest, and another was waiting for drying the baby's chest. There were many operations happenings simultaneously on the baby's body; a HCP's view could be blocked by another's hands, which may lower the quality of the interventions. If HCPs could choose their standing position wisely, this problem could be reduced. In this case, the HCP who was operating on the baby's left should stand on the left side of the baby and vice versa. Besides avoiding interference with other's work, helping team members complete the operation is also essential. Team members should be able to form a tacit understanding with each other. That means not only assisting others when they ask, but also keeping situational awareness of what team members are doing and being ready to help them if needed. For instance, if an intubator starts intubation, one team member must be aware of the intubation status and assist the intubator in time, such as passing a suction catheter or endotracheal tube.

Teamwork is a critical component of successful neonatal resuscitation. Although the problems that occur during the resuscitation indicate that a standardized concise communication method remains to be improved, the problems could be reduced by repetitive simulation practice. Excellent communication and handoff skills require HCPs to keep practice via up to date simulation so that misunderstandings, interruptions and uncoordinated teamwork could be minimized.

3.3 Cognition Factors Analysis

Keeping good cognition is also a key element to optimize HCPs' performance in

neonatal resuscitation. The cognitive process involves perception, attention, situation awareness, working and long-term memory, knowledge, and decision-making (Endsley, 2000; Law, 2019). Each element plays a role and is associated with each other in neonatal resuscitation performance. During the intervention, HCPs perceive and observe the baby and the environment condition, assess the treatment plan for the condition, and make further decisions. Losing situation awareness could lead to poor patient outcomes. Law (2019) gave a list of the situation awareness "Demon" in neonatal resuscitation through analyzing 30 performances of HCP in eye-tracking videos: (p.23)

Demon	Description	Examples in neonatal resuscitation
Attentional Tunnelling	An individual becomes focused on one source of information or one aspect of the environment, failing to reassess the situation as a whole.	A HCP focused on trying to obtain a difficult endotracheal intubation fails to notice that the neonate's heart rate has fallen below 60 bpm.
Requisite Memory Trap	Limitations in size and duration of working (short term) memory restricts an individual's ability to retain all situationally relevant information.	A HCP cannot simultaneously remember all vital signs and trends, birth weight, antenatal history, and the timing and frequency of all the interventions that have been done thus far in a complex resuscitation.
Data Overload	An individual is overwhelmed by the amount of data being presented, particularly if it is disorganized.	Presence of multiple sources of data such as vital signs monitor, respiratory function monitor, NIRS data, multiple auditory alarms, and conversations from the team overwhelms a HCP's ability to coherently process the information.
Errant Mental Model	Application of the wrong approach or general understanding to the given situation.	HCPs apply usual SpO2 targets to a neonate with known cyanotic congenital heart disease, where the SpO2 is not expected to be above 85%.
Misplaced Salience	An individual places more attention or importance on information or stimuli that are of minor relevance to the situation.	HCP troubleshoots a nuisance alarm (e.g. apnea alarm in a non-intubated infant) because of the loud and high-pitched sound.
WAFOS	Workload, anxiety, fatigue and other stressors that degrade cognitive functioning in multiple ways, such as degrading working memory, decreasing cognitive processing, decreasing attention, and increasing susceptibility to cognitive errors.	A tired team leader at hour 20 of a 240-hour shift, already managing a busy NICU, has difficulty directing the resuscitation of a 23 week infant not responding to bag-mask ventilation.
Complexity Creep	Increased complexity of a system or algorithm leads to decreased understanding of equipment and system function.	Incorporating NIRS targets with SPO2 targets to neonatal resuscitation algorithm increases decision-making complexity.
Out-of-the-Loop Syndrome	Automation leads to systems changes that are done without the knowledge of human operators, leaving the operator with an incorrect assessment of the current system status.	Modern ventilators can make automatic adjustments in ventilation pressures without operator intervention. Therefore, HCPs may not be aware of current ventilation settings.

Table 3.3.1 Situation awareness "demons" and neonatal resuscitation (Law, 2019)

Regarding the situation awareness problem above, most of them could be reduced by training HCPs and changing the intervention environment and organization. The importance of teamwork is represented in improving situational awareness. When a HCP failed to keep situation awareness due to paying too much attention to a specific aspect, other team members' continuous information sharing and assertions could draw the HCP's attention back to the task at hand. For example, when an intubator is focusing on intubating a baby, it is other team members' responsibility to remind the intubator if the time has been over 30 seconds. It is hard for one person to perceive everything in a medical emergency, especially when they have their individual tasks at hand. Therefore, every team member should trust each other, keep sharing the observed information and their intention so that the whole team can be aware of the situation.

Neonatal resuscitation is a medical emergency that can highly increase HCPs'stress and anxiety. The increased stress and anxiety could hurt HCPs'working memory, concentration, and decision making (Müller et al., 2009; Quilici et al., 2005). Due to stress and fears, HCPs may hesitate to initiate treatment or make suboptimal decisions under challenging situations resulting in poor patient outcomes. As a result, patient safety could also be jeopardized. It is imperative to train HCPs so that they can manage a critical medical emergency under stressful conditions.

However, studies found that stress can also have positive effects on decision making as well, but only if the stress is not perceived as a threat but as a challenge (Starcke & Brand, 2012). For relatively easy tasks, HCPs may lose their attention from resuscitating the baby for various reasons such as talking with a parent at the same time. An appropriate level of stress could narrow HCPs' attention back to focusing on their work and lead to improved performance. Therefore, in this thesis, for the game design, it is essential to adjust the balanced level of HCPs' stress for gameplay. The adjustment could be achieved by the design of game fidelity and difficulty. More detailed information is discussed in Chapter 4.

Other factors which contribute to cognitive problems such as fatigue, excessive workload, and "out of the loop" could be improved by the local hospital policy, organization, and environment setting.

3.4 Physical Factors Analysis

Besides the subjective factors such as teamwork and cognition, the objective factors, physical factors such as environment and equipment setting also has a significant impact on HCPs' performance. These physical factors could range from the organization of equipment storage to the design of a ventilation mask. Below is a table that demonstrates the physical problems observed in the video recording and the potential negative impact they may have on neonatal resuscitation.

Physical problem	*Potential negative impact on neonatal resuscitation*
Due to shape and material texture, the ventilation mask does not fit correctly on the baby's face	*The leak occurs during the ventilation, especially between the check and the bridge of the nose. Head fatigue because it is too slippery to hold the mask.*
The equipment wires are messy and disorganized on the warmer	*HCPs waste time on tracking back and finding the correct equipment*
The interface of warmer is complex, and HCPs have never used some functions	*The unnecessary functions increased the difficulty of usability and learnability for HCPs.*
The design of sticky tape on the pulse oximeter	*The tape sticks together when a nurse is attaching pulse oximeter. The nurse needs to spend time to sperate it, which delays SPO2 showing.*
When a baby reached a targeted temperature, warmer keeps alarming loudly.	*HCPs' attention is distracted by the alarming from the operation on their hands.*
The monitor is placed behind the top of warmer which place is not readily in HCPs' sight	*HCPs need to move their sight from baby away to see the monitor, which may result in the delay of knowing vital signs and lose concentration on the baby.*
The organization of the equipment storage is dizzying and not well classified.	*HCPs may take a long time to find the equipment they need, which delays the treatment.*

Table 3.4.1 Physical problem and potential impact on neonatal resuscitation

Although the physical factors are not the focus on the game design in this thesis, this game provides alternative solutions for some of the problems, which would be introduced later in Chapter 5. The problems and alternative solutions pointed out here could contribute to other studies to improve neonatal resuscitation outcomes.

Chapter 4 Core Elements and Serious Game Design Framework

4.1 Core Elements of Serious Game Design

4.1.1 Immersion and Engagement

For the serious game design, especially the targeted users working in time-intensive stressful medical emergency fields, a high immersive, engaging learning environment is required. The simulated immersive learning environment has been proved to be useful for training in many crisis situations (Buljac-Samardzic, Dekker-van Doorn, van Wijngaarden, Jeroen D. H., & van Wijk, 2010; Chiniara et al., 2013; Wallin, Meurling, Hedman, Hedegård, & Felländer-Tsai, 2007). By practicing the real-world context in the virtual learning environment, learners' ability to maintain knowledge and skill in a stressful situation could be improved. Accordingly, they could make correct decisions easier when they start to operate in the real world without being affected by emotional factors such as stress and anxiety.

To provide an immersive, engaging learning environment, one of the design key factors is deep engagement while people are playing games (Denis & Jouvelot, 2005). Engagement is often viewed as a crucial factor in game enjoyment and the outcome of an excellent gaming experience. Deep engagement is always related to the term "immersion." Immersion is an experience that when learners are engaging with the game (Bouvier, Lavoué, & Sehaba, 2014). Their undivided attention to the game so focused that they even do not notice the passage of time and forget the real world exists. They are so focusing on the game and even feel that they are "in the game." Brown and Cairns (2004) identified three levels of immersion: engagement, engrossment, and total immersion. They consider engagement is the first level that people pay their attention and effort to the game. The engrossment level is the experience that learners by being involved in the game, and their emotion is affected by the game. The last phase, total immersion, would cut off learner's awareness from real life into the virtual world, which is not always achievable (Brown & Cairns, 2004). The total immersive environment is an extraordinary and rather fleeting experience when gaming. The game design to provide the immersive experience could be

focused on the engagement and engrossment levels, which are achievable and sufficient to provide a good learning experience.

The first step to promote engaged learning is to understand how engagement processes happen in gaming. Tan (2019) described how engagement occurs in learning with three phases of engagement processes: promoting, motivating, and supporting engagement.

The first phase of engagement processes is promoting engagement. In this phase, learners experience the new learning environment and perceive the game mechanics and learning materials. Learners start to interact with a variety of game resources and initiate interest in the content of the game. It is essential to provide learners with opportunities to discover game elements that would activate their background knowledge and interest (Tan, 2019). Especially for the learners who are unfamiliar with the activities related to the game, it is necessary to give instructions such as telling them the game objectives that need to be achieved and the gameplay to follow. For example, regarding neonatal resuscitation, the game objective is using the correct equipment and operations to save a baby. Giving clear game goals and providing a variety of game resources establish the initial motivation of playing and therefore promote game engagement.

Once the learners get familiar with the game mechanics, they come to the second phase, motivating engagement. At this stage, learners interact with the game elements and relate them to the activity in the real-world (Tan, 2019). To improve game engagement in this phase, the game must provide learners with interesting materials and appropriate challenges. Facing the challenges, the learners may realize their flaws in the related field. Then, to beat the challenges, they would pay more attention and passion to the game and using strategies to solve the problems. Accordingly, learners would have a sense of enjoyment and be motivated to engage with the game.

The third phase is supporting engagement. Supporting engagement is required when learners have difficulties in completing the game tasks by themselves. If there is no

extra help being provided to them, the learners disengage themselves from the game (Tan, 2019). Like the example mentioned in section 2.3.1, in the NRP eSim, because there is no way to call for help, watching the baby's heart rate decreasing and having no clue of the next intervention step, a learner would feel frustrated and tend to shut down the game. Therefore, it is crucial to provide different levels of difficulty according to learners' competence. If it occurs that the game difficulty does not suit learners' abilities, there must be some ways to guide and support the learners finding solutions during the playing. These supporting methods, for instance, could range from the voice prompts to achieving higher scores as a reward. Regarding how to set different levels of difficulty and more detailed supporting methods would be discussed in the later sections.

4.1.2 Fidelity

The benefit of utilizing simulation to educate people is that it can provide an authentic learning environment that replicates the situations that learners facing in real life without risks such as harming a patient. To create an authentic learning environment, one of the critical elements is the fidelity configuration of the game. Fidelity is defined as the level of realism that a simulation presents to people (Chiniara et al., 2013). It is an intrinsic element of simulation that defines "how similar a training situation must be, relative to the operational situation, in order to train most efficiently"(Hays & Singer, 1989). A simulator with high-fidelity can impose realistic environmental task requirements and pressure sources with a fraction of actual training costs, and the risk is greatly reduced (GAO, 2016).

Fidelity could be subcategorized to include issues relating to physical, functional, and environmental fidelity (Frank, 2018). Physical fidelity refers to the realism of the component that is simulated, such as a patient simulator that was designed to look life-like. The functional fidelity describes the degree of a simulator reproducing observable human behavior characteristics (Allen, Hays, & Buffardi, 1986). For example, if a simulator could elicit an anxious emotion from the learners and in the real-world, this simulator has a high functional fidelity (Neubauer, Khooshabeh, & Campbell, 2018). Physical fidelity in healthcare simulation refers to the realism of the patient or of the

component that is simulated. As such, it could also be called patient fidelity. Environment fidelity refers to the realism of all elements not directly connected to the patient, including instrument setting and the personnel. To these two domains, we should add temporal fidelity, which refers to the way time flows during the simulation session. At the high end, time flows unimpeded. At the low end, temporal contractions or pauses take place. The environmental fidelity refers to the extent of the surroundings that replicate the environments in real-life (Frank, 2018).

Fidelity is multifaceted. It is difficult to measure the degree of fidelity in a learning environment. A game could be relatively low in environmental fidelity but still represent a high level of physical fidelity. Many studies researched the relationship between fidelity and training effectiveness and found that a higher level of fidelity does not translate into a better learning outcome (Allen et al., 1986; Feinstein & Cannon, 2014). Moreover, high fidelity may inhibit learning effectiveness because it overstimulates novice learners.

Therefore, designers must focus on and reproduce only the most necessary and appropriate details of fidelity for simulation game design and implementation. To identify the appropriate fidelity configurations, designers must analyze the related task components that are necessary for learning effectiveness and give priority to simulator capabilities that can improve the authenticity of these components (Neubauer et al., 2018). This refers to providing practical physical, functional, and environmental characteristics of real-life features that are needed for a successful educational experience. The game characteristics must be able to replicate the task demands and stressors that are placed on the leaners to be deemed valid. The fidelity characteristics could be, for instance, 'contextually-relevant stress' such as noise, time pressure, and exposure to distressing situations. As mentioned above, to avoid overstimulation and understimulation, it is important to consider the targeted learners' competency and experience when designing the fidelity configurations.

In addition, the fidelity configurations must be able to elicit a learners' desired behaviors of interest, and the design of these activities must be thoughtful in advance

(Neubauer et al., 2018). For example, as the previous section emphasizing the importance of effective communication, learners would benefit from a high-fidelity communication environment. The communication is not only existing between team members, but also between the game characters such as a NPC. To mimic communication in the real world, the design strategy may consider utilizing verbal communication as well as physical contact instead of text.

Overall, it has been recognized that the game fidelity could have an impact on learning outcomes. However, it appears that simply increasing the fidelity level does not directly lead to a better task outcome. The design of game fidelity should focus on the transformation from physical realism to the functions that confirm to the specific learning objectives (Hamstra, Brydges, Hatala, Zendejas, & Cook, 2014). The design strategy in this study is, based on learners' experience and competence, using a selective fidelity approach that matches the stressors and learning objectives within the live and virtual environment.

4.1.3 Emotion

Learners' emotion is an essential factor that should be considered when designing a serious game. During the gameplay, a users' learning engagement would be significantly influenced by their emotions such as boredom, stress, frustration, joy, confidence, and curiosity, and these may have a positive or negative impact on their learning experience.

Stress is one of the most important emotional states that should be focused on first, as it can further elicit other emotions such as frustration, anxiety, and reduced confidence. As mentioned before, stress can have two opposite effects on people's performance. First, when the task is relatively easy, a learner may become overconfident to execute the tasks and doing somethings that unrelated to the tasks (such as discussing a baby's appearance written in Chapter 3). As a result, they may fail to pay attention to the detailed operation or environmental changes. The modest level of stress elements could increase the challenge for learners and narrow their attention back to the works at hand. However, people's performance could also be significantly

impaired by the stressful learning environment. With the increment of stress, learners may selectively focus their attention on selected tasks only and thereby increase the danger of neglecting potentially valuable information. This phenomenon is known as "tunnel vision" (Keinan, 1987). Also, because of the stressor such as time pressure, learners may make a decision too rashly, which based on insufficient consideration of information (Beilock & Carr, 2001). As stress increases, people may become too anxious to concentrate on their tasks. For example, they may start to worry about their performances, or their minds simply shut down and ultimately resulting in misjudgments. Furthermore, if there is no additional supporting from team members or game systems, the decreased performance due to stress may, in turn, further increase a person's stress level (Hunziker et al., 2013).

To avoid this stress cycle occurring, it is essential to predict learners' emotional changes and the relationship between emotion and learning transfer. During the gameplay, when learners' behavior contributes to the game objective, they are prone to produce positive emotions such as a sense of accomplishment. On the contrary, when their performance jeopardizes the game objective, they could generate negative emotions such as confusion (Dweck, 2002). However, studies show that learning gains could be accompanied by negative emotions (Craig, Graesser, Sullins, & Gholson, 2004; Guhe, Gray, Schoelles, & Ji, 2004). Negative emotions could occur when learners have cognitive disequilibrium, which is the result of facing barriers to objectives, anomaly contradictions and inconsistencies. Generally, learning happens after cognitive equilibrium is restored after deep thinking, reflection, problem-solving, and other meaningful deliberations (Ritterfeld, Cody, & Vorderer, 2009). This process is also a representation of Kolb's learning cycle. Hence, to achieve the learning objective, a certain level of negative emotion is necessary.

When designing a serious game, designers could place some obstacles for learners to conquer and let them go through the learning cycle. Notably, the challenge setting should be adjustable based on learners' emotional changes and their competence. For example, if the task is hard for learners and they get confused, the game could leave them in the cognitive equilibrium status first for a while and wait for them to

figure out the solution by themselves. If the learners still cannot solve the problem, to prevent learners from getting dispirited, the game system could reduce the difficulty and provide some prompts to advance the learner in constructing knowledge and motivate them to go on playing. To the contrary, if the task is too easy for learners, and they get bored with it, it is necessary to present more challenges for learners, since knowledge gains after they genuinely thought the solution to solving the problems. Serious games would benefit from a mechanism that can manage learners' emotions productively by dynamically adjusting the elements of learning rate and game challenges.

4.1.4 The Balance Between Learning and Playing

The best way to motivate learners to embrace learning is to "make it fun." Accordingly, making learning fun seems to be a powerful tool to foster learning. The learning method that transforms learning activity into serious games has been named "sugar coating learning" (Mohammed & Mohan, 2007). To sustain a player's interest in learning, designers are facing the challenge to create the entertaining elements of the serious game, while remaining learning as the primary goal. Achieving the balance between the main goal of learning and the entertaining elements is critical for a serious game to be successful.

Commonly, serious games face the challenge of keeping a good integration of learning and fun. The learning techniques or content used in games often lack a meaningful relation or even conflict with the entertainment elements. Under this circumstance, learners may be distracted by playing games and unable to achieve their learning goals, or they may be disengaged because learning elements may destroy the fun of playing (Tan, 2019).

For example, one of the biggest problems that designers may encounter is to keep the balance and, to achieve the learning goal, repetition, as a fundamental and universal learning technique, may be utilized in learning. It is manifested as a constant demand for learners to understand the same concepts in a learning activity (Tan, 2019). However, presented with memorization and repetition of the content in the game,

learners may lose interest quickly after playing one or two rounds. Hence, to sustain a learners' interest in playing, designers must use the design strategy to hide the repetition behind variation, such as increasing levels of difficulty or tweaks to the game mechanics.

For example, commonly, to motivate learners' engagement, a game could design a trading system that requires learners to complete specific tasks with the corresponding game currency. Learners could use the obtained game currency to purchase goods in the virtual market. The virtual goods, such as time credits, may have features that can provide help to learners during gameplay, or it may be a key that can open a new level of the game for learners. With the desire to accumulate the game currency, learners would be motivated to continuously apply effort to achieve a higher performance, which leads to a virtuous cycle.

Although such a trading system may boost the fun aspect of gameplay and hence increase the engagement, the potential risk of the trading system is that it may distract learners' attention from the learning aspect to the entertainment section only. It should be emphasized the need for the sufficient integration of synchronization with learning objectives and entertainment elements. A designer must always see knowledge gains as the primary goal, which means that the learning quality cannot be sacrificed because of entertainment.

4.1.5 Level of Difficulty

As the previous section demonstrated, the setting of serious game difficulty could directly have a significant impact on learners' emotions and further influence their game experience and learning outcomes. Difficulty in serious games can be defined as the level to which the game represents a personally demanding circumstance that requires a considerable number of learners' cognitive or physical efforts to develop their knowledge and skills (Orvis, Horn, & Belanich, 2008).

To improve learning outcomes, a serious game must provide learners with an optimal level of game difficulty based on their experience. The optimal range of the game

difficulty should be challenging enough for learners to gain knowledge, but not exceed the ability of the learners to prevent game disengagement due to frustration. Whether the game is too difficult or too easy can both result in poor game experience and further reduce the quality of learning outcomes. The optimal level of difficulty is that it does not provide learners with absolute success or failure but offers them an intermediate probability of success (Orvis et al., 2008). Keeping the difficulty at the optimal level is key in keeping the learners' engagement with the game.

At the beginning of play, it is necessary to provide whether novice learners or experienced learners a game tutorial with easy tasks. The purpose of the tutorial is not for learning knowledge but to concentrate on teaching learners the flow of the game. For example, they may get to learn the game objective and how to catch an item with a VR controller. The simple tasks provided at the beginning of the game could help to prevent learners from getting overwhelmed with too much information resulting in disengagement of the game. A universal tutorial design method is that it provides learners a fundamental introduction of the game flow and the simple tasks of practice without decision making required. For example, in the tutorial section, the game interface could show guides to learners going through the game flow steps by steps. What learners need to learn at this phase is the operation of gameplay with highlighted options, which means they do not need to use their professional knowledge to choose between one or another. Besides, the tutorial should be short and straightforward. As learners are not looking to digest masses of information at the beginning of the game. A long tutorial with full of information may lead to the learners losing patience and skip some of the instructions.

After learners get familiar with the game flow and the game operating system, the game could provide more challenging tasks with different levels of difficulty for learners. The tasks may go from easy to difficult levels for learners to choose. For the learners who are novices in the professional field or not confident about performing a hard task, they could choose an easy level of the game. On the contrary, for those who are experienced in the field may choose to undertake a more challenging level. Such game mechanics allows learners to have the autonomy to the level of difficulty by

themselves based on their confidence and personal experience. In addition, after playing a few rounds of the game, learners would benefit if the game could suggest the level of difficulty for them based on their performance data and detecting their competency of the topic.

With going through the practice multiple times, learners' game abilities would be improved. They may feel more confident in their capability to successfully learn and perform well at a more challenging level of the game. Miettinen asserts that reflective learning is not based on the experience itself but on finding the inadequacy and contradiction in the experience (Miettinen, 2000). Hence, in order to initiate and drive the reflective learning, the game difficulty should be increased for learners at this moment. The optimal levels of difficulty should always be set in the stage that makes the learners feel that they are playing at the edge of their comfort zone. With the learners progressing within the game, their competency would be improved with each game level that they play with more challenges than the previous level. For instance, as one of the serious game objectives might improve learners' ability to anticipate and overcome unknown stressors, especially in the medical education field, increasing the level of difficulty may eventually grow the learners' abilities to perform at a higher level despite challenging or stressful circumstances.

4.1.6 Feedback

As an essential part of learning, feedback plays a critical role in improving a learner's learning outcomes. Feedback is defined as a type of communication in which a sender or a source conveys a message to a receiver regarding the receiver's performance (Ilgen, Fisher, & Taylor, 1979). After a round of gameplay, receiving the feedback facilitates self-regulation for learners to reflect on their game performance and recognize the gap between current performance and desired performance. Being aware of their learning status, learners get the guide of learning goal settings and manage their strategies to reduce the gap. Hence, their learning outcomes could be enhanced.

There are many forms of feedback in a serious game. Generally, according to its

attributes, feedback could be classified by type, source, time (Chiniara et al., 2013).

There are two types of feedback that are widely recognized in studies: process feedback (also defined as learning-oriented feedback) and outcome feedback (also defined as performance-oriented feedback) (Chiniara et al., 2013).

Process feedback, as its name implies is focused on the task process and provides feedback to complete the task. It focuses on "growth rather than on grading" as a method to enhance learning (Sadler, 1983). It facilitates learners by providing feedback during the task that helps them to go through the process and achieve their final goal. Process feedback has an explanatory value that gives descriptive and confirmative information on learners' specific game behavior (Johnson, Perlow, & Pieper, 1993). For example, process feedback could be as simple as a buzzing when a learner makes an error or could also be informative that provides explanation and prompts the next step for learners. Process feedback can be utilized as a powerful tool to support learners'performance, especially on completing a complicated task.

Outcome feedback, on the other hand, is directed toward the outcome or result. It provides learners with the result of their performance so that they can modify their learning actions and plans according to the feedback. Good outcome feedback must be clear and detailed enough that enables learners to relate the feedback to the cause of their errors or inadequacy in the game. If the outcomes give a grade or a mark of correct/incorrect only without comments and explanation, it is meaningless since learners are uncertain about which behavior reduced their grade and the reason for it. Moreover, feedback addressing the grade only may lead to learners focusing only on their grades and not attempting to evaluate their performance and fix strategies for future practice. Thus, each feedback should be directed to the learners' behavior so that they could connect their behavior to feedback. Being aware of the cause of the errors, learners could correct the errors and readjust their learning strategies for the next learning round.

The timing of feedback also plays a critical role in improving learning. Feedback could

be classified into immediate feedback and delayed feedback. Immediate feedback is given to learners as soon as they act. Delayed feedback is provided to learners withheld for a while after a task is completed (Lemley, Sudweeks, Howell, Laws, & Sawyer, 2007). Some studies noted that immediate feedback might boost short-term performance, while delayed feedback is appropriate for long-term knowledge retention (Schmidt, 1991). Although studies show diverse attitudes towards whether immediate or delayed feedback is more efficient in learning, they all agree that people who receive feedback would have better learning outcomes than those who do not (Kulik & Kulik, 1988; Masadeh & Elfeky, 2017; Metcalfe, Kornell, & Finn, 2009).

Immediate feedback is necessary for a serious game. Whether a learner makes a mistake during a task or not, simple immediate feedback could confirm his/her decision and hence motivate their game engagement. Besides, in some procedural games, a decision made in the early stage of the game could have a significant influence on the rest of the game process. In this situation, keeping the mistake could further result in more errors, foment additional struggle as the remaining operations are based on a fault cornerstone. In addition, studies proposed that if a learner makes an error and the error is not corrected immediately, the error may be rehearsed and entrenched in the learner's mind during the delay. Even though it is corrected later, the learner is likely to make the error again (Metcalfe et al., 2009).

However, an alternative view is that learning can be strengthened by delayed feedback. Though the error could be recognized during the play, it could also be forgetten during the delay. If the learner forgets the wrong answers when he/she is reviewing the delayed feedback, there would be less proactive action for them to memorize the correct answer (Metcalfe et al., 2009). Even though the learner remembers the errors, a study proposed that the learner struggle to figure out the errors could support a more significant impression in the long-term knowledge retention, and they could have productive learning from the errors (Kapur & Bielaczyc, 2012). Moreover, due to the recall of effect, knowledge retention in the long-term is in the favour of delayed feedback. Delayed feedback can be considered as a spaced learning that strengthens the knowledge gained during the gameplay, as people could reflect on their

performance through the delayed feedback.

Besides, a potential shortcoming of immediate feedback is that it causes learners to depend on the feedback and prone to get an answer immediately instead of taking a thoughtful approach and trying to solve the problem on their own. Learners may become nonchalant and do not pay careful attention during the game because they could decide that the virtual environment does not impact the real world. When they are facing a question and uncertain about the answer, they may give up pondering and hastily choose between one or another as they know that errors would not result in a severe outcome and they can get the correct answer immediately. To avoid this issue happening, in some circumstance, especially for the complex task, instead of directly giving the immediate feedback, a serious game might provide some extra processing time for learners to deliberate and try to resolve the problem by their own or provide some implicit hints to support them when it is necessary.

Overall, a practical learning experience contains a mix of immediate feedback and delayed feedback. To optimize the feedback, designers must fully consider the timing element regarding its impact on task difficulty, game engagement, knowledge retention. Immediate feedback and delayed feedback should be both implemented into the game and be given to learners under different appropriate circumstances to help game processing and reflective learning.

Besides the type and time, feedback can also be divided according to its source. Generally, there are three sources of feedback: the task and environment, the learners performing the task, and others observing the performance, such as team members and instructors (Ilgen et al., 1979).

The feedback from the task and environment plays a critical role in a serious game. Besides the explicit feedback such as the comment and grade of performance, the task itself also provides learners with implicit or inherent feedback. For example, in the RETAIN web-based simulator, during the gameplay, instead of directly telling learners their errors in verbal or text, the feedback is represented on the baby's status. If

learners make a mistake, they may see a heart rate decline as feedback of their mistake. The second source of feedback is learners themselves. During and after the task, they could provide their feedback by reflecting on their behaviors. However, it is not so achievable for learners to simply reflect and evaluate their performance on their own. A possible reason is that individuals have blind spots and the minimal comprehension of the knowledge. Hence, it is very likely that learners fail to notice and fix their errors and weakness by themselves. Especially for the learners who execute tasks under time pressure, they rarely have time to reflect their behavior during the task. After the task completed, they possibly fail to recall every decision they made. Thus, it is worth considering how to facilitate learners' recall and reflect their performance through the game system.

Lastly, feedback could also come from others who are involve in or observing the task being performed. This feedback could happen both during the task processing and after the task completed. As the importance of teamwork emphasized in chapter 3, team communication could be considered as vital feedback to support the individual as well as team performance during the gameplay. Whether it is a correction or confirmation, the feedback from a team member could enhance a learner’s confidence and facilitate them to continue training. After the task is finished, learners interact, and discuss with peers and instructors in the debrief session. They may get comments from others, such as what went well and what remains to be improved. Getting feedback from the interpreted experiences and explanations of other people could considerably impact a learner’s reflective learning.

In addition, observing team members’ performance could also be considered as feedback. Observing peers and drawing conclusions from the behaviors of peers can also provide knowledge to learners. Performances of others have reference value that could help learners compare their performance with others and track their learning progress so that they could get motivated and make changes accordingly. This feedback also highlights the importance of the multiplayer atmosphere that boosts motivation and self-evaluation. Thus, a serious game must ensure that a peer's performance is visible so that learners could gain insight into their own performance.

To assess learners' performance, the instructor and learners must be provided with an informative assessment tool. The assessment tool may be represented with a video recording of learners' behavior, grade tracking, mistakes tracking, and other data reporting of their performance. The feedback should be clear enough with one-to-one correspondence (Olszewski & Wolbrink, 2017). Especially for the group tasks, there is a potential risk that a reviewer could confuse the tasks of an individual's performance and responsibility. If all feedback is provided in groups, then learners may mistakenly reflect specific feedback to other team members but not themselves. This erroneous recognition could result in that users fail to learn from mistakes and further dilute the qualities of learning outcomes. Hence, the feedback must be as explicit as possible that directly indicates each comment to a specific learner to avoid confusion.

In brief, feedback is an essential element in a serious game involving various types of factors. It plays a significant role in encouraging and supporting learners to achieve a superior learning outcome. When designing the feedback system, designers must carefully pay attention to all its features, including but not limited to type, timing, and source. Feedback must be clear, meaningful, purposeful, and compatible with learners' ability and provide logical connections of learners' game behavior and desired learning objective.

4.2 Serious Design Framework

In the serious game field, there is a great need for a framework for game design. It is essential to establish a framework for serious game design and provide guidance to designers and educators when designing a practical and entertaining learning experience to optimize learners' learning outcomes.

Considering the realities and essential elements of the serious game design described in the previous sections, this study proposes a framework for serious game design illustrated below (see Figure 4.2.1).

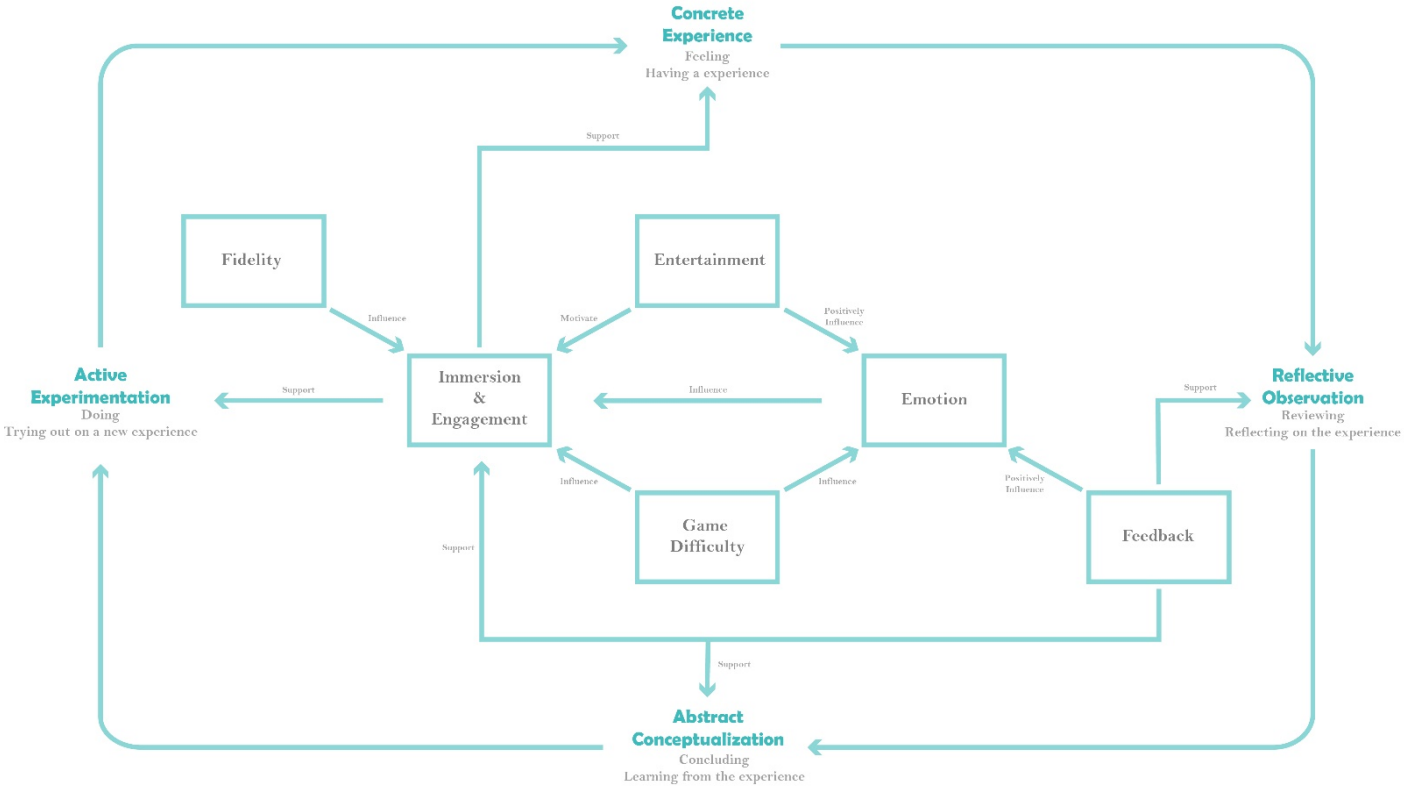

Figure 4.2.1 Serious Game Design Framework

This framework consists of an experiential learning cycle, which refers to Kolb's learning theories (Kolb, 1984), and a series of essential game elements enhancing the learning experience. The framework embedded game design and game principles within the experiential learning cycle to help learners complete the serious game's learning cycle. The learning cycle describes a four-stage learning process: concrete experience, reflective observation, abstract conceptualization, and active experiment. The critical game elements that would influence the quality of the learning cycle include Immersion and engagement, fidelity, entertainment, game difficulty, emotion, and feedback. Every game element is correlated with each other in terms of cause and impact and can be considered a collective whole to reinforce the learning experience and help design and evaluate game-based learning.

Starting with concrete experience, learners can interact with one another and game elements at this stage. During the interaction, they may apply their knowledge to

complete the tasks and meet new situations with new knowledge. To provide learners with an impressive learning experience, a serious game needs to motivate learners to engage with game playing intensely. Learners must actively synthesize the situation in the game and make appropriate decisions rather than passively accept the game's knowledge.

To achieve engagement and improve learners' immersion, the game first needs to tell learners the game goals and game mechanics. Then, to further motivate learners' game engagement, the game may have some entertaining factors to attract their attention. For example, the entertainment factors could be a reward system. Whenever the participants reach a new high score, for instance, they may get some reward. With a sense of achievement, such an entertaining factor could encourage them to pay more effort to game playing and positively influence their emotion, such as enhancing their confidence.

Meanwhile, fidelity, which is defined as the experience's realism, plays a role in immersion and engagement, especially for the simulation-based game. Fidelity represents the game's degree of reproducing observable human behavior characteristics and the realism of all game elements connected to the real world. However, high fidelity is not necessary to produce a deep sense of immersion in the gameplay. Game elements with high fidelity, such as blood in the medical field, may potentially over-stimulate learners, especially for the novice. Hence, to better enhance learners' immersion, designers should consider the targeted learners' mental capacity and experience when designing the game fidelity.

According to the users' background and experience, customizing the game could also be applied in game difficulty configuration. The game should have enough flexibility to allow learners to choose the level of game difficulty that matches their knowledge and capacities. This level should be challenging enough to attract learners' attention and encourage them to engage in games to overcome the challenge, but not too tricky beyond learners' abilities. If the task is too challenging for a learner, then they may be prone to negative emotions such as over-stressed and further get disengaged.

To avoid this situation happening, set the appropriate game difficulty level for a learner, the game should also have a feedback system to support learners when they have negative emotions and get disengaged. Feedback has an explanatory function and can provide learners with descriptive and confirmatory information about their game behaviors. When the game task exceeds learners' capacities, feedback appears as support that may provide learners with some prompts that help them overcome the challenge and complete the task.

Feedback also plays a role after the learner finishes the first stage embedding the experience, and coming to the next two stages, reflective observation and abstract conceptualization. Through reflecting on the learning experience, learners would be able to consolidate their understanding of the new knowledge. Feedback as a powerful tool could help learners to reflect on their performance. Detailed feedback could guide learners that enable them to link the feedback to their game behavior to understand the reason for their errors or correct operation. Based on the deep understanding of the learning experience, the learners could integrate their experience into a more abstract model. At this stage, the serious game may provide learners with feedback such as analysis data of their performance and suggestion that helps them modify their conclusion and create learning strategies for the next learning round.

The process of learning is not just understanding knowledge but also making use of it. Thus, in the fourth stage, learners could test their learning strategies and apply them to the new learning experience. This new learning experience leads to a new learning cycle, which requires the stated game elements such as engagement and feedback, improving the quality of learning. Ultimately, through constant, reflection, and testing out the learning experience, learners would be able to gain and retain knowledge and examine their ideas and integrate them into professional situations.

In conclusion, this study proposes a conceptual framework for serious game design. It employs the foundational principles of experiential learning and describes six critical game elements that designers should focus on to enhance the learning experience

through serious games. The framework emphasizes the importance of considering the targeted users' experience and background as antecedents while designing the game characterizes such as game difficulty and fidelity. Matching the game configuration with users' capacity reinforces their game immersion and engagement and optimizes learning outcomes. It works as a guideline in the serious game design process that addresses both conceptual and practical issues about game-based learning.

Meanwhile, each game element in the framework could be picked in isolation for specific educational game research. The proposed framework can also be applied in the analysis and evaluation of any of the game elements in game-based learning, and the framework deficiencies that contributes to adding or improving them. In the next chapter, this study would adopt the framework into the neonatal resuscitation simulation game design showing how it works in the practical serious game design process.

Chapter 5 The Design of the VR RETAIN

5.1 Setting Core Game Mechanics

Game mechanics refers to an activity structure composed of the game rules and game actions that defines the possible space for the interactions between players and the game world (Järvinen, 2007). The players follow the game mechanics executing the game tasks with their game behaviors and strategies to achieve the game objective. In the VR RETAIN, the core game mechanic is the simulation. The procedural simulation aims to help players to acquire and improve resuscitation knowledge and skills. To create an engaging and educational play experience, the game strives to marry learning objectives, improving learners' performance of decision making, technical skills, and teamwork, with the game's mechanics.

The VR RETAIN game design focuses on restoring the scene of neonatal resuscitation via spatial narratives and storytelling. Narrative elements such as game background presentations are infused into the game, enabling players to replicate the resuscitation operations inherent in the real-world counterpart. In the virtual environment, players can resuscitate newborn babies via contextualized scenarios and interactive game elements. They would be trained to do standardized equipment checks and resuscitate the baby by performing interventions in a correct NRP flow diagram sequence.

As the learning cycle discussed in the framework, knowledge to be acquired depends on what content is embedded in the game and whether the learners obtain reflective understanding after the game experience. Hence, the core game mechanics also involve evaluating game performance and the game reward system, which helps learners reflect their performance, recognize the level of knowledge understanding, and motivate them to adjust their learning strategies.

The user flow below illustrated the relationship between each game stage and demonstrated what is presented on an interface.

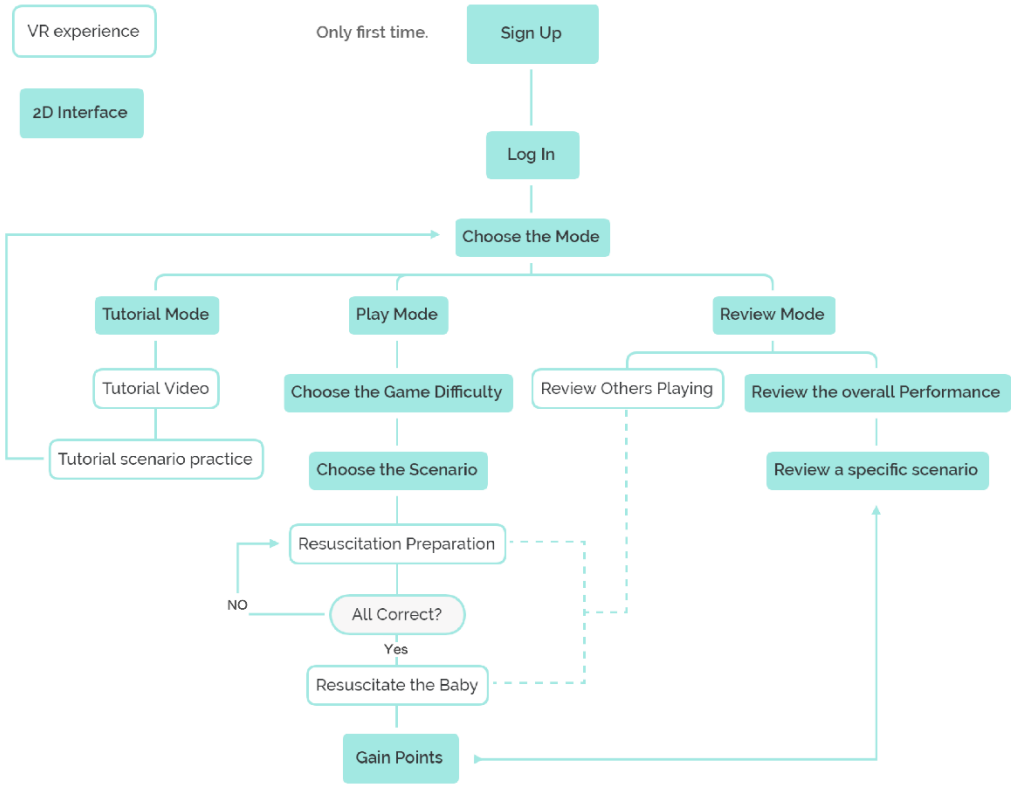

Figure 5.1.1 The VR RETAIN user flow

Based on the illustrated above, the initial prototype of VR RETAIN encompassed the following three game modes (see Figure 5.1.2).

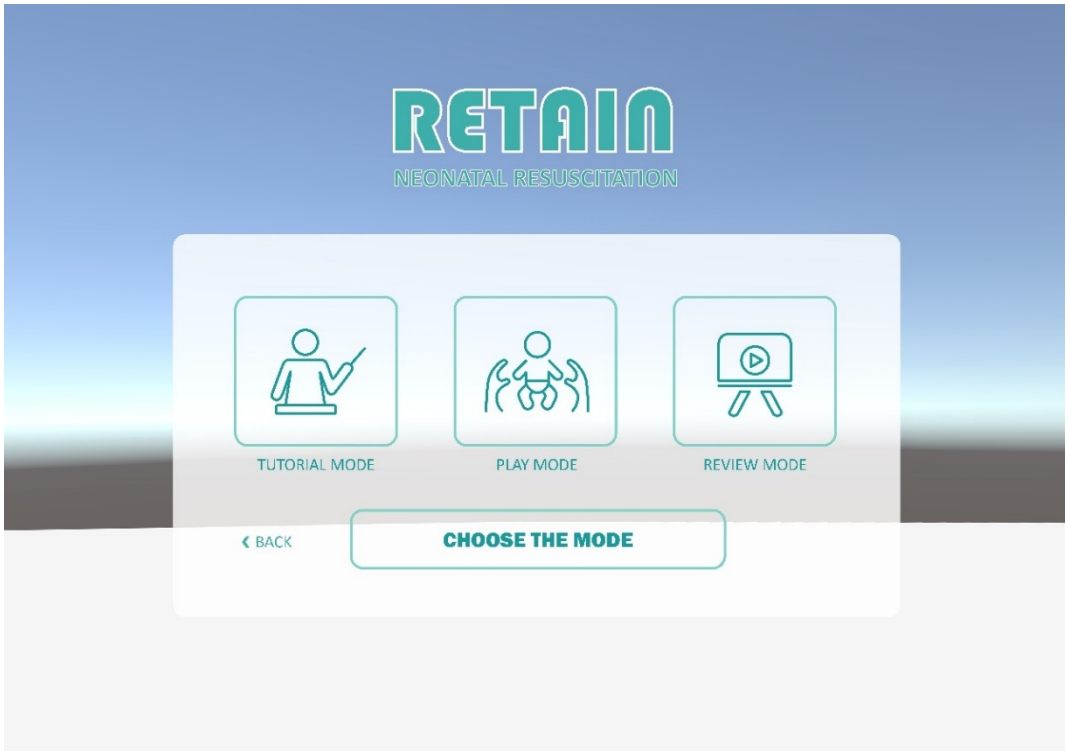

Figure 5.1.2 The interface of choosing the mode

(a) Tutorial mode: the game mode teaches learners the game's rules and controls through a bare minimum scenario play experience.

In this mode, the learners play a short and straightforward scenario in the first-person vision with the game instructions. Embedding lengthy tutorials to players with too much information may overwhelm players and stretch their patience, resulting in skipping the tutorial. To avoid players skipping the tutorial section and encourage players' game engagement, the game blends the tutorial. Instead of providing text or video instruction with the players to read or watch, the game offers a game scenario for learners to get started with, which is more enjoyable and memorable. The tutorial mode scenario is simple, with the initial resuscitation steps. The players would not get overwhelmed with too much information and forget the essential information at the beginning of the game.

After the scenario loads, the players would enter into the resuscitation room and be told that they would resuscitate a newborn baby. In the following section, the players

do not need to use their professional knowledge to consider which resuscitating steps they need to execute. The game system would tell them the answer through the blinking equipment icon or the hint banner. Hence, they could pay attention to learning gameplay, such as operating the VR controller. The tutorial section is not isolated from the learning and playing experience, which reduces learners' chance of getting bored with the tutorial and skipping the tutorial.

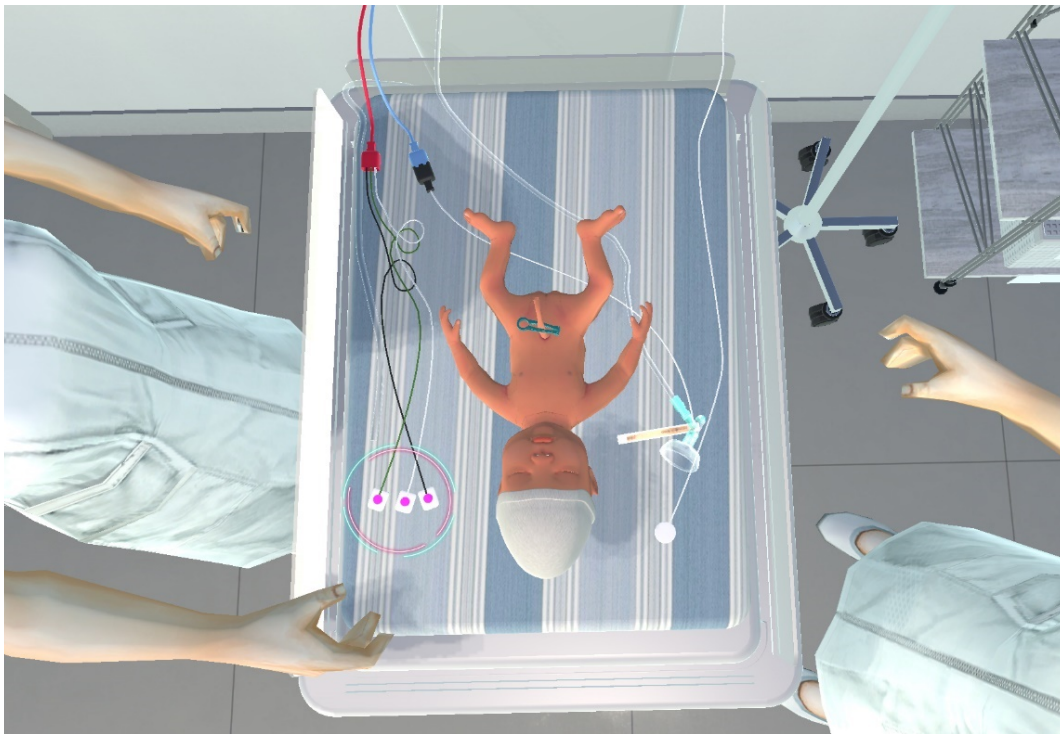

Figure 5.1.3 Game interface with highlighted equipment

(b) Play mode: The player gains knowledge and skills by practicing a series of evidence-based neonatal resuscitation scenarios.

After being familiar with the game rules, the participants focus on learning resuscitation knowledge and skills in the play mode. Before the game begins, they would be provided with a series of game scenarios of different difficulty levels to choose from. A brief information board of each scenario shows in the virtual environment so that the learners could choose the scenario based on their capacity and preference. They take HCPs' roles working as a team and perform neonatal

resuscitation using available supplies and following the NRP flow diagram in the correct sequence in the first-person version.

As the scenario loads, the learners will be called to attend a delivery. In the NICU room, the learners first need to assign team roles and tasks and prepare for the birth. An obstetric provider (NPC) would tell the participants the four pre-birth questions to assess the potential risks and prepare for the birth. According to the provided patient's information, the team identifies and adjusts all the equipment they need. Equipment and supplies are available on the storage shelves behind the radiant warmer. People could come to the storage shelves and grab the resuscitation supplies and equipment and set them up in the appropriate places (Figure 5.1.4). They will also need to adjust the instrument panel to the recommended setting as part of their equipment check. As a correct equipment setting is the cornerstone of a successful resuscitation case, if any equipment is set incorrectly, the game would not move on to the next section until the setting is fixed.

Figure 5.1.4 A Player is collecting the equipment

After completing the equipment check, learners will indicate that they are ready to receive the baby. The baby would arrive at the radiant warmer 20s after the completion of the preparation section. To successfully resuscitate the baby, the learners must work as a team, watch and observe the baby responding to their interventions. For example, they may see the chest movement for the PPV steps and adjust the oxygen concentration according to the monitor (Figure 5.1.5). Depending on how complicated the case is, the intervention steps could range from the initial step (e.g., drying, warming, suction) to medication (e.g., using IV epinephrine). The learners could decide when to end the scenario. They decide whether the baby is to stay with the mother of is to be transferred to post-resuscitation care. With practice, they could learn how to resuscitate quickly and perform several actions simultaneously.

Figure 5.1.5 Warmer operation panel

Initially, the VR RETAIN was designed to be played individually or with up to three players who take different roles, such as a nurse or respiratory therapist, and work as a team. For the single play mode, the player has easy access to practice neonatal resuscitation anytime and anywhere. He/she will take the role of a leader and assign the resuscitation tasks to the other two assistants (NPC). During the intervention, he/she is focusing on decision-making skills. Once he/she gives the medical command to the assistants, the assistants will execute the command automatically. The player must keep situational awareness to perceive and comprehend the condition and make the treatment plan. After the resuscitation is completed, he/she may review their performance, recognize their shortcomings, and practice as many times as they want. For the multiplayer mode, the three players can enter the game remotely and work together as a team. They will have opportunities to practice their communication and teamwork skills. They are going to communicate with each other verbally as well as using body language. When the game is finished, besides technical skill feedback directed to an individual, they will also receive feedback based on the teamwork. For example, the system may indicate that the team did not communicate as a closed-loop, or the medical ordering is unclear. The play modes are designed to focus on improving the different abilities of the players. The players can choose the play mode they want to practice.

Also, apart from the three players, other learners or instructors could enter the game as spectators. The spectators could communicate and coach with the players during the game, making the online simulation classes more interactive. In the meantime, other spectators like a learner, for example, may observe the practice and coaching process. Then they could gain knowledge from the recording and the observation.

(c) Review mode: the review mode that the game shows feedback to people and enables them to review, conclude, and modify their performance. As with the instructor, others could also access the review mode and change his/her teaching plan accordingly.

There are two pathways to access the review mode. People could directly choose the

review mode in the choosing mode interface. After finishing the resuscitation, the game would automatically load into the review mode. In this mode, the learners would assess their game performance by being provided with a time list feedback of their game actions (Figure 5.1.5). The time list feedback is divided into three parts corresponding to each individual's game performance. Each part consists of several blocks that state every decision and action the learner made. It also shows what he/she did well and what can be improved next time. On the bottom of the time list feedback, the team would see their final score based on their performance.

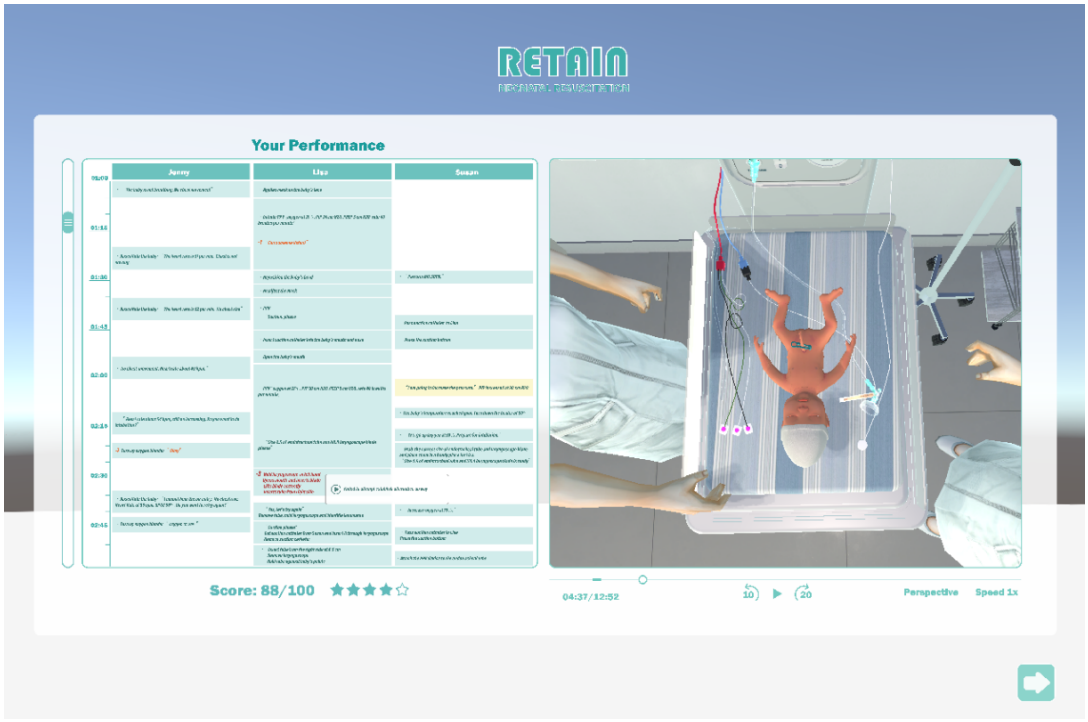

Figure 5.1.6 Performance Review Interface

On the right side of the time list feedback, there is a video player. People could playback the game process through the video player, which helps them reflect on their game behavior. To access their game behavior, they can either click the play button below the play screen and watch from the beginning of the game process or click a square in the time list and jump to the moment they want to watch. During the watching, people could choose the speed and the primary team leader perspective or any other team member.

After completing the game performance review, the learners would be offered a dashboard that summarized so far all their performances. The summary includes a line data comparison of each scenario's score, strengths, and weaknesses in each resuscitation category, an error review list of every scenario. With the comparison of the game experience, the learner could better understand their learning status and modify the learning strategies accordingly.

In summary, these are the game rules for the VR RETAIN. Prepare for the birth by learning the answers to the pre-birth questions (What is the expected gestational age? Is the amniotic? Is the amniotic fluid clear? How many babies are expected? Are there any additional risk factors?) and performing the equipment check. Resuscitate the newborn with the team member following the NRP flow diagram in a correct sequence. Review the performance and learn from the feedback system. Learners could play patient cases until they are satisfied with their scores. They will learn more each time after they practice the VR RETAIN.

5.2 Game Actions and Rules

To get started with the game, the players need to set a space to play the game. Otherwise, they may hit an item when they put the VR headset on. In space, the players enter the game, trace the space, and mark the safety play zone. Then the system would know the physical boundary. Once a player goes out of the boundary, the game would be paused, and he/she would be able to see the real world, so the player would not accidentally hit a wall.

As the Figure 5.2.1 shows, players interact with the game through the VR controllers. In the Login and game setting section, people use a pointer to fill out the information and press the trigger button to confirm their choice. The reason for displaying pointers instead of hands here is that the pointers are more convenient for players to interact with the game icon. The pointers can reach the icons at a longer distance than hands. Hence, to make choices, a player only needs to turn their wrist instead of moving arms.

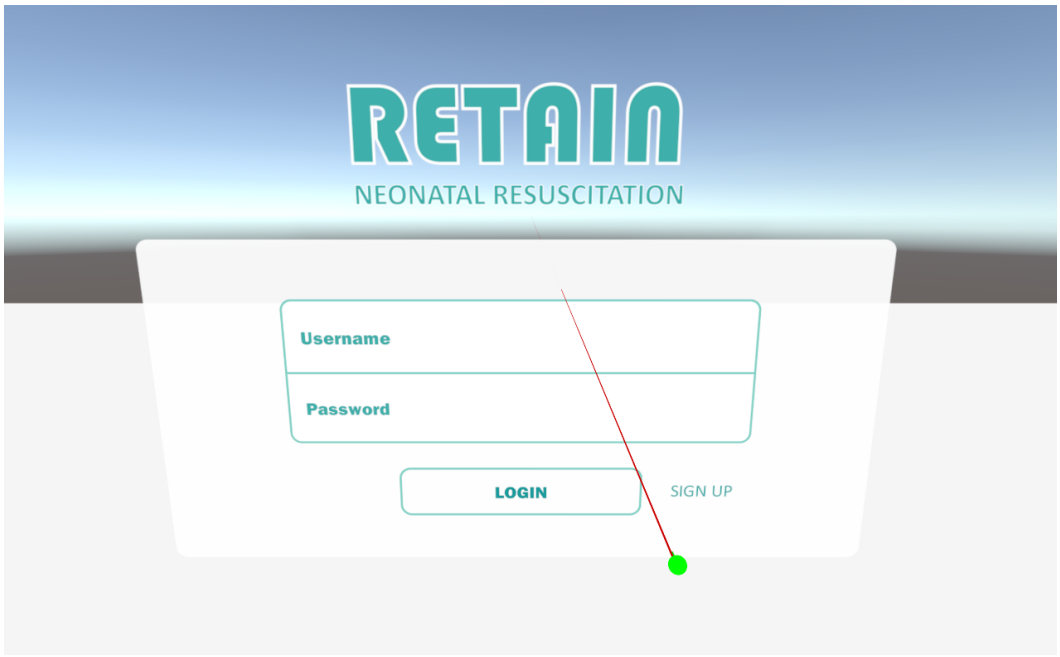

Figure 5.2.1 Game sign up and login Interface

Players would begin the serious game in the operating room, taking on the role of doctors or nurses, viewing the scene in a first-person perspective. The world is viewed through the viewpoint of the players' avatar, and as such, the avatar's body will not be in view although their hands will (Figure 5.2.2). Several other avatars will also appear in the scene, including the patient (lying on a bed), assistants, and nurses. Avatars will be animated using simple pre-defined motions, and the option of controlling them remotely by other players or controlled using artificial intelligence techniques will also be provided. The trainee has the ability to move and rotate the "camera" (the view as seen from the player's avatar) in a first-person style, thus allowing them to move within the scene. A cursor appears on the screen, and the trainee can use this cursor to point at specific objects and locations in the scene. Objects that can be selected ("selectable objects" include assistants, nurses, patient tools) will appear to glow when the cursor is placed over them (details regarding the implementation of the glow effect are provided in Figure 5.2.2.

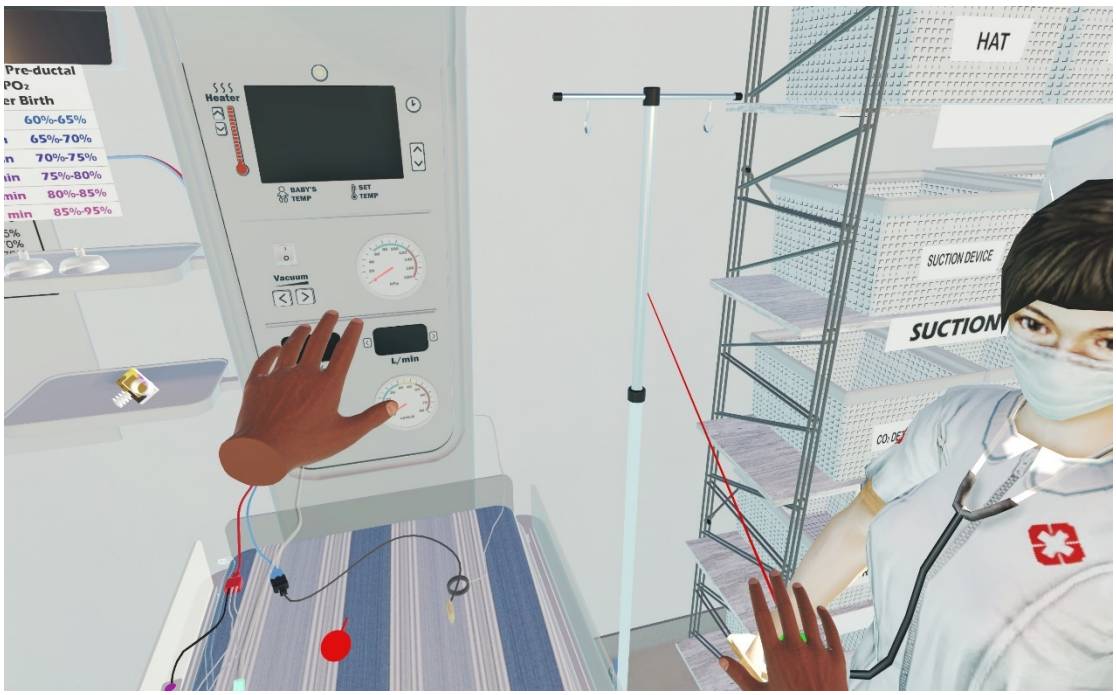

Figure 5.2.2 3D display in the game

The first scene shows most of the elements relating to the immersive environment. If a player wants to grab a piece of equipment, he/she could move the hand with the controller over the object until it appears to glow and then press the grip button to pick up the object and move it around. To place the equipment on a baby, the player releases the grip button. The equipment would not automatically be snapped to the correct position on the baby. By decreasing the intuitiveness of object operating interaction, the game has made it mandatory for player to consider the baby's correct equipment position, which will train their equipment placement skills. They could also activate and operate the equipment by pressing the grip button and the trigger button at the same time. For example, to suction a baby, a player may grab the suction catheter by pressing the grip button, insert it into the baby's mouth, and press the trigger button to perform the suction action. Some actions, such as chest compression will keep running until the player chooses to stop them. To stop the action, the player must release the trigger button. The Figure 5.2.3 illustrates the layout of the VR controller using both HTC VIVE and Oculus.

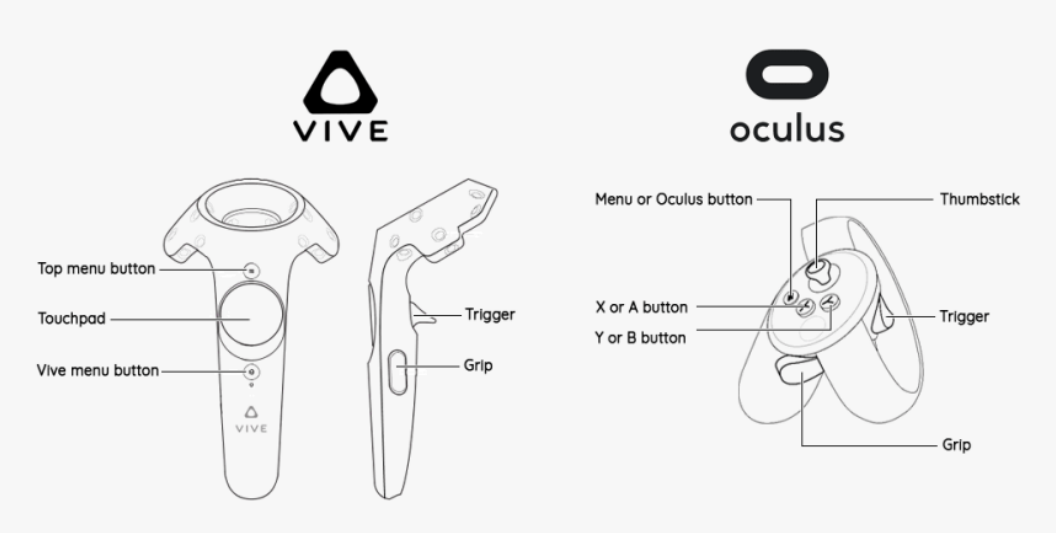

Figure 5.2.3 The instruction of the VR controller using in HTC VIVE and Oculus

Source: (VR Sketch, 2019)

The players play the game in the resuscitation room, which is not a large game environment not unsimilar to other adventure VR games. For the close-range movement within a few steps, they could move by walking. For the relatively long-distance movement, they could move their thumbs on the touchpad or thumbstick. As most of the time, the players are standing behind the radiant warmer resuscitating the baby, they are not required to move a lot in this game. They play the game with a first-person view, which offers the freedom to move and give the player a sense of presence.

This operating system is standard in a VR game. For the experienced VR game players, this may be second nature. For the beginners, they would learn game control quickly by playing the game tutorial.

5.3 Design Effort for Improving Game Engagement

The game mechanics' design frames for game engagement include technical task engagement, communication and teamwork engagement, and cognitive engagement. After iterative refinement and design, game mechanics have the features of integrating game engagement into gameplay. The game identified a narrative and context within the virtual world. It is challenging to engage players by simply transferring resuscitation

knowledge to the virtual world without a clear relevance between the real world and the virtual world.

To enhance players' sense of engagement, the game makes them aware of the urgency associated with neonatal resuscitation in the real world and the tasks' multi-level character. The players would actively engage in the intervention of a baby, communicating with team members, using clinical knowledge to make a decision, and followed by executing a series of actions to complete the task. This process corresponds to the Neonatal Resuscitation Journey Map (see figure 3.1.1). Depending on how complicated the scenario is, the player may continually evaluate the baby's condition and resuscitate the baby with teammates by applying their knowledge and skills from preparing for resuscitation to medication.

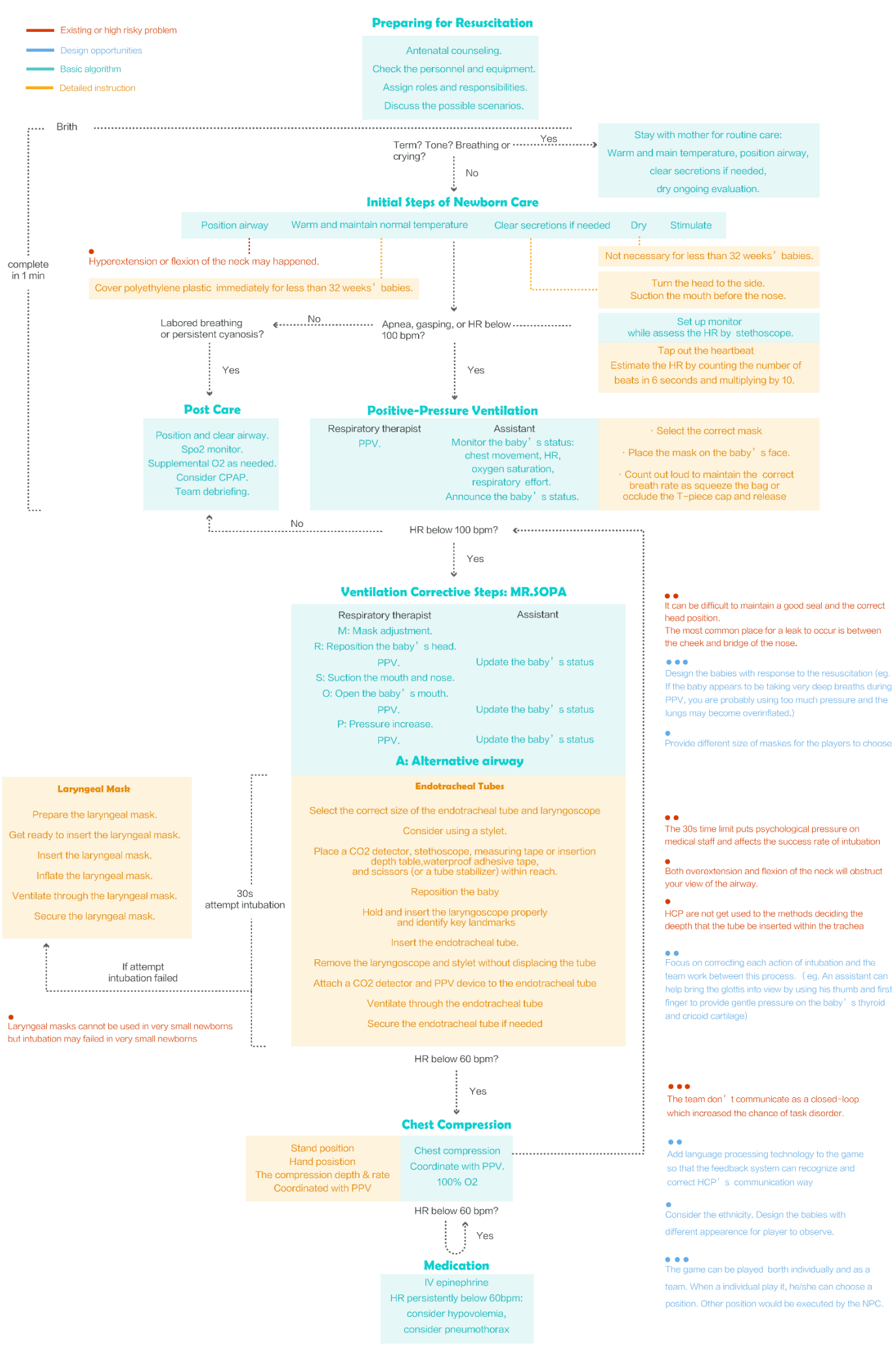

Figure 2.3.2.1 The Neonatal Resuscitation Journey Map

As discussed in the previous chapter, the sense of immersion is explicitly recognized as a core component of in-game motivation. Regardless of the technology limitation, the game is designed to offer a multi-sensory immersion for players. From a designer's perspective; apart from background narratives, the game presenting interactive information via visuals, auditory action feedback, and properties of interactive game objects. The text entry may interrupt the game flow because players are prone to spend minimal time reading texts on the screen while playing, and this is rare to have text reading in real neonatal resuscitation. Therefore, the game design has tried to avoid a large amount of wordy descriptions. Most information is delivered to players verbally. For example, when the players are doing antenatal counseling, instead of reading texts, they communicate with an antenatal nurse (an intelligent, social agent) verbally. Players may follow the basic social cues treating the NPC nurse with politeness, like talking to a real person. In this way, players would feel a higher sense of presence and be motivated to engage in gameplay.

To further reinforce the game engagement, they would receive a passive prompt, facilitating gameplay. However, the player may lack the disposition of actively looking for a solution to solving the problem. Instead of thinking intently about the treatment plan, the player may simply guess the answer or try out the different solutions in a mindless way. Moreover, merely guessing the answer lacks mindful planning, reflection, and critical thinking. In this case, if the game provides a few options for the player to choose, he/she may choose the right choice by accident but not truly master the knowledge. When reviewing their performance, they might be prone to ignore or forget to deduce how well they master the knowledge critically. Therefore, a crucial challenge in the game design is how to motivate players' intentionally and mindfully engage them to interact with the game element using resuscitation knowledge.

In order to motivate initiative thinking, the game offers more autonomy for players. To treat the baby, instead of providing a few explicit options for players to guess with a trial, for example, an interface with a few squares will be displayed to choose the answer. The player must evaluate the situation, establish and optimize the treatment strategies on their own, which motivates them to engage in the game and solve

problems independently. Help is always available for players when they have tried their best but failed to solve the problem. Players may have negative emotions, such as getting depressed when facing the challenge. It is crucial to providing help to players at an appropriate time in case they get disengaged. After finishing the resuscitation, they would receive feedback about their requests for seeking help. The following score deduction may include in the feedback because the task is delayed reflecting a negative impact on the baby. The feedback helps players realize their resuscitation weaknesses so that they can refine their learning strategies and practice with a focus.

5.4 The Setting of Game Difficulty

The setting of game difficulty follows the principles of the framework. The game offers three levels of difficulty for players to explore: beginner, intermediate, advanced (Figure 5.4.1). The players could choose the level that matches their capabilities and experience. The optimal difficulty level is challenging enough for them to acquire knowledge but not exceed their abilities, so they won't get frustrated and disengage.

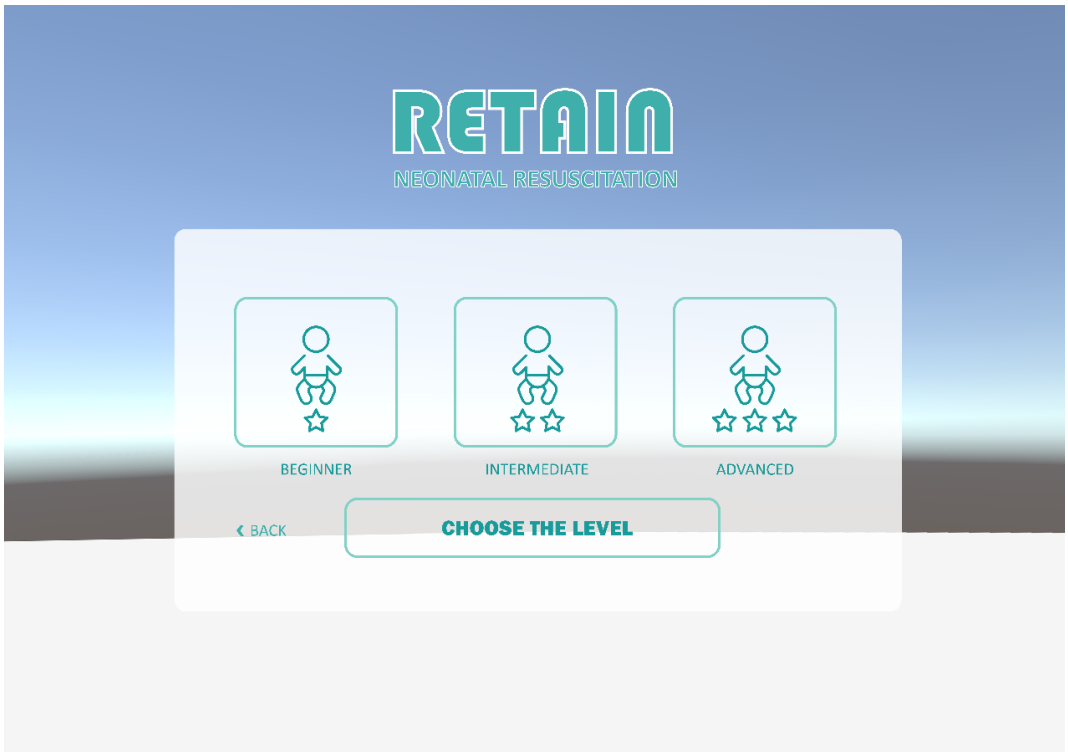

Figure 5.4.1 Choosing the game difficulty interface

To create an optimal game difficulty level, a standard method is to gradually increase the challenge by adding the variables to be managed in a scenario (Tan, 2019). In the VR RETAIN, the scenario in each level varies in the content. The scenario content is build based on the RETAIN tabletop simulator menu (Figure 5.4.2). Currently, each level includes up to 20 scenarios. The figures in some of the examples of the scenario content show, the baby's initial status and required intervention steps are different at each level. Most babies in the problematic scenarios have lower heart rate and oxygen saturation levels than the babies in the easy scenarios and require more intervention steps.

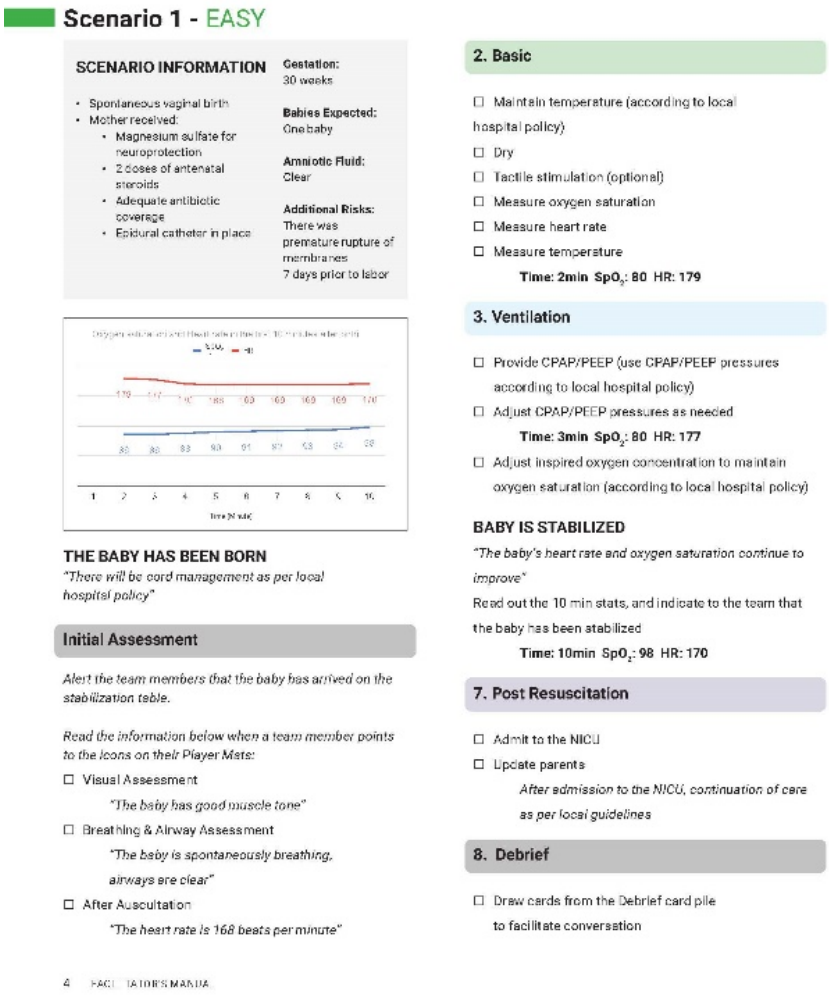

Figure 5.4.2 the RETAIN tabletop simulator menu

Source: (Centre for the Studies of Asphyxia and Resuscitation, 2020a)

In addition, the time limit on each level differs as well. Players vary in both play fluency that is comprehending the game mechanics and neonatal resuscitation experience. Players would have more time to digest the information and make decision making at the beginner level, which represents the baby's status getting worse slower without correct treatment. While there may occur a sudden deterioration of the baby's status at the advanced level, it is required that players make decisions and execute intervention promptly. The time limit setting enhances the sense of presence and trains people's ability to cope with stress.

Although players can practice and learn the game in the tutorial mode, they may still be unfamiliar with the game flow. Some of them may lack entry-level conceptual knowledge of the game rules. Arranging an abundance of tasks for a novice player might get them overwhelmed and further deter learning, even for a player experienced in neonatal resuscitation. Hence, it would be better for them to start with the beginner level, which contains fundamental intervention steps.

If the players learn fast and can handle the tasks at the beginner level, they are ready to participate in a more complicated game level. Offering the game level with progressively more challenges can motivates the player to engage with the game and gradually digest knowledge.

5.5 Choosing Scenarios Design

After choosing the level of difficulty, the players would choose the scenario they want to practice. Their previous performance in a scenario is also displayed on the interface. As mentioned before, people would receive stars as representing their performance grades from a high performance as five stars to low performance as no stars. "/" means that they have never practiced the scenario yet. The preview information of a scenario is presented to players with information such as the mother's condition, the baby's gestation, and additional risks. As players tend to spend minimal time reading texts on screen during play (Ke et al., 2018), the scenarios information is presented concisely. With an overview of a scenario, they would have a sense of whether the feature of that particular scenario what they want to focus on today.

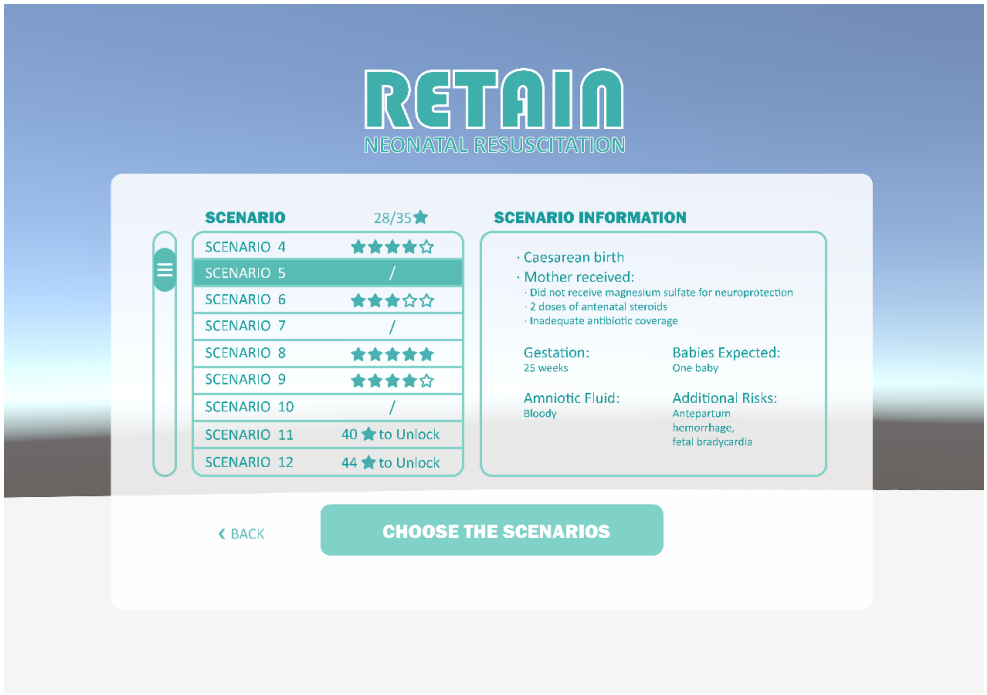

Figure 5.5.1 The interface of choosing the scenario

People would be provided with ten scenarios to choose from initially. The subsequent scenarios will be locked. The reason for locking the subsequent scenarios is that players may prioritize exploring different scenarios over each scenario's qualities. Moreover, facing challenging scenarios, they might be prone to bypass them but not overcome them. Hence, to cultivate a positive disposition for learning, the game will restrict the available scenarios for players. There are still some scenarios available. However, to unlock more scenarios, players must reach an average of 4 stars in previous scenarios. In this way, players could be motivated to reflect on their performance, investigate their weaknesses, and replay the scenarios to reach a higher grade.

5.6 Design of the Current Equipment and Room Layout

The game environment displays the NICU room scene with the equipment and supplies that fulfill resuscitation needs. The NICU room is presented via diverse objects and associated resuscitation themes such as radiant warmer and equipment shelves, and other everyday items in a room such as an office desk and garbage can. The NICU room's design is focused on the essential resuscitation equipment refinement and the

layout that reproduce the space fidelity. The critical content of a series of environmental settings was first modeled via Autodesk 3D Studio Max and then developed in Unity 3D. The development in Unity 3D coordinates with the game programmer, who completed the coding work.

When modeling the equipment, the models are developed initially with a relatively high-fidelity appeal to the entire NICU room. However, when testing the prototype, it was found that the high-fidelity prototype loaded very slowly on the VR headset and would cause dizziness in some visions. To adapt to the existing configuration, the fidelity level of the environmental setting is scaled down. As stated in section 4.1.2 Fidelity, as long as it keeps the most necessary and appropriate fidelity in detail for a simulation game, a lower fidelity configuration would not reduce the players' engagement level. The necessary details refer to providing practical physical, functional, and environmental characteristics of real-life features such as noise (e.g., warmer alarms), time pressure, and exposure to stressful situations.

As the pictures presenting, the game environment is built based on the NICU layout in Royal Alexander Hospital. To reduce the screen clutter, the game simplified the objects in the NICU room. The environment's layout is simple with the essential equipment that the players would interact with and along with the everyday contents such as sink and window to keep the necessary fidelity. At the beginning of the game, the players would consult the nurse (NPC) from the delivery room and perform a pre-brief. After discussing potential risk and the task assignment, they would come to the storge rack and radiant warmer checking and setting up the equipment and supplies. As the equipment is set, they are then ready to receive the baby. Subsequently, they could use the equipment on the warmer or supply cart to complete the resuscitation task. During the game process, the players interact with the warmer and the storage rack the most. Hence, the environmental setting's design refinement is focused on the optimization of warmer and the reorganization of the storage rack.

Figure 5.6.1 The layout of current NICU room in the Royal Alexander Hospital

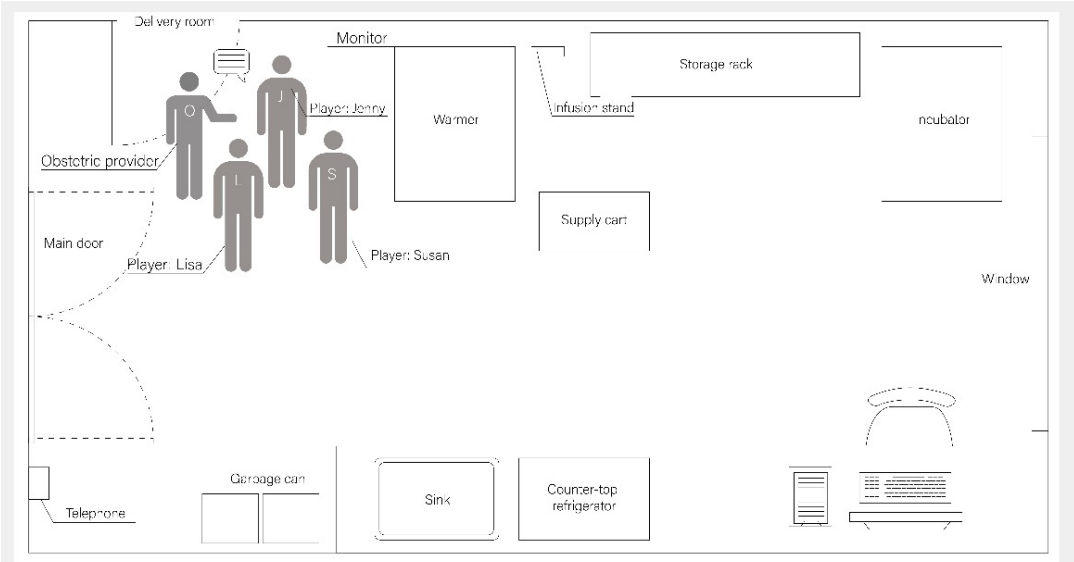

Figure 5.6.2 The game design layout of NICU room

Figure 5.6.3 The game rendering of the NICU room

As mentioned in section 3.4, Physical factors analysis, the current NICU equipment storage organization is confusing and not well classified that with small labels stuck on the baskets (Figure 5.6.4). It may take a long time for HCPs to check the unorganized equipment storage, increasing the risk of equipment checking errors in the time-intensive situation. Studies have proved that well-organized resuscitation equipment could speed up equipment acquisition and further improves the performance of HCPs in simulated resuscitation (Chan et al., 2015).In addition, there are some comprehensive arrays of instruments rarely used in neonatal resuscitation or used for post-resuscitation care, which is not included in the game practice.

Figure 5.6.4 The equipment storage at NICU room in the Royal Alexander Hospital

Based on the discussing above, the equipment categories are simplified in the VR RETAIN, eliminating some equipment not required in the game process. The equipment storage is reorganized for quick acquisition as well. The equipment storage is divided into several units based on the functionality and usage stages in neonatal resuscitation and placed in the basket from top to bottom on the storage rack (Figure 5.6.5). The functional units include warm, suction, ventilation, intubation, medication, and other miscellaneous instruments. Large labels are placed on each basket for a clear presentation in the VR game.

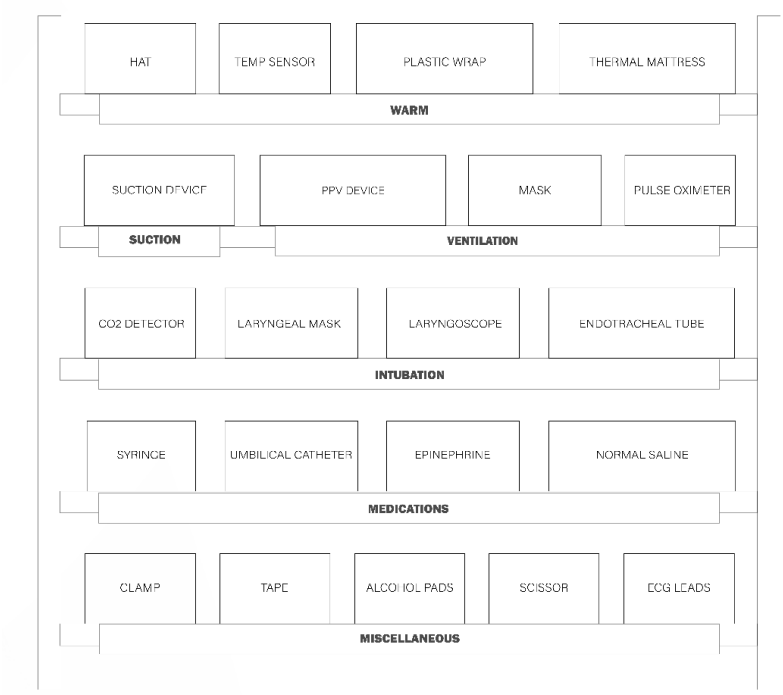

Figure 5.6.5 The equipment storage design wireframe

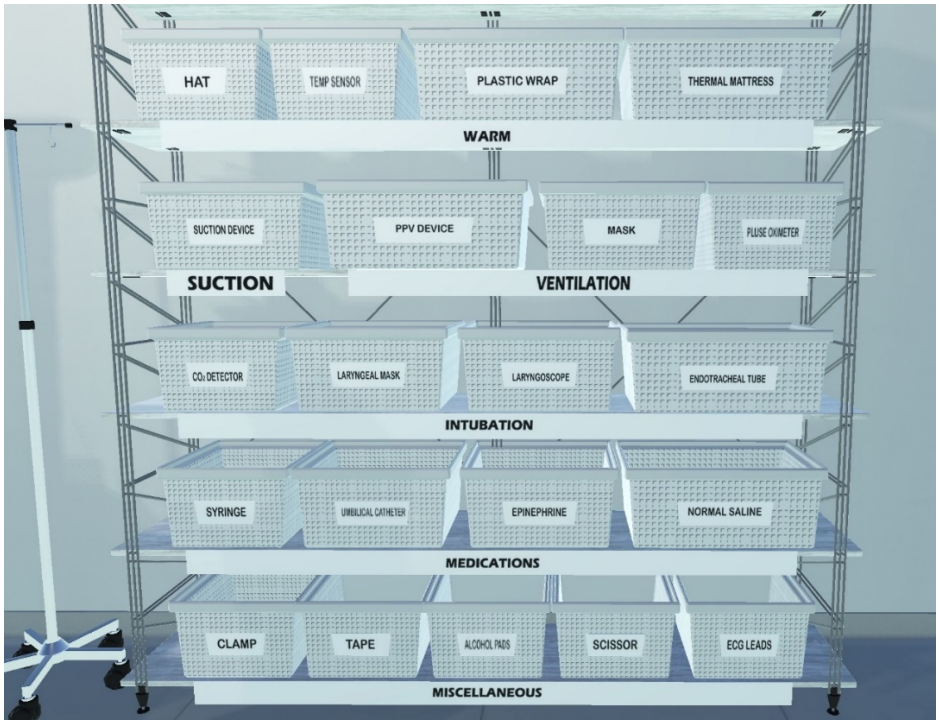

Figure 5.6.6 The game rendering of equipment storage at NICU room

The refinement design of the radiant warmer is to simplify the warmer's original operation panel in NICU and adapting it to the VR display. The operation panel is classified into three functional partitions.

The first partition consists of a screen and a few soft keys on the side, including the power button, Apgar timer, heater, and temperature setting. To active the warmer, players need to hit the power button. Then they must preheat the warmer by turning up the heater to one hundred percent as soon as possible before the baby arrives. They may also set a targeted temperature for the baby in advance. Once the baby is born, they need to press the Apgar timer immediately to record the time. After the baby arrives at the warmer, a temp sensor would be placed on the baby. Once the baby's temperature reaches the targeted temperature and shows on the screen, the warmer would keep beeping and blinking until the players acknowledge it and adjust the heater down.

The second partition is the suction panel. The suction panel is composed of a vacuum switch, suction regulator, and a vacuum display. A suction canister under the warmer response to the operation of the suction regulator (Figure 5.6.7). When a player suctions a baby, he/she must turn on the suction switch first and adjust the suction regulator to the desired parameter. He/she could then pick up the suction catheter connected to the suction canister to suction the baby's noses or mouth.

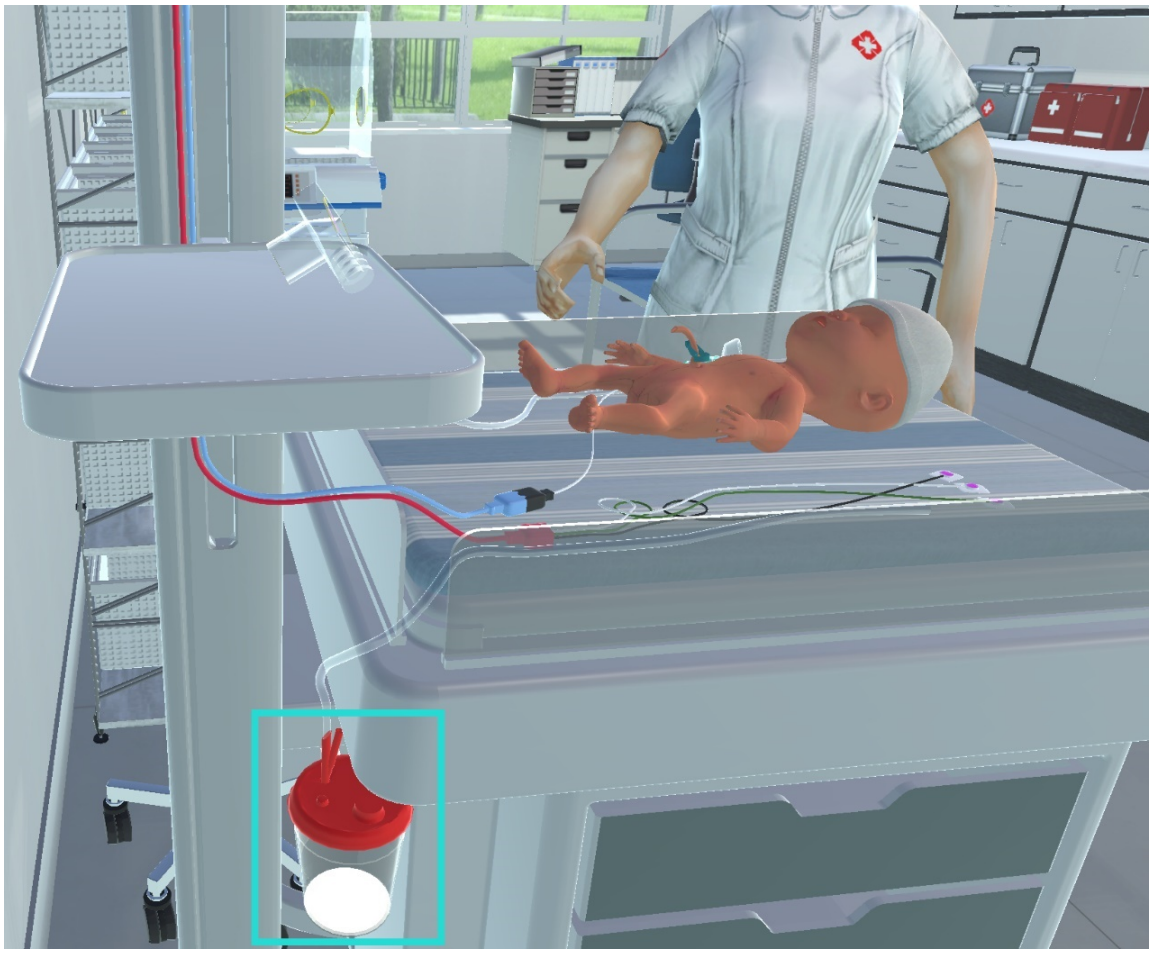

Figure 5.6.7 The rendering of the suction device

The last operation panel refers to the gases. It includes the gase switch, a gas display, a PIP regulator, a flow meter connected to an oxygen blender, and a hole to connect the T-piece or inflation bag. The PIP regulator allows people to control the pressure of the PPV device manually.

The following image presents an example of the warmer panel preparing for a preterm baby.

Figure 5.6.8 The radiant warmer at NICU room in the Royal Alexander Hospital

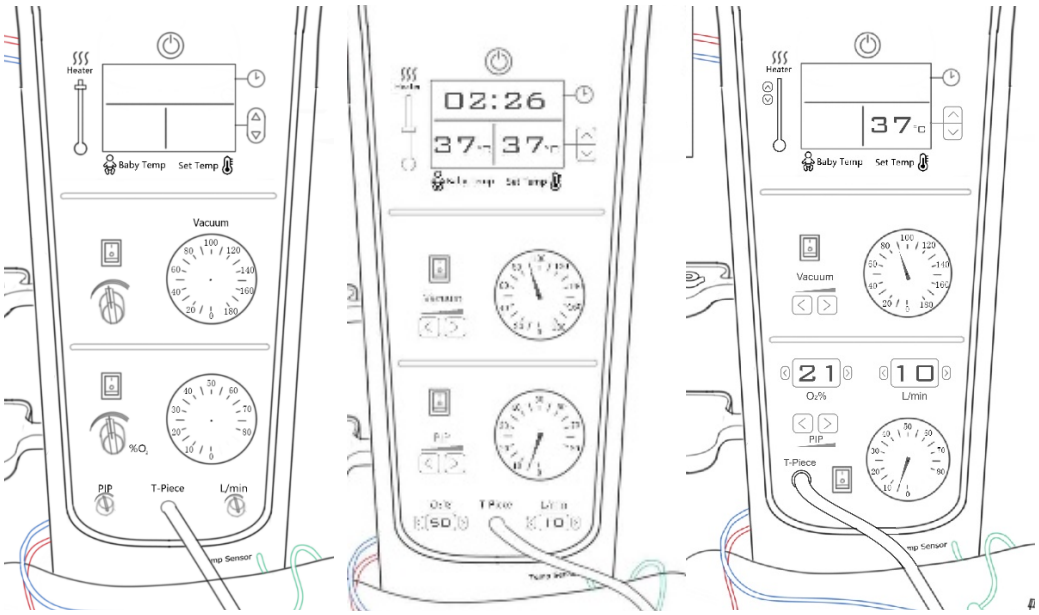

Figure 5.6.9 The iterative design of the radiant warmer

As the picture shows, after simplifying the panel's functionality, the warmer's iterative design represents changing the interaction between players and panels for VR game playing. The equipment regulators on the initial warmer panel were designed as knobs with pointers for players to twist. Figures surrounded the Knobs to display the values of the adjustment when the values were reached. The game action (or the player input/output controls) should foster functional interactivity between the players and the game system (Ke et al., 2018). The game interface should promote intuitive game behavior. However, the interaction in the initial game version may not be suitable for VR gaming. As the character that the VR controllers come with joysticks, it would be easier for players to adjust the regulators by swiping the joystick right and left or up and down with thumbs than twisting the knobs with arms. In addition, displaying the critical value of digital meters is required in the VR game. The digital meters in the previous version is too small for a player to read clearly. Based on the discussion above, in the latest panel version, the regulators' interaction has been changed to the form of soft keys. People could change the value of digital meters by swiping the joystick on the VR controller. The character display is also enlarged in the screen area.

Figure 5.6.10 The rendering of radiant warmer

5.7 Integrative Design of Task and Feedback

Learning occurs when players are actively engaged in the cognitive process of decision making and then get feedback from the game regarding their performance. In the VR RETAIN, the feedback system is integrated into the experiential game to help people evaluate their game behavior and help them modify their learning plan.

5.7.1 Feedback during the Gameplay

Regarding the complexity and the length of the resuscitation task, partitioning the tasks into sub-goals has been considered. Getting feedback in each phrase gives players confidence in engaging with the game. The game process is partitioned into two phrases: 1. preparing for resuscitation before the baby's arrival (such as counseling, equipment checking, assigning roles), and 2. resuscitating the baby. The reason for splitting the game into the two phrases is that: neonatal resuscitation is a time-intensive task that requires mental and operational coherence. Partitioning the resuscitation section may interrupt people's logical thinking and further influence their overall performance. For the preparation section, as HCPs usually get time for pre-brief, showing feedback helps them reflect on their behavior. Besides, it saves players time to correct their mistakes in the early stage. If they remain in the faulty equipment setting into the resuscitation section, the baby might not be helped even though their following treatment is correct. Therefore, the game setting is there only when all the personal and equipment are in an appropriate position can the player move on to the next stage.

The resuscitation section is tricky and includes multistep that may stop the player from progressing. It is crucial to keep players informed about what is going on through appropriate feedback within a reasonable time. This comes from the nature of neonatal resuscitation. Players could get feedback from their teammates and the baby (such as changes in the heart rate and chest movements). However, as mentioned in Chapter Two, it may come across that the player receives information that there is no improvement on the baby after several attempts. Then, under that situation he/she has no clue on what the next treatment step should be, the player may feel a negative emotion and get disengaged.

In case where disengagement occurs, the game provides two types of feedback as support to motivate players to continue gameplay. First, they would receive passive feedback that the next correct intervention step's equipment is highlighted. Second, like in the real-life resuscitation, the players could call for help by using the telephone. They would receive a voice prompt that indicates the next correct step.

Notably, the instant feedback may potentially become a learning barrier that reduces the chance of trial and failure-driven learning (Tan, 2019). A player may depend on the instant feedback but not gain knowledge from the experience of the game task. To avoid people overusing the game support, the VR RETAIN provides support to players at a reasonable time, such as when the player has no game operation for a while after a few wrong attempts. Besides, to encourage independent thinking, the telephone placement is not within reach, but still in an accessible distance behind the main entrance (Figure 5.7.1.1.). The players could walk for a few steps to reach it and call for help. Furthermore, overusing the game support may result in a loss of points as prompts appearing after a time limit delaying the treatment. All the design strategies above aim to encourage players to persist towards eliminating from bottlenecks and independently solving the problems.

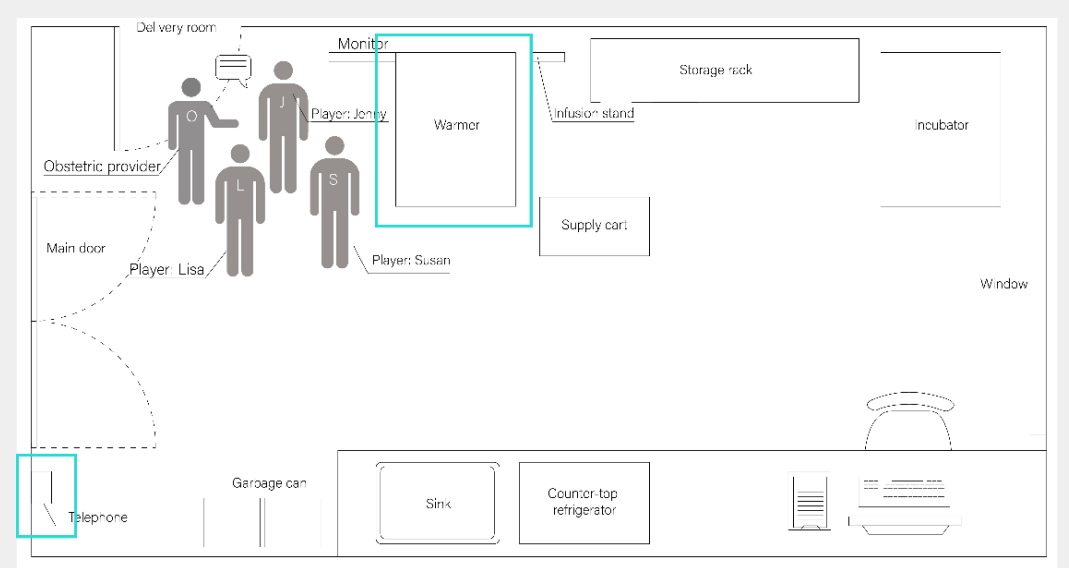

Figure 5.7.1.1 The distance between telephone and warmer

5.7.2 Feedback after the Gameplay

Apart from giving feedback during the gameplay, a summary of players' game performance is also presented after the resuscitation finishes. A stealth assessment system runs during the gameplay that captures and analyzes players' game behaviors such as resuscitation action and team communication while not being intrusive to interrupt people's game flow. The assessment system follows the NRP Flow Diagram. It evaluates players' performance based on all the neonatal resuscitation aspects stated in Chapter 3 including the technical skill, communication and teamwork, and cognitive performance. The data would be kept in the player's profile and be accumulated and for future learning strategies refinement.

As the Figure 5.7.2.1 showing, after the baby is secured, the players would receive total points for their overall performance. The performance is categorized into six grades on a scale of zero to five stars. The player scored 88 out of 100 and got four stars. As the visualized progress bar shows, the grades are not equally divided into six parts. Since the higher scores are harder to achieve, the gaps between adjacent grades in higher points are narrower than those in low points.

Figure 5.7.2.1 Gain points Interface

To activate a players' reflection on their game behavior, the assessment system presents a feedback interface (Figure 5.7.2.2) summary of their performance after the game finished. The feedback records people's game action based on the timeline on the left side of the interface. The right side of the interface is a video player. Players could review their game behavior by playing back the game video.

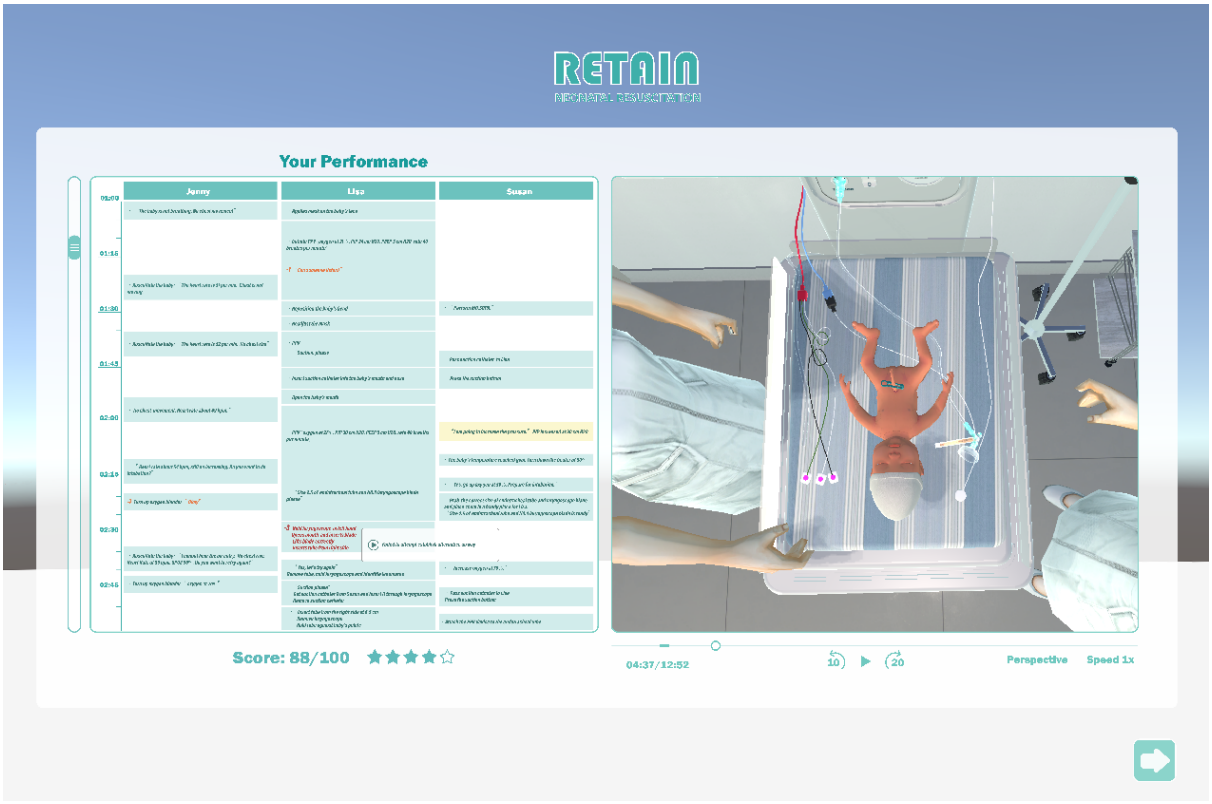

Figure 5.7.2.2 Performance Review Interface

The feedback is focused on the sequence in which resuscitation steps are executed and the equipment required to use each step with the operation's correct technical aspects. As illustrated in the Figure 5.7.2.2, game action is recorded as a green block with a description and directly responds to the individual with name on top. The feedback description means the text with dark green color means the players acted in a correct sequence. Text with orange color means that there is some room for improvement. Maybe the action happened too late. Maybe the player forgot to do this action. The text with red color means that the player missed a critical step or did it incorrectly. Score deduction shows on each block as well. People make a small error deducting one point and a critical error deducting three points. When moving the pointer (the VR controller) on the corresponding block, the information and the case's suggestion would read out. By hitting the suggestion block, the game video would jump to the moment of the game action occurrence, which helps the player review their performance efficiently.

The feedback functionality is designed to increase cognitive interactivity. As previously described, a player might be reluctant to think of mindfulness and engage the game cognitively. Alternatively, they are unable to ruminate their behavior because of the time limit or negative emotion. There is a possible chance that the player gets the right answer or decision with frequently guessing and random clicking but does not truly understand it and forgets to review it, in this instance, the game provides the player with additional in-game learning support that is the "Rapid record the moment" function. During the game playing, when people are not sure about their decision but do not have time to think mindfully, they could record this uncertain moment by quickly double hit the trigger button on the VR controller. Subsequently, after they finished the game, they would see the recorded moment on the feedback interface, presenting with a yellow block and description. This function serves as an intermediary that promote players' reflective learning after experiencing the game.

The following table is an example of the game action feedback recording full list.

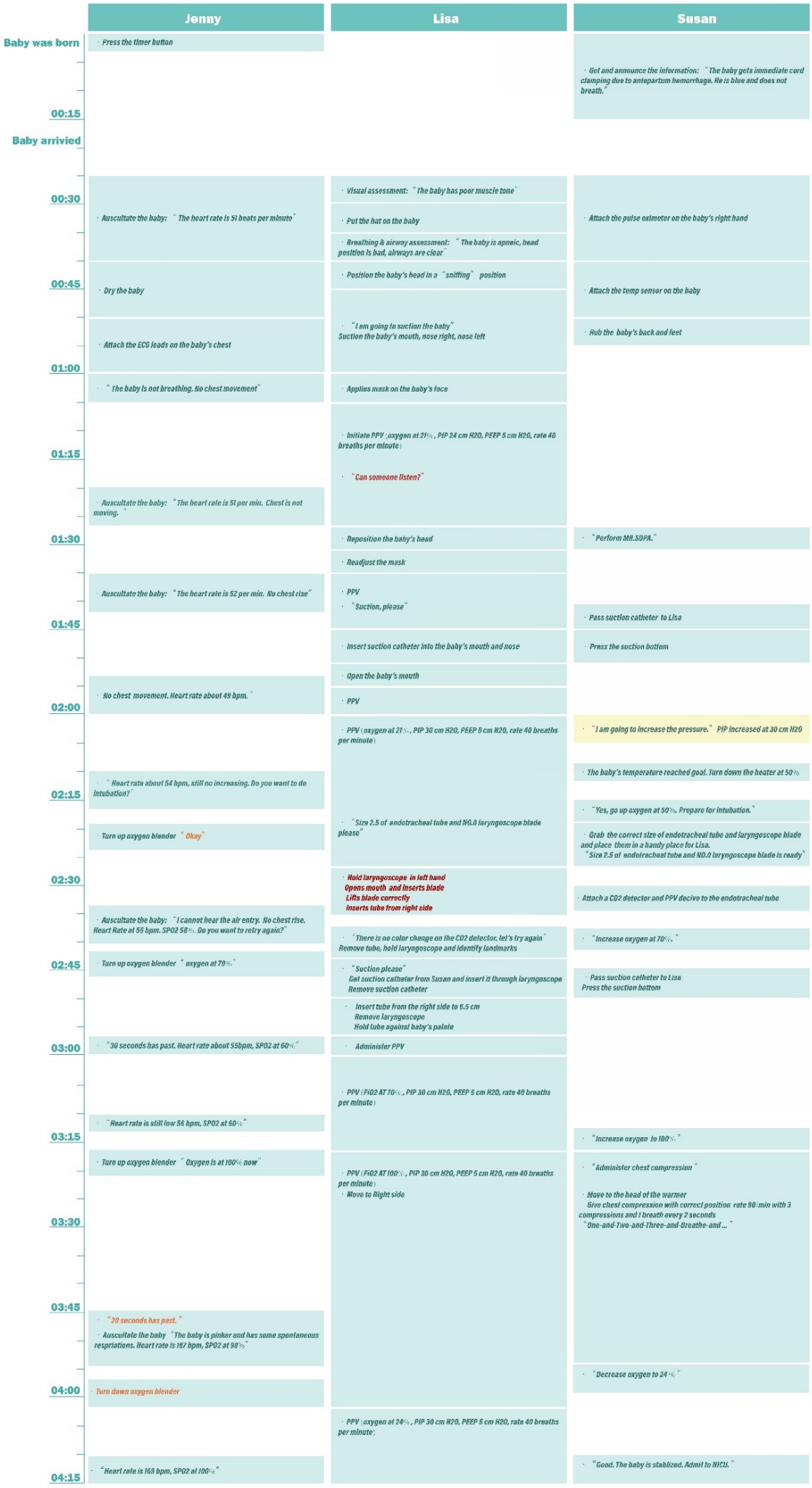

Figure 5.7.2.3 An example of the game action feedback recording full list

When reviewing feedback regarding the specific scenarios is completed, the players would come to a summary interface with the overview performance display based on all the scenarios they have experienced (Figure 5.7.2.4). They would see a line chart with the scores of their game performance on each date. Below the line chart is the bar graph that concludes the player's strengths and weaknesses by counting the statistical data of the small and critical error rates in every resuscitation stage. Players are also able to review the scenarios they have participated in previously quickly. By clicking the listed scenario, they would see a brief description of their errors in that scenario. More detailed information is available by clicking the play button, bringing the player back to the previous feedback interface.

Since not all players are alike, to improving learning, people should identify their problems first. This display helps people to recognize their current knowledge of the problem and their shortcomings in resuscitation. By knowing one's learning status and understanding the knowledge level, the players could precisely formulate their learning plan and optimize the learning outcome future.

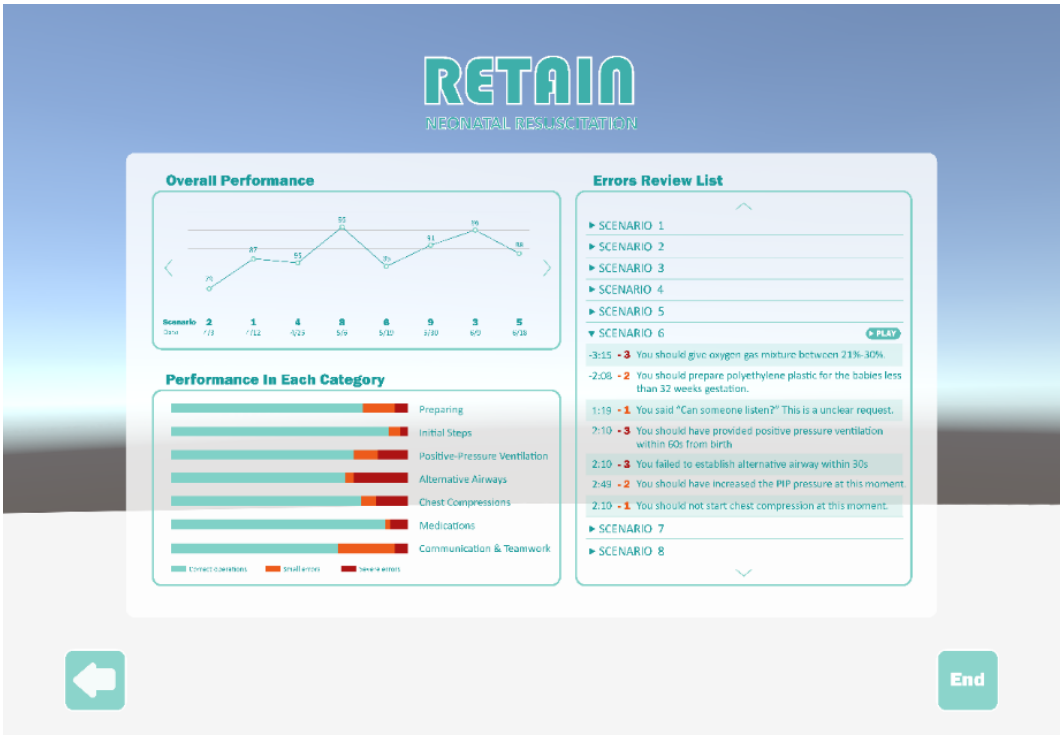

Figure 5.7.2.4 The interface of the overall performance review

5.8 The Overview of the Game Flow

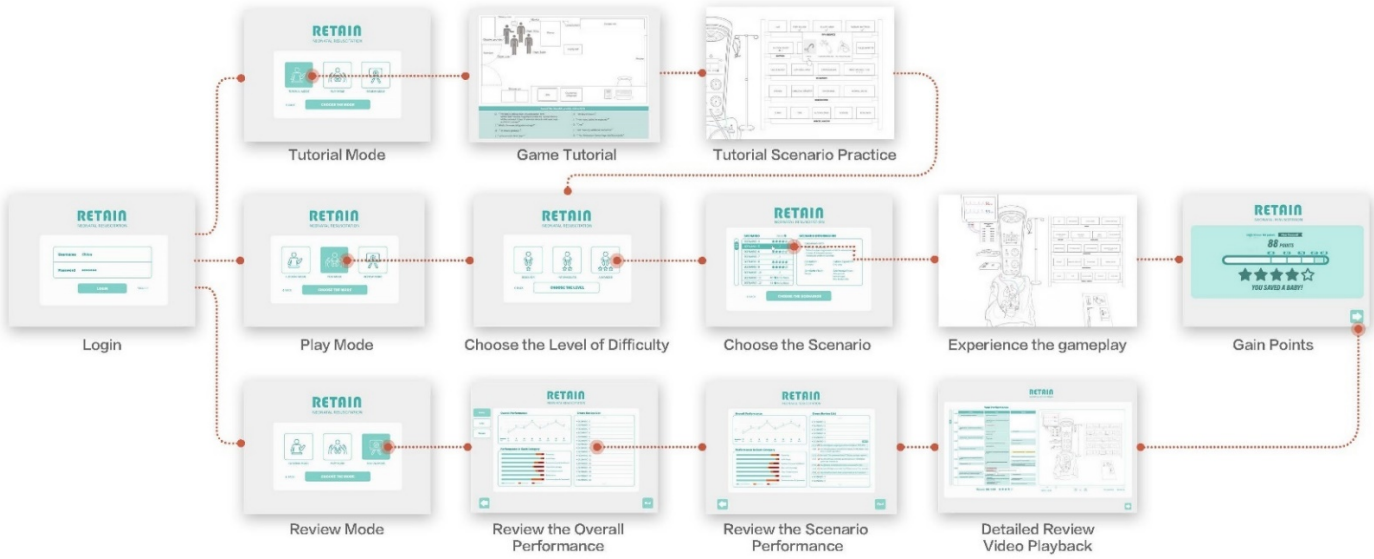

Figure 5.8.1 The overview of game flow

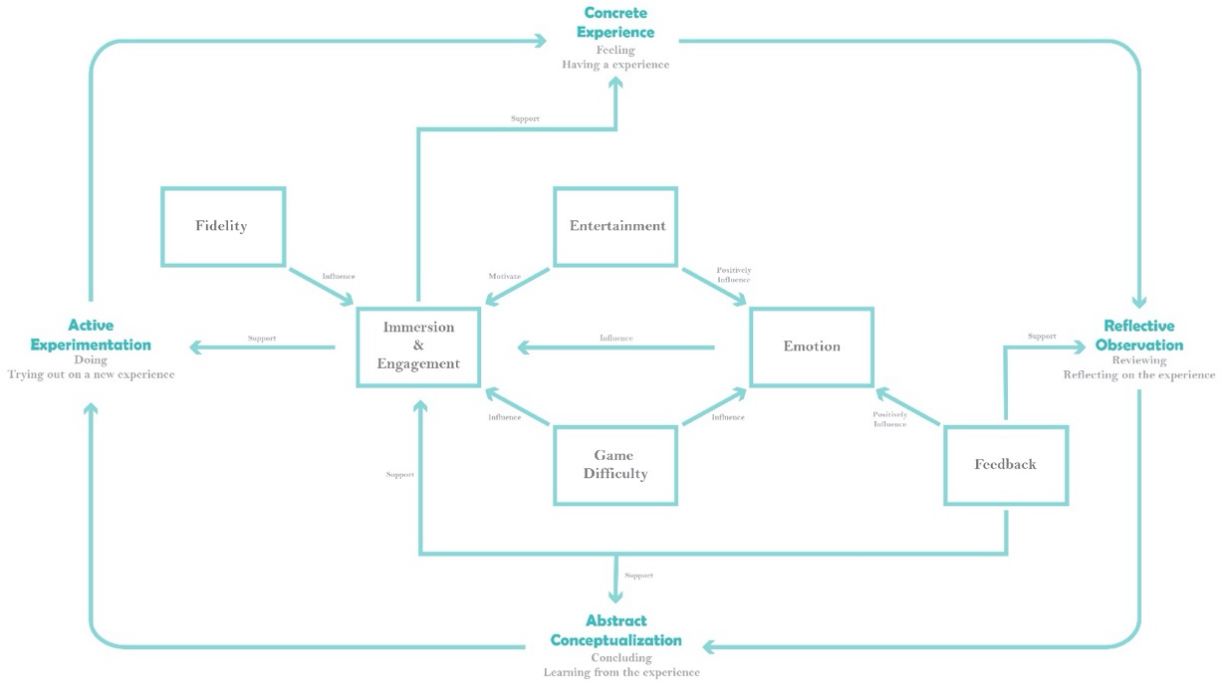

Figure 4.2.1 Serious Game Design Framework

Overall, the VR RETAIN game design offers people a game-based learning experience responding to the experiential learning process. Simultaneously, the core facets of the serious game design framework were also integrated into the gameplay. Entering the game, the players would first be provided with three modes: tutorial mode, play mode, and review mode. A novice player, he/she chooses the tutorial mode first to familiar with the game rules. For an experienced player, he/she may either choose scenario and play the game first and then review their performance in the review mode; or they could review their previous performance first and make a learning strategy accordingly, then apply their strategy in a new game experience. As an experiential learning process is a learning cycle, there is no start point nor an endpoint. People could start their learning at any experiential learning phase within the game.

Chapter 6 Conclusion and Implications for Future Work

6.1 Limitations and Future Directions

There are serval limitations in this study. The design issues and study limitations are presented below, which could be addressed to improve the design concept in the future.

With the field still in its infancy, there has been a paucity of available serious game design studies for medical simulation. Moreover, while some existing theoretical frameworks are relevant to integrating learning and playing, few of them are discussed explicitly from a designers' perspective. It is thus challenging to implement these studies to separately evaluate the serious game framework in this thesis. Besides, although the proposed framework has been applied to the VR RETAIN serious game design process, the framework aims to provide not only structural guidance for this specific game design but also other serious game design processes. The overall design of the framework still remains to be validated. Further research should be conducted using other game design process to identify the effect of the framework.

The neonatal resuscitation research was done via literature review, informal interview conversations with HCPs, and watching resuscitation eye-tracking playback videos. However, most of the video recordings were HCPs resuscitating relatively healthy babies. A very limited number of videos involves intubation steps, and none of the videos includes chest compression and giving medication such as epinephrine. As there is a very low occurrence rate of the before mentioned steps in neonatal resuscitation, the user's cognitive and behavioral analysis resource is merely from the literature review. Therefore, the findings in this thesis may not be applicable enough to resuscitate a more ailing baby. In addition, HCPs' performance may be impacted by putting on eye-tracking glasses. The generalizing and veracity of the findings in this study could be limited by the issues discussed above. To identify the HCPs' cognition and behaviors, more user research should be done towards innervation steps for a more ailing baby in the future.

Prototype testing is an essential step in evaluating if the design solution identified user needs and is applicable to solving problems. In this project, the prototype testing of the proposed design outcomes was not conducted due to budget and technology limitations. This prototype is the first iteration of the game. It is not ready to play yet. Although I collaborated with a computer programmer working on game programming, some of the game functions, such as interweaving Artificial Intelligence with natural language processing, require a high level of software developing skill and more budget to achieve it. Developing a well-defined game prototype requires an interdisciplinary team, including designers, HCPs and medical experts, 3D artists, and game programmers working together. In the future, the research needs to investigate the effectiveness of the VR RETAIN when implemented on a VR headset. The study could then test the design of the VR RETAIN and delve deeper into how the game influences the learning outcomes of HCPs for future iterative design.

6.2 Conclusion

This study presented a comprehensive overview and detailed analysis of neonatal resuscitation, and proposed a framework integrating the core elements of serious game design and experiential learning. With the gamification design based on the proposed framework, the VR RETAIN game was designed and developed to offer the HCPs an accessible and immersive learning platform for neonatal resuscitation training. With the learning platform, HCPs could improve their neonatal resuscitation knowledge and skill by continually going through the learning cycle of experiencing, reflection, concluding and experimentation.

This thesis has explored the serious game's potential as a tool to supplement traditional learning methods for neonatal resuscitation training. It is essential to highlight that a serious game can motivate a user’s learning interests and enhance their learning outcomes.

One of the design considerations is to allow people to play together remotely via VR games. It is essential to give people the flexibility to quickly do medical practice and

gain knowledge. Since the outbreak of Coronavirus disease 2019 (COVID-19), there is even more attention and need to be focused on designing educational tools for people to learn knowledge at different places. Hence the game is designed to be played both individually and with multiplayer modes. At the same time, others are allowed to enter a game session as a spectator to watch or coach the players' performance.

Despite some limitations, this study fills a void in the area of serious game design and research for healthcare simulation. I hope that the framework and the serious game provided in this study will be adopted by simulation proponents that are not limited to neonatal resuscitation in Canada and elsewhere to design effective training curricula and standardize the design process. To improve the quality, reliability, and usability of serious games, a shared understanding and mental mode between professionals from different fields need to be developed. It is further my hope that the findings and the design outcomes in this thesis can serve as a catalyst for the simulation community, which includes designers, medical experts, HCPs, educators, and experts in other fields to engage in a discussion and work as an interdisciplinary team towards the serious game development in the fields of medical education.

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Chapter 8 Appendix

8.1 Interview Transcripts

The questionnaire and interview scripts were supplied by Dr. Georg Schmölzer and Emily Zehnder under their ethics application.

Interview Guide for Analysis of Visual Attention, Team Communication and Cognition during Neonatal Resuscitation using Eye-Tracking.

The following questions were developed after a pilot study using investigators as study participants. Based on this pilot study we approximate that the interview will take 45 minutes to an hour. We will stop the interview at one hour. Variations of these questions will be asked as the participant is watching the eye-tracked video of a resuscitation they performed, and the video is paused at pre-set time points (below in bold). Not all questions below will be asked of all participants as certain questions will be irrelevant to some participants. For example, if the infant was stable after just drying and warming no questions about intubation will be asked. The questions asked will also depend on the participant's response to earlier questions. If a participant discusses aspects of a later question earlier in the interview that question will be skipped.

General Characteristics

1. What is your professional designation?
2. What was your role during this resuscitation?

How many years of experience do you have resuscitation newborn infants?

3. How long have you been practicing in the NICU?
4. Can you estimate the frequency at which you participate in neonatal resuscitations?

Probing Questions for Clinical Variability and Expertise Elicitation

Pause video when the baby is just born

1. Do you have a checklist that you go through in your head prior to a resuscitation?

a. Can you share this with me?
b. Are there any items on this mental list that a novice would not have considered?

2. Did you directly or indirectly communicate with the obstetric team upon arriving or before arriving at this birth?

a. What information did you request from them?
b. In retrospect was there any other information you should have asked for?

3. Did you or another team member initiate a briefing prior to the arrival of the baby?

a. What was discussed?
b. In retrospect is there anything which could have been discussed which was not that may have improved the resuscitation?

4. What are some things you consider when attending the birth of a baby which might not be considered by all individuals in your role?

5. Were you in charge of assigning roles to your team members in the resuscitation?

a. How did you go about this?

6. At this point, did you predict any difficulties with this resuscitation?

a. What made you think this?
b. Did this prediction in any way change the way you went about or prepared for the resuscitation?
c. Would a more novice health care professional have made this same prediction? Why might this have been difficult for a novice?

Pause after baby arrives and is being dried and warmed

7. List in order of importance the patient characteristics you are considering at this point when deciding what to do next?

a. Do you have a methodological or procedural way of gathering this information (e.g. do you try to get the most important info first) or do you just gather it in whatever way occurs naturally?
b. Did you have any difficulty gathering this information? If so what did you do about this?

8. At this point, did you predict any difficulties with this resuscitation?

a. What made you think this?
b. Did this prediction in any way change the way you went about the resuscitation?
c. Did you share these predictions/ difficulties with the team?

Pause is respiratory support is started

9. Did you make the decision to put the baby on respiratory support? What lead you do this decision?
10. How did you ensure that all team members are on the same page as to the next steps? Or do you assume that everyone knows what is going on?

Pause if mask ventilation is started

11. Did you decide to start mask ventilation? What lead you to this decision?
12. How did you ensure that all team members are on the same page as to the next steps? Or do you assume that everyone knows what is going on?
13. How did you ensure mask ventilation was effective?

a. Which if any corrective steps did you take?

Pause If the baby was intubated

14. Did you make the decision to intubate this baby? How did you decide to intubate?
15. How did you communicate this to your team?
16. Were you in charge of determining who performed the intubation?

a. If so how did you make this decision?

17. Was all the appropriate equipment prepared beforehand?
18. At this point, how did you think the intubation would go?

b. What made you think this?
c. How did this prediction change the way you went about the intubation? (Improvising)
d. Would a more novice health care professional have made this same prediction?

Pause If chest compressions were administered

19. Did you make the decision to start chest compressions? How did you decide this?
20. How did you communicate this to your team?
21. Were you in charge of determining who performed the chest compressions?

e. If so how did you make this decision?

Pause following resuscitation

22. How do you think the resuscitation went overall, regardless of the outcome? (Self-monitoring)

23. Did you take any steps during this resuscitation to ensure that all members of the team were feeling comfortable in their role and minimize stress?

24. How did you address disagreement between team members?

25. How would you describe yourself as a leader during this resuscitation?

a. Were you generally happy with your performance and your team's performance? (Including how you dealt with expected and unexpected difficulties?)

26. Did you make an effort to distribute workload among team members? How did you do this?

27. How do you deal with distractions during a resuscitation? (e.g. phone calls, unrelated chatter)

a. Do you try to zone it out, prevent it (e.g. turn phone off before hand), or actively stop it (e.g. ask team members to please stop their discussion)

28. Are there any environmental or team factors (which you have not yet discussed) that added stress or difficulty to the resuscitation? Could these have been altered to improve the resuscitation? (e.g. Layout of equipment, additional tools available, team composition, etc.)

29. Are there any personal factors (which you have not yet discussed) that added stress or difficulty to the resuscitation? Could these have been altered to improve the resuscitation experience?

30. Did you take any conscious or unconscious steps to foster an environment of mutual support amount team members during this resuscitation?

a. What did you do?
b. Do you think this was effective?
c. How did you asses the effectiveness of these steps?

Pause if family member was present

31. How did you decide that it was appropriate for the family member to be present during this intubation?
32. Do you think the presence of this family member added to the stress experienced by you and or your team? Did this stress alter performance?

Pause if there are any deviation from NRP guideline?

33. Did you intentionally deviate from the NRP guideline?

a. How did you decide to do this?
b. How did you share this decision with your team?
c. In retrospect do you think that this deviation was justified/ best for the patient?

July 2nd

Interview date July 2nd

Resuscitation July 2nd

Professional designation Registered nurse

Role in resuscitation - team lead and transport nurse, managing Airway

Years experience resuscitating infants 7 years

Years experience in NICU 7 years

Frequency participating in resuscitations - more frequently over the last 2 years (2012 to 2015 did not do a lot of initial newborn resuscitation) now a minimum of 5 resuscitations is a month.

P- okay so we were just getting ready, Trish is my assistor or she is supposed to be so the twin delivery we went to we thought that we were going to get the smaller twin like we were anticipating to get twin A who was smaller in utero but they came out reversed so we ended up getting the bigger twin which was fine but Trish was just checking the bed to make sure that everything was turned on. The only thing that I am going to be critical about is that we are not supposed to plug in the sat probes to the monitor cable because then they don't calibrate so if they are plugged in they calibrate to the oxygen content in the air so I know that George is a really big stickler for this you are supposed to put the sat probe on the patient and then plug it in so I think that she did recalibrate it once the sat probe was on the baby but that was just something picky that I had noticed that day where I was like oh I would not have liked that in I would have just left it..

I- and did you mention anything to her?

`p- I did not no

I- okay and why not?

P- because Trish has been doing this for a very long time

I- okay so was it in awkward thing then?

P- not awkward it was just like not that big of a deal if it had become an issue then I would have said something.

I- and you had said that you were planning on getting the smaller of the two twins how did you decide who would be getting which twin?

P- because on the other resuscitation team there is only one transport nurse on so the

transport nurse is typically try to take the sticker baby and the other intubator was just an intubating RT so they have glass delivery room experience than we do.
I- perfect okay
I- so as you are getting prepared for resuscitation is it you or someone else who is in charge of ensuring all the equipment is there?
P- it is a team effort the nurses typically check the bed but we both do it and most of our equipment is in the room so anything specific that we may need we assess based on what the risk factors are, so for 30 week twins we had the intubation equipment available if we needed that typically we try these babies on CPAP and then we have everything for line insertion but it is a waste of equipment to open it when you do not necessarily know if they will need it all the time so in terms of this equipment yes everything was ready unchecked and it does get checked by all team members for sure.
I- and do you have any specific strategies that you use to make sure that nothing is forgotten in the prep?
P- no not really...
P-So this is the problem I changed our masks size because I thought that we were getting the smaller twin but we ended up getting the bigger twin so I think that my masks size was a little small because they were opposite so this is something that I'm realizing now.
P- so again we have everything on the shelves by the rescued like different sizes of masks that are close by so we can always reach them if we need to.
I- okay and were you in charge of assigning team roles?
P- yes.
I-and can you explain to me a little bit about how you go about this
P- so again it depends on the risk factors if the twins are equally does not really make a difference but if someone has a preference or if there is learning needs that need to be met then we will try to identify those things.
I- and have you had a chat about that beforehand?
P- yes we did
P- I noticed that we were doing a few different studies like COSGOD which has another little piece that needs to go into the neo-puff and my one suggestion is I think

we should tape or secure that tubing to the side of the bed because all of the tension is on your hand and I feel as though it is pulling a lot.

I- here you are?

P- so before we were totally ready to go we had to decide like someone has to go catch the baby because it's a C-section so Trish and Katie we're going to catch the babies and we needed someone to hold the door to make sure that we could shout out times.

I- And where you expect any difficulties with this resuscitation?

P- I'm a little bit not like an obscene amount they did not give the mom her two doses of betamethasone[00:07:42] like her steroids before and they were 30 weeks so I thought they would definitely need CPAP that was not surprising to me. And I think that we were sectioning those other two twins right after so we would usually have more time to stabilize and put in lines in that room but the logistics of planning out our day were difficult so we had to take the babies right up to the unit and do line insertion up there so I think I was just processing our timeline and seeing how long everything was going to take to make sure we were ready for the next delivery,

I- and were you doing the next delivery as well?

P- yes and that changed it because we had to move the babies up faster usually we would get lines in and all that stuff and then usually our NPs would come down and we would do admission stuff down there but today was really busy and we did not have enough people so that was a challenge.

I- and do you think that made it any more difficult for you?

P- I do not think so because sometimes when you have too many people it makes it challenging also like too many opinions.

P- (oh crap i forgot to call the resident in the video) so I forgot to call the resident

I- and did you need her?

P- no it was more just for her experience because I think with this resident in particular there have been some concerns about her so some of them are very competent and we would trust them to do initial assessment and admissions but this one the NPs had talk to me and told me got her practice is not quite where we wanted it to be so she was not necessarily coming in as an assistant.

I- and what made you remember that?

P- just as we were getting closer and I was looking around
I- and you think when you have extra time to prepare for these things it changes your stress level or how you prepare?
P- I think the longer that you wait you almost get more anxious and we were down there really early but we wanted to make sure that everything was ready to go.
P- just waiting here waiting for the babies to come out so I can push the apgar timer. And I feel like something that some people do is label the warmers Like A and B because even though you talk about it inevitably someone will ask me and they do not know so that is something I can probably do next time. It does seem a little bit extra to do it but inevitably you have to spend time telling people where to go.
i- and if you do mix the babies up....
P- it doesn't really matter that's what one of the girls who is doing her orientation asked I think it would be difficult if one twin had something really specific that was wrong with him like we have had a lot of twins lately where one twin has a cardiac issue and the other one doesn't so we have to be very cognizant of which twin We are following.
i- and here do you remember how you knew that you had the wrong twin
p- because they were so different they were like four hundred grams apart
i- Baby is born and that's 45.
P- so that's delayed cord clamping, we do delayed cord clamping for every baby now and we usually do a minute I am relying on Trish in this situation because she is catching the baby to assess whether the baby is breathing adequately because even if they are not making any effort we will do at least 30 seconds but if the baby is trying to breathe then we will give them the whole minute so the Obstetricians just want to know the timer so we can tell them when to clamp the cord because they are not looking At the clock They are focussing on what they are doing.
I- okay and she did not give you any information about the baby status here?
P- no so it is a no news is good news situation, if they were concerns they would have said something so we are trusting our team in that scenario and the obstetrician like if the baby was very flat the obstetrician would not feel comfortable keeping him there.
I- okay and an ideal world is there anything else you would have liked to know before

the baby came

P- like I knew everything beforehand and terms risk factors unfortunately I had prepared for the smaller baby but really there was not anything that significant to know for these guys I think that this one was pre-eclamptic so that is why they sectioned her so we were expecting them to be a little bit sicker and they did not get their beta right before delivery and there was no magnesium or anything so we were expecting them to be a little bit worse than normal.

P- so that's with the confusing part that we had talked about again so it's like she was taking A and we were taking B but it was a confusion over like this is the bigger twin and I think everybody got a little bit confused it ended up being fine.

I- okay and so you can just explain to me now that the baby is here what are the things that you're looking for

P- so I am assessing for any effort, I think my first thing was to get the hat on so in a way you are stimulating the baby so I would have probably like to trash to have stimulated a little bit more while I was putting the hat on and he is crying what you can see but then he starts pausing and it goes a little bit apneic, and the one thing that I would have liked Trish to have done was like I appreciate that you was giving me the heart rate but the baby did have tone and was moving so I was not thinking that it was going to be less than 60 at that point and honestly the heart rate to me does not matter initially because I was going to do ppv regardless so that does not change my steps of NRP you are always going to start with giving PPV and I think she had quite a delay in putting on the saturation probe she waited a lot longer than I would have liked her to because the saturations were quite bad when they finally start showing up...

I- okay so initially the the most important thing that you're looking at is...

P- if they have respiratory effort yeah so we will stimulate them and if they still do not do anything then we need to do something more urgently but he at least had some tone in his legs so we could see that he was not completely flaccid I'm looking gather colour are they breathing do they have any tone I basically the three initial things.

I- and you were able to gather that information easily here?

P- yeah for sure and you can see here that I am going through my Mr. sopa steps and I can see that the mask is too small here because it is the bigger baby so I found it

hard to get a super good seal and see here Trish is still assessing a heart rate and she does not have the saturation Probe on yet so I was a little bit frustrated by that especially because if you have the saturation Probe on it should give you a pulse waveform if you have it on correctly so it kind of does dual Duty like I am not so concerned about the ECG but that would be the more important thing (sats) or maybe to assess air entry if we are not seeing good chest rise with the ppv because that tells me that I need to go through my steps and look at things a little differently.
I- and again you did not say anything to her..
P- not at that time because I am focussing on my steps and what I am doing and I knew she would get there eventually it's not like it was a 5 minutes delay it was maybe a 30 second delay so I cannot really fault her for that.
P- okay now she is drying the baby and getting the saturation Probe on. And I think sometimes it is helpful you have Brenda there but she almost needs to be there in a totally research capacity because I found that I was doing all my steps and I know she was just trying to help like asking me if I had done these things and it was distracting at that point but I had already done them so it ended up being fine but sometimes like you can see all the tension on those cords (COSGOD) it's not like they were totally displacing the mask but you do not want to put too much pressure on the baby's face because you do not want to cause soft-tissue damage so I found that difficult because you're still has to be secure but not too tight and I felt like I was using weird pressure and maybe changing the angle of my mask because of that.
i- okay and in terms of Mr. SOPA how do you know to go to the next step and when/
p- so you will do an initial five breaths and if you see no improvement then you know that you need to change something so it is just a logical progression of trying different things so you do like your mask adjustment reposition the Airway, suction and all that kind of stuff and then you can increase your pressure after that which I do not think we ended up needing to do. If you have an improvement in the heart rate that means that you are giving effective ventilation and if you don't then you need to get going
I- okay great thank you like I said I really have no idea what is going on so I appreciate it.
I- and what we're looking at here?
p- I was looking to see what the saturation response was and if her heart rate was

improving because I think the baby was kind of gassing at this point or taking very intermittent breaths but did not have consistent effort which is normal for a preterm baby at this gestation and then I am making sure that my mask seal has not moved because I found it difficult to open the baby's mouth with a mask size that I had chosen because the baby was smaller so I was just trying to make that happen.

I- but there is no need to get a bigger mask at that point?

P- I could have but it did seem a little bit picky at that point because I think our ultimate goal it's just to get him on the Visas as soon as we could. Yeah you can see her that I am pulling the tube. So he would intermittently cry for a few seconds and then he would have apnea periods sorry I was trying to make sure that I was assessing whether he was breathing or not and I did have to give him a few breaths in between and you were just watching for chest rise, and I'm giving him more ppv and a couple more breaths so sometimes they just need that extra stimulation to get them to breathe.

I- and you think that having the other twin in the room there was distracting at all.

P- oh no not at all it's totally like horse blinders, I think the other twin was good if the other twin had been worse then I may have been more concerned because you cannot be at two places at once but I think I would have just encourage them to call the NP or the neonatologist there are other resources.

I- okay and I will point during this whole process do you think that you actually realized that this was the bigger baby?

P- oh not until the end because I was not looking at all, when we weighed him probably which was like after.

P- so I think that he was asphyxial again so I was just giving him some breath or if you can see on the monitor if the heart rate start to drop and that is usually a sign that they are not taking respirations, his tone is not that great either which for his gestational age is not totally surprising but I think I expected him to breathe more than he did

I-did and did your team know exactly what was going on here?

P- yeah I think we were good it was actually kind of nice to have Brenda telling us about the oxygen (Part of study) it was just one less thing that we had to think about like doing the adjustment myself it was kind of a rule which was taken away from me so it was actually really helpful. I am just watching my mask seal and chest

rise I'm giving intermittent breaths. Here I am looking at the apgar timer to see what our age is and making sure that our saturations are appropriate for the age of life because they do not come out and saturate perfectly so in a resuscitation where we were not doing COSGOD I would have been the one who was responsible for telling my assistor to increase the oxygen but because Brenda was there and she was going off of the cerebral stats she was doing that stuff. So I'm looking at the apgar timer see why are sats were so low, I think it is just habit I could have ignored it but it is always good to just monitor, and I think it is good like once are ECG leads are on but you do have a rhythm and are mindful of pulseless electrical activity they are very rare but sometimes weird things like that happen so it is a good habit to get into. Just checking my heart rate and saturation again continuing PPV because the baby has a good heart rate with it and is making inconsistent effort. And it is good to check that the vitals are still good here he is making a little more effort so I stopped PPV.
P- so here we go discussion in the video about twins relative size) she said this is the bigger twin and I was like oh oh oh. I am still giving him some ppv here because I could hear him grunting while I was giving him PPV and when they grunt that is their version I'm trying to prevent their lungs from collapsing. So here you can see that his heart rate is little bit lower than it had been so something was off with the seal or my breaths or something so I adjusted my mask and pressure a little bit with my left hand.
I- okay and having the dad in there now do you think that that alters how you were going about the resuscitation?
P- not at this point sometimes it can most of the time they are so in shook that they are not in your face and not asking many questions which is good. I do not think that he was distracting at all. It is hard because you want to concentrate I am pretty good about telling them in a second and I will explain everything once he is better and I think again because we were doing COSGOD we had to do a full 15 minutes of resus. On the bagger vs. I would have put him on Viasis a lot earlier under normal circumstances so that would have freed me up to explian things a little bit more because we do not usually continue with PPV for this long

I- and did you have a say as to when the the dad came in?
P- no usually they will just ask us, I do not have any issues with them coming in they

may just not always get an explanation right away I think it ultimately depends on the parents Comfort level I learned later that this Mom is actually a NICU nurse as well so she would understand stuff I do not think the dad did, I am wondering if she had questions and the dad was sent in to be some eyes for her. And here Trish was like should we weigh him and I was like no I knew that he needed a really good seal and I think that he would have decompensated if I had taken the mask away and it is hard to weigh the baby and also apply pressure so I made sure I was just like no let's wait till he is on the Viasis and a little bit more settled it is not going to change anything. So she was doing Airway for the other twin and I think she was quite occupied doing CPAP and I wanted to make sure that she was not feeling stressed about managing too many things at once so I got Trish to go and see if we had any extra staff to come down and give us a hand ` getting our kid on cpaps.

I- and what made you think that she may have too much to handle?

P- it is not that it was too much I just did not want to have a delayed because we were waiting for her because at that point we had already had a delay because of the study I think I was just trying to optimize things. I am just orally suctioning because I had realized that there was a lot of secretions before she went on to a CPAP mask so that we were not blowing more things into her it's always good to suction them and his mouth is really clamped down I had the tube was too big to suction him all the way I was getting a lot of resistance and I was trying to not go too deep then again my mouth size was probably a little bit too small and I was checking my vital signs to make sure that my seal was still okay. And now she's asked me about weighing him again... So I had to say no.

P- I think that sometimes assistant nurses especially in this situation feel like we are not doing anything and want to get everything done I just wanted to finish the study first.

I- and did knowing that this next baby was coming along did That speed up how you went about things here?

P- no I think like we had a little bit of time we did not rush anything.

I And here there is some discussion about the Viasis

P- yeah so it sounded like there was some sort of leak so she had to fix that before... So she was worried that the pressure hoses to the wall were leaking, and she did not

want the pressures to be inconsistent so she did not want to switch him over and then have the machine not work so she was just getting the RT's from upstairs to get different connectors so she could change them. We all know that there's something wrong with the Viasis.

I- Was it distracting?

P- it was annoying we got over it, it just added to the white noise, just checking my vitals again making sure my seals good. And it is always a little bit frustrating because we know we do not get as good of a seal like it's a nasal CPAP and they do better on that so I think yeah and he was still really irregular and not taking good breaths like they were very shallow.

I- And you could

P- I could tell from his pattern.

I-Overall were you happy with the resuscitation?

P- Yeah I think it went fine, I do not think that the outcome of the baby was any different

I- And were there any enviromental or equipment factors which affected

P- Umm the CPAP macheine was annoying and this room is always really tight so if you are moving around a lot.. I think It was good, becuase we had most of our stuff that we needed ready if I had wanted to intubate or anything else then I can be frustrating to bring stuff around, and I find these monitors like I did not work at this site initially and I find the monitor settings really frustrating like they will be different all the time so you have t to be very diligent and checking but all the monitors are actually set up.

I- so between different monitors in different rooms?

P- yeah they will be set up in different modules so like all of a sudden You will not be able to do a blood pressure and then you need to go and take time to go inactivate the blood pressure module it is just little stuff like that

I- and do you think that you did anything during or before resuscitation to make it a more supportive environment for the team?

P- making sure that everyone knows the history I'm being very open about the information so no one is guessing and giving people as much notice as they can have like I called Holly quite a few times before he went down just keep everyone in the

loop of what the timelines were looking like and I think that is important because some people need more time to mentally prep than other people so I always think it's nice to have the information and all of it that you could potentially want.
P- and here we are done just getting the baby on the Viasis
I-And any personal factors for you which...
P- I think the longer that I do the job the better I get at asserting myself I'm just making sure.. Like I was just talking to Trish about that after I remember I have the glasses on for one research study when I first started as a transport nurse and Caroline was the assistor and I felt like she was going to be critiquing my recus skills but she kept asking inappropriate questions like oh should we weigh the baby and that really reminded me of when Trish kept asking me that here and I was like no it is not important just move on, but I think the longer that I keep doing this the better I get at asserting myself and working with the other people in the room like there are definitely some personalities which are trickier and you do not feel as confident with so I think them critiquing you and the way that they are critiquing you can affect your confidence level in what you were doing and Defending Your decision-making. Not recently but for example people will be like oh why did you do that at that time are there like oh do not do that.. But I think that the way that people provide feedback it's an important indication of how the team is working together So that is why I will make note of what Trish was doing it is not that she did it wrong it is just that she did it differently then I would have done it so I cannot really get mad at her or critique her because that would affect our team functioning at the end of the day. So I was like yeah this is a nit picky and the baby is still fine there is no reason to say something so I would rather just not

I- So to keep the team in good spirits?
P- Yes exactly
I- Ok well that is everything that we have for that.
Discussion about eye-tracking, she enjoys and feels that they are helpful in thinking through thoughts.

Dorothy
July 24th interview
Resuscitation June 14th
Professional designation registered nurse
Role in resuscitation - transport nurse
Years experience with neonatal resuscitation 10 years
Years of practice in NICU 15 years
Frequency several resuscitations three times a week (2-10 per day)
In the last year I have taken on a leadership role but I also act as an assister

P-Oh I the view is very different
I- Yeah it is
P- okay so I'm just waiting at the end of the bed for them to have the baby surgically removed, and now I'm there standing and watching surgery it looks like part of the baby is out but it might be a breech delivery it's hard to tell. Okay so they're the babies coming out.
I- okay so does knowing how the baby came out alter how you go about the resuscitation in anyway?
P- yes so if the babies head has been stuck for quite some time and the baby is breech and it's a difficult extraction then the baby can be a little bit more Flatter at birth and take more time to resuscitate. So may need some more support.
I- Ok so knowing this is helpful..
P- it can speed along when I'm trying to or intend to do. So I may not give the baby as much of a chance to spontaneously start breathing, so if the baby is not breathing or is apneic then I may intervene quicker than if it was born without any extraction issues.
I-thank you
P- so baby is out and is having delayed cord clamping now. I don't know if it's been a full minute but there's lots of secretion.
I- okay and here they're asking if the mom can see the baby and you said that you would rather not, how to do at that point decide that.
P- because the baby was clamped early because the baby was not vigorous, so just looking at the babies tone and spontaneous effort also Mom was on the other side of

the OR so for me to walk there that is valuable time for me to put into resuscitating the baby rather than.... I realize it's not as family-friendly but at that point the resuscitation was my main focus.

I- okay so I apologize I forgot to ask earlier at this point are you done a breifing with the members of your team at all for this resuscitation?

P- to assign roles, I believe we did this beforehand I can't remember what was discussed (video started right before baby came)

P- so the baby was not making much effort here she was coming around a little bit

I- coming around as in...

P- she was starting to make some spontaneous movements at that point she was also a little bit pale, I'm not sure if she had some blood loss it was possible. So we are drying her off and trying to get her stimulated and started hearing some coughing noises she had a lot of secretions so we suction those right now and it was quick bloody.

I- you knew she had a lot of secretions because..

P- I could hear she's doing that silent cough trying to cry but there is stuff in the way so she can't. So now we're putting the sat probe on monitor her vital signs. She's taking some pauses they don't have the sat probes on so the monitor not being on is not important (there was discussion in the video about the monitor still not being on from a team member). I took the mask out so I could give her some support because she was intermittent she was apneic. And now my mask is not fitting....

I- okay so you did tolerate her intermittent breathing for some time how did you decide now to provide support?

P- I don't think I waited that long..

I- oh I'm not saying that I have no idea what's appropriate. I am just curious how you decided to start the mask right now?

P- because she wasn't maintaining herself so I need to give her some pressure and some breaths because she was not maintaining herself. Sometimes the fluids from the transition can cause apnea. She may have more fluid which can sometimes block the airway so I'm stimulating her now to get her breathing.

I- so so far your steps have been guided I just observing the baby? because the monitor is not setup?

P- well we be taking the steps of NRP, so the drying and stimulating you are always assessing visually what your baby is doing and how they are responding, if that doesn't work then your baby is it a secondary apnea so you start with the mask.
P- I feel like I'm talking to the dad now and this is one of the residents she is gone now.
I- okay and you are looking at the monitor now
P- yes I'm looking at her saturations, she is only satting like it registered at 40 so that is not enough so we turned that up. It may have been calibrating to but we did not have full vitals, So I'm looking here if she is breathing or not..... And when I'm saying she is intermittent she's going a little bit and then she stops and then she will be flat she just has so many bloody secretions that are preventing her from breathing on her own. Now her probes are falling off because they do not stick to the babies, now I'm getting her some more CPAP now she's getting ppv because she is still not responding and sating like 49, I am looking very quickly at this monitor I'm not sure but I can even see the numbers..
I- and you're looking at?
P- just her saturations I want them to improve. So I am asking if the probe can be readjusted because this person does not typically put them on so it is possible that it is not reading. So now she is breathing and we are giving her some CPAP and oxygen. Sylvia is now adjusting the probes so that we can get a better reading. She looks Pinker then what the number (sat) is saying so you know sometimes is just do to equipment failure versus the actual baby and how they are doing medically.
P- now just looking at how many minutes old we are compared to the saturation, she is breathing so we do not need to give her any more breaths, so I am verifying with the vital signs that my interventions are working, she is working to breathe now so she remains on CPAP..
I- and you are looking at her chest
P- yes so she is sucking her chest in, so now I'm waiting to get a good reading So we can give her less oxygen and then we will start the CPAP with the other machine.
I- okay and what would be a good reading?
P- anything over 90% ideally at 21%. Now I am just supporting her with the CPAP, Sylvia is putting her CPAP hat on.

I- and how do you decide when to switch her to Viasis

P- as soon as possible, whenever the RT is available to come the better they get on the viasis or any other type of CPAP is more beneficial to the baby Plus it gives us the opportunity to be hands-free and work on the baby more efficiently. So now our oxygen is at 21% because the probes placement is proper. Sometimes when there is a lot of fluid I'm being born by a C-section you need a little bit of CPAP the clear out or for lack of a better term to dry it out and then the baby can inflate their lungs more efficiently. So the baby is responding and breathing and looking way better then when she was first born but this person who was assisting with the resuscitation I'm not sure what her background in neonatal resuscitation was but her shaking the baby's leg like that really irritated me at this point and I was quite irritated with her because some of the things which I was directing her to do she was not able to do for the resuscitation so I needed to stop her from doing that.

I- okay and when you were needing her to do things which she could not do...

P- well it did affect things, like the sat probe placement I don't know how many times she has put on a sat probe but I know she has put them on before and has not done it correctly, this did affect the way the resuscitation went because the baby ended up needing more oxygen based on false number potentially so it was frustrating at that point so I needed to politely ask her to not do that because the baby was fine we just needed to make the baby a nest and let the baby settle well CPAP what's going on.

I-Ok perfect

P- so I'm making sure that my Vital Signs look good and that my CPAP is working for the baby still she is obviously nice and pink

I- and were you happy with the mask size once you had got started? (discussion about it being incorrect earlier)

P- yes I think she was a little bit slimy at first but once you dried off the mask fit.

P- okay so now we're just moving on with treatment, she was not well enough to weight without the CPAP, so we will put the CPAP on first and then weight her and subtract that from there. she is at 91% So getting her on the Viasis will be better for her and be more effective. She is drifting down (sats) so I think I went up on her O2 here and sectioned her sometimes they bring up more secretions after a few minutes you know.

I- and you are just waiting for the machine to get set up?
P- guess they're setting it up now just to my left it's just a matter of getting it together and waiting. And they ask if Mom can see baby before going up and I said yes she could but we were going up pretty quick so we were preparing to go upstairs I don't remember if we were super busy that night that we could not leave her in OR with an rst person just to observe for the 4-Hour time frame. I forget the exact gestation of this baby she looks a little small. I am just looking at the age of the baby comparing to my saturation and the temperature as well she is 40% oxygen but within the 10 minutes so I was just checking that with my chart, now checking my seal
P- wow my eyes really go all over the place, I did not realize I was looking around that much.
I- I think but the glasses are really really sensitive
P- so I'm just watching her put the prongs in and we will tied up after that something is not working there haha (with the hat)
I- technical difficulty!
I- okay super so did this resuscitation differ in any way from how you had expected it going into it?
P- no I do not think so
I-Ok, overall how do you think the resuscitation went regardless of the outcome?
P- I think that it went fairly smooth considering that we had a non cohesive team who does not work together all the time I think it went fine the baby got what she needed and got resuscitated within the appropriate time frame.
I- okay and did you take any steps to make sure that your team members felt comfortable?
P- I'm beforehand when we were assigning roles everyone had a role which was assigned to them so I thought that people were comfortable doing what they were but the performance and their ability... I was working with someone who I had never resuscitated babies with before which should not matter people are teachable and coachable but there was maybe a little bit of a language barrier as well so it was frustrating at times..
I- And you think that this impacted your performance at all?
P- no I do not think so, I was still able to step in and say the probe is not placed

properly and Sylvia stepped in to fix it.

I- okay so because someone else was there it was not such a big deal? If you were alone with her...

P- I wouldn't go alone but I would have just asked another assistant to fix it..

I- and during the resuscitation did you make any effort to distribute the workload between team members?

P- during everyone had their role assigned so I did not need to direct anyone they knew what they were doing. They were drying and stimulating as they were supposed to and putting on probes so I feel no

I- and do you think that you were distracted at any point?

P- no I feel like I was focussed now watching the video I feel like I was looking around anywhere and everywhere but I think I was focused on what was happening with the baby what are oxygen requirements were and how she was responding whether she was breathing or not

I- okay and aside from the one person who was maybe struggling a little bit was there any other environmental team or equipment factors which added stress or difficulty?

P- the CPAP took a long time to get set up but we were short that time too so I think that people were just busy.. And then I do not know what the machine or the sat problem was there. But we did get the CPAP on and sometimes it is faster and sometimes it is lower.

I- and how did you decide or did you decide when it was appropriate for the dad to come into the room?

P- I do not remember verbalizing I think that L and D just open the door and sent him in...

I- and for you okay with him being there?

P- well we have to be because we are family centered care so we have to explain to him what is going on?

I- and does that change anything for you?

P- I just could not take the extra time to go see the mom at the beginning because she wasn't making big resps

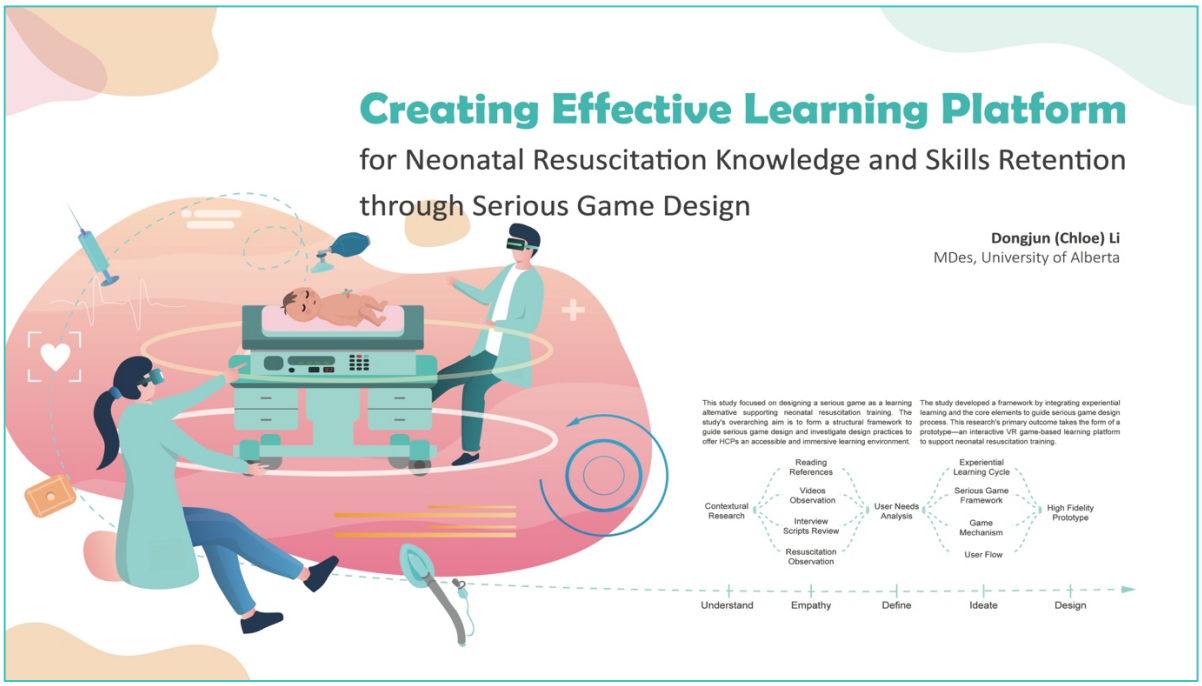
P- no the dad did not (effect me) because I still need to focus at the primary task at hand and I need to talk to parents at the same time so.. it is fin

I- and watching this did you notice any deviations from the NRP guidelines
P- no we stuck to it
I- so do you take any steps to share with the team what will happen.
P- in this video specifically I think I said I am going to give some ppv and then she is not breathing so we kept going with the ppv I did not direct people
I- okay my final question is do you think watching this video How to Think Through your thought process during the actual resuscitation?
P- yes it is a while ago so over a month ago but some of it did for sure

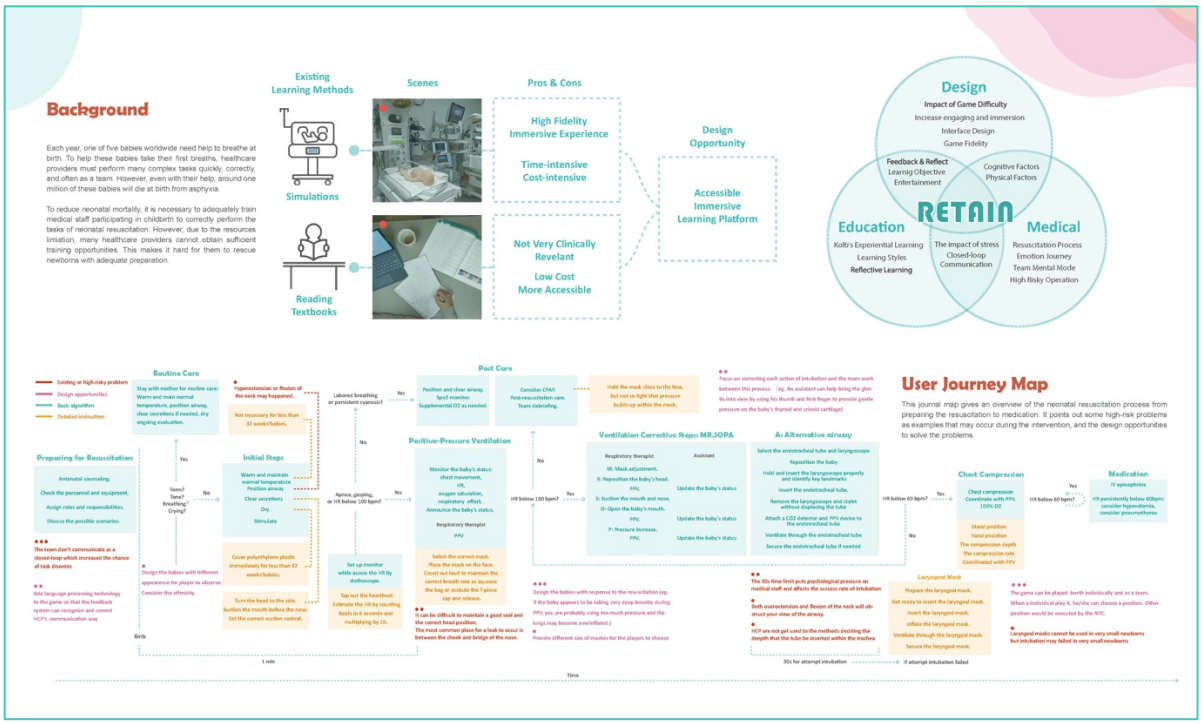
8.2 Exhibition Documentation

Appx 8.2.1 Thesis Exposition: Fine Arts Building, University of Alberta

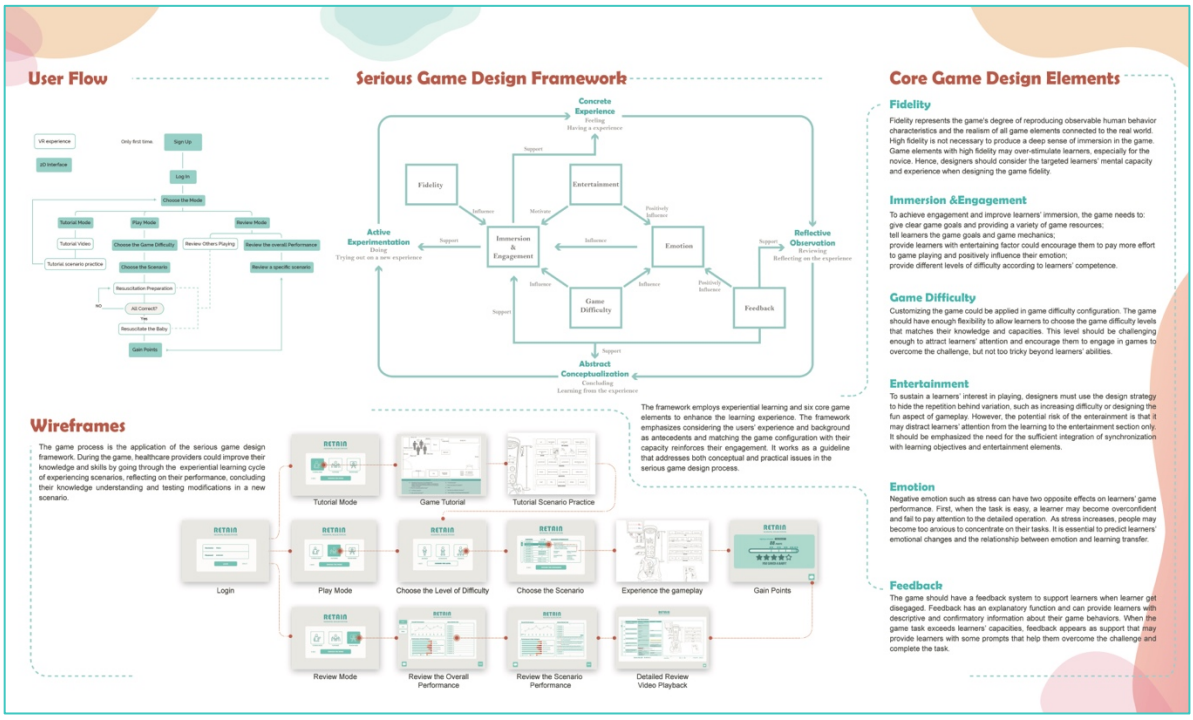
Appx 8.2.2 Thesis Exposition: Fine Arts Building, University of Alberta



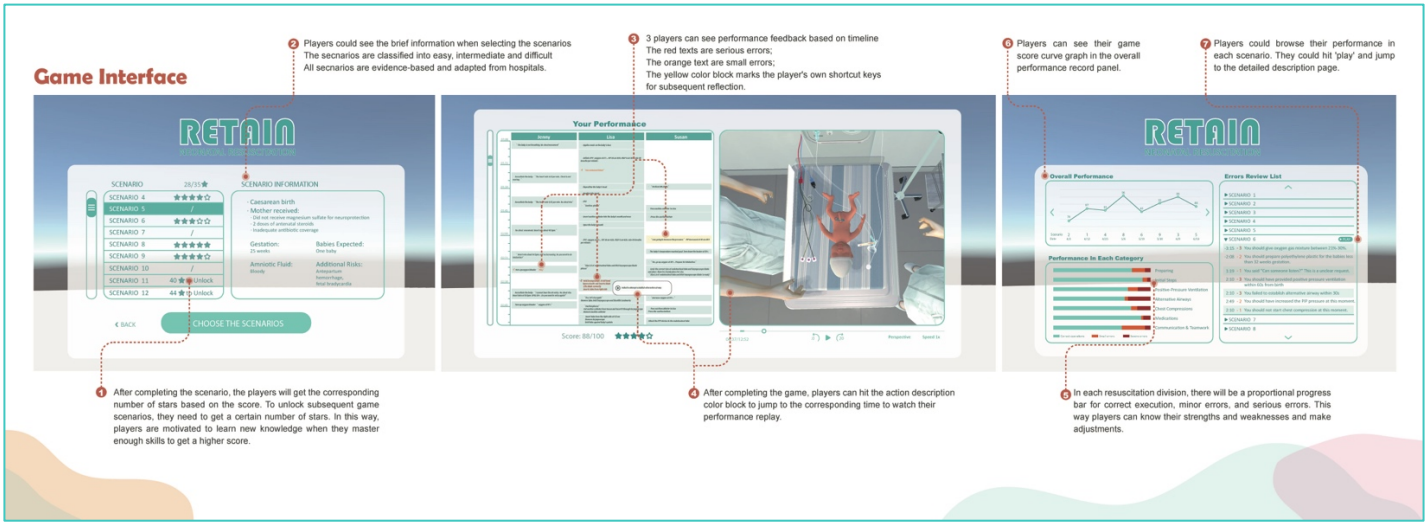
Appx 8.2.3 Poster 1



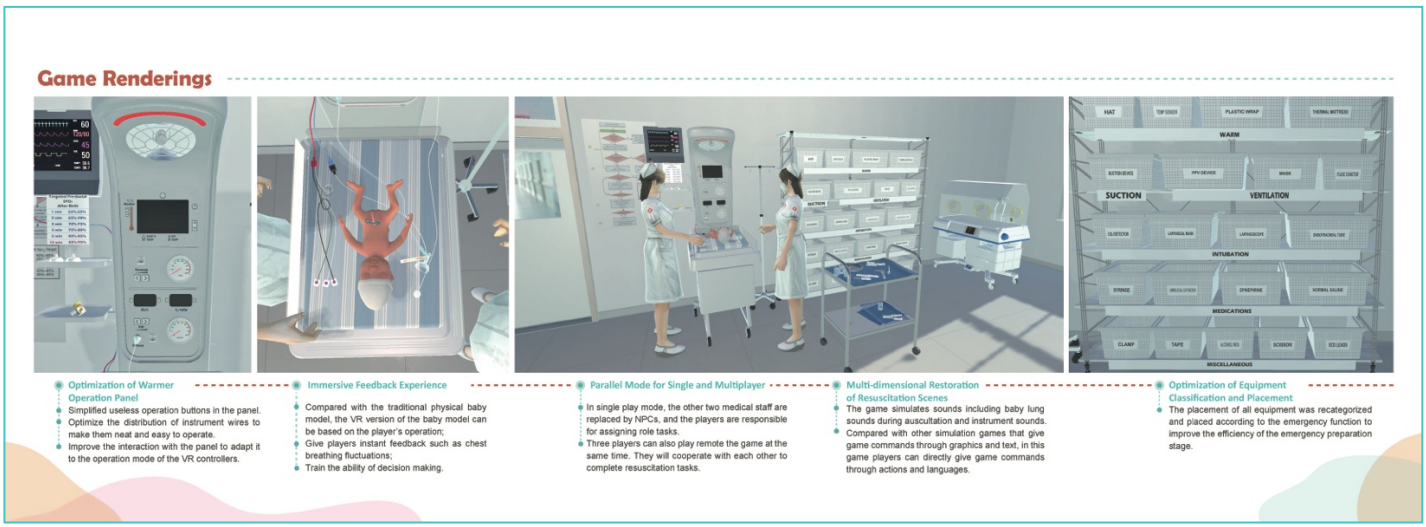
Appx 8.2.4 Poster 2



Appx 8.2.5 Poster 3



Appx 8.2.6 Poster 4



Appx 8.2.7 Poster 5

Appx 8.2.8 Poster 6

Game video link: https://youtu.be/pnSslRyZK_s