Serious Games to Train Neonatal Resuscitation

by

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Abstract

Each year, 10-20% of newborns (about 13-26 million babies) worldwide will need help to breathe at birth. Helping babies breathe is the cornerstone of neonatal resuscitation. Healthcare providers (HCPs) must perform many tasks quickly and correctly to help babies breathe and prevent irreversible organ injury or death. However even with their help, one million of these babies will die.

Medical errors by HCPs remain common and are responsible for 60% of this mortality. To address this staggering gap, guidelines recommend frequent simulation training. Simulation training prepares HCPs to deliver high-quality care while maintaining patient safety. Therefore, to be certified as a neonatal resuscitation provider, HCPs must complete the simulation-based Neonatal Resuscitation Program course once every two years. However, HCPs' knowledge and skills decrease significantly over time, as early as three months after training.

More frequent training is needed but is often prohibitively resource intensive, requiring significant financial and personnel investment. Traditional simulation requires learners to coordinate time away from the clinic to practice under the supervision of a trained instructor and operations specialist, in a lab outfitted with expensive manikins and equipment to mimic the delivery room. Therefore, most HCPs are unable to access adequate training to safely provide care for their newborn patients.

Simulation-based serious games may offer a solution to improve access to training. Serious games use elements like competition and emotional design to teach knowledge or skills. This thesis examines the simulation-based serious game RETAIN (REsuscitation TrAINing for healthcare professionals, Retain Labs Medical Inc., Edmonton, Canada) which fits this description. In the RETAIN board game and digital game, learners undergo neonatal

resuscitation scenarios to practice their knowledge, communication, and decision-making skills while stabilizing a simulated newborn in distress.

The main goal of this research project was to investigate the educational outcomes of using the RETAIN simulators for training and assessment of experienced neonatal resuscitation providers from a level-three perinatal center in Edmonton, Canada. I hypothesized that i) the board game could be used as a summative assessment of HCPs' knowledge, and ii) training with the digital game would improve HCPs' short- and long-term knowledge retention, maintenance, and transfer.

In the first study to assess summative assessment with the board game, I measured HCPs' performance on an open-answer written test, compared to their performance on the board game. In the second study to assess longitudinal knowledge with the digital game, I measured participants' incoming knowledge with a pre-test simulation scenario. Next, participants underwent two training scenarios with the digital simulator to practice their neonatal resuscitation knowledge. I then measured participants' knowledge improvement by administering a post-test immediately after training, long-term knowledge retention by repeating the post-test 2 months after training, and knowledge transfer by administering a novel assessment scenario and medium, 5 months after training. Across the two studies, I quantitatively and qualitatively measured participants' mindset, habits, and attitudes towards RETAIN, technology, board games, and other educational media with post-session surveys.

The results showed that participants performed better on the board game than on the open-answer test, especially if they reported having more experience with board games overall. The board game also allowed for deeper probing of HCPs' knowledge, like explaining ventilation corrective steps, compared to the written test. In the second study, I observed a significant improvement in participants' performance immediately after training, which was maintained 2 months later. I also observed successful knowledge transfer, with participants' best performance demonstrated on this assessment. Overall, participants reported positive attitudes towards RETAIN, technology, and growth mindset. Negative feedback was clustered around usability issues with the digital game.

I concluded that the RETAIN simulators supported successful educational outcomes for experienced neonatal resuscitation providers. The board game functioned as an enjoyable and clinically relevant summative assessment, and the digital game facilitated knowledge improvement, retention, and transfer over time. HCPs also expressed positive attitudes towards the simulators, indicating their receptiveness towards these media for continuing healthcare education. Simulation-based serious games are well-positioned to address challenges of traditional simulation training, including improving access to training for urban and rural providers; or facilitating distanced learning during the current pandemic and beyond. Further research is needed to understand how training may ultimately lead to better care and improve health outcomes for our smallest patients.

Preface

This thesis is an original work by Simran K. Ghoman. This thesis consists of two research projects that have received research ethics approval from the University of Alberta Research Ethics Board: i) RETAIN – Video Game to Improve Neonatal Resuscitation Skills, Pro00081221 and ii) RETAIN – Summative Assessment of a Board Game, Pro00085271.

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Abbreviations

AP	Anteroposterior
BPM	Beats Per Minute
COVID-19	Coronavirus Disease
CPAP	Continuous Positive Airway Pressure
ECG	Electrocardiogram
eHBB	Electronic Helping Babies Breathe
ETAT+	Emergency Triage, Assessment and Treatment Plus
FiO_2	Fraction of Inspired Oxygen
HBB	Helping Babies Breathe
HCPs	Healthcare Providers
HR	Heart Rate
IQR	Interquartile Range
LIFE	Life-saving Instructions for Emergencies
MCQ	Multiple-Choice Questionnaire
NHS	National Health Service

NICU	Neonatal Intensive Care Unit
NRP	Neonatal Resuscitation Program
PPV	Positive Pressure Ventilation
RETAIN	REsuscitation TrAINing for healthcare professionals
SBE	Simulation-Based Education
SD	Standard Deviation
SpO_2	Oxygen Saturation
VR	Virtual Reality
WHO	World Health Organization

Chapter 1: Introduction

1.1 Neonatal Resuscitation

Paradoxically, the deadliest day of life is the day of birth[1], especially when evaluated as the number of years of life lost.[2] Being born is a dangerous and high-risk activity and, tragically, more than one million newborns worldwide do not survive beyond their first and only day of life.[1] The three biggest causes of infant death are infections (36%), pre-term birth (28%), and birth asphyxia (23%).[3] Asphyxia at birth describes a lack of blood flow or gas exchange immediately before, during, or after being born.[4] This may be associated with an intrapartum event such as maternal hemorrhage, uterine rupture, placental abruption, or cord prolapse.[4] Decreased blood flow to organs like the muscles, liver, heart, or brain can cause irreversible systemic and neurological damage, resulting in severe and detrimental short- and long-term health outcomes.[4] To reduce morbidity and mortality from asphyxia at birth, it is vitally important for these infants to receive immediate and competent care—known as neonatal resuscitation.

To improve healthcare providers' (HCPs) ability to deliver high-quality care during neonatal resuscitation, the Neonatal Resuscitation Program (NRP) was developed in 1996. The NRP consists of a 2-day certification course in which HCPs train their knowledge, technical skills, and decision-making skills according to the neonatal resuscitation algorithm. This algorithm delineates important assessments and actions to be undertaken by HCPs during neonatal resuscitation (Figure 1-1).[5] Since its widespread uptake, NRP training has increased the number of infants who are resuscitated, and it has improved first and fifth minute Apgar-scores (a measure to assess newborn health)[6] while decreasing duration of hospitalization.[7] However, despite this training, nearly one million infants still die each year from asphyxia at birth[8,9], with half of deaths caused by deficiencies in HCPs' competence to safely provide care.[10]

During neonatal resuscitation, HCPs are expected to work quickly together as a team to safely provide complex, coordinated care within a stressful, time-critical, and demanding situation.[11] Their newborn patients may require ventilation, intubation, chest compressions, or intravenous medication—all which must be administered within tight temporal and physical confines. These challenges can impair HCPs' concentration, decision-making, and working memory[12–14] even in experienced providers.[15] As a result, deviations from the resuscitation algorithm are common[16] and have the potential to cause serious medical errors. Therefore, international guidelines recommend frequent simulation-based education (SBE) to better prepare HCPs to safely provide neonatal resuscitative care.[5,10]

1.2 Simulation-Based Education and the Current Approach to Neonatal Resuscitation Training

To prepare for neonatal resuscitation, healthcare providers undergo the standardized NRP simulation-based certification course once every two years. The NRP course is rooted in SBE, prioritizing immersive and interactive learning experiences over a pedagogical approach.[5] The course consists of two parts—during the at-home portion, learners read the NRP textbook, complete a multiple-choice assessment, and undergo a few online simulated resuscitation scenarios. Following the at-home work, learners attend the in-person portion of the course consisting of individual-skill stations and structured simulation scenarios as a group. However, neonatal resuscitation providers are only required to complete the course once every two years, which may be insufficient to maintain long-term competence.[17] This insufficiency is particularly significant for neonatal resuscitation, as this high-acuity low-occurrence event presents limited learning opportunities for HCPs in the clinic.[18]

While more frequent SBE is needed beyond the requirements of the NRP certification course, traditional approaches to simulation training can be resource-consuming and therefore inaccessible and impractical for a majority of HCPs.[19,20] Traditional training requires access to a simulation lab, outfitted with expensive equipment and manikins which must be monitored and maintained by simulation operations specialists and technicians, as shown in Figure 1-2.[21] HCPs must coordinate their schedules to take time away from their clinical duties, so that they can participate in planned scenarios under the supervision of a trained instructor.[21] Moreover, undergoing hands-on training is arguably ineffective unless specific feedback is provided to learners.[22] Feedback and reflection through debrief is essential for learners to apply their training to improve their future performance in the delivery room[23] but can be time intensive to provide (especially written feedback) and, therefore, not always feasible.[22]

Due to these barriers, frequent SBE opportunities are limited, and gaps in neonatal resuscitation provider competence remain common. This leaves HCPs dangerously underprepared to act quickly and correctly during a clinical emergency. An alternative approach is needed to improve access to frequent SBE and target this root cause of preventable infant morbidity and mortality.

1.3 Serious Games for Neonatal Resuscitation Training

An alternative approach to improve opportunities for SBE in neonatal resuscitation training is needed—one that is effective, engaging, efficient, and grounded in experiential educational psychology.[11] Immersive media like serious games are one such potential approach. Serious games use elements like competition and emotional design to engage learners within an interactive and challenging environment, while simultaneously training their skills, knowledge, or attitudes for professional, academic, or therapeutic applications.[24,25] These immersive media (including board, video, or computer games, as well as tabletop, digital, or extended reality simulators) offer promising solutions to augment traditional neonatal resuscitation SBE. They also teach relevant knowledge or skills within an engaging learning environment[11,26], especially as deficiencies in non-technical skills (e.g., working memory, decision-making, and teamwork) are the reason for a majority of fatal errors and poor patient outcomes during neonatal resuscitation.[27] While serious games require an initial investment of time and resources to develop, the games then have the potential to be quickly and inexpensively disseminated depending on the developer. On the user end, games have the exciting potential to improve competence and reduce error rates at low time and resource costs.[28,29]

1.4 Literature Review

Indicative of the universal barriers which limit access to frequent SBE for neonatal resuscitation, different serious games have been developed around the world to help overcome these common, shared challenges.

1.4.1 NRP Approach to Digital Simulation

The latest edition of the NRP provider curriculum introduced the eSim (Laerdal Medical, Stavanger, Norway, and American Academy of Pediatrics, Itasca, Illinois, USA), a digital neonatal resuscitation simulator that is accessed online by learners prior to attending the in-class portion of the NRP certification course.[5,30] Learners perform assessments and interventions on a simulated infant with responsive heart rate, oxygen saturation, breathing, color, and tone. There are four scenarios to navigate, and feedback is provided by a list of actions performed by learners, scored based on adherence to the NRP algorithm as "correct" or "needs improvement". Pre-NRP course preparation with the eSim plus textbook (compared to textbook-only preparation) improved HCPs' performance of several steps of the NRP algorithm during an in-person simulation.[31] These steps included initial set-up (80% eSim vs. 59% textbook, $p<0.001$), initial steps (88% eSim vs. 70% textbook, $p=0.024$), correctly initiating ventilation corrective steps (MR SOPA mnemonic, where MR stands for "mask adjustment and reposition airway" [84% eSim vs. 61% textbook, $p=0.01$], SO stands for "suction mouth and nose and open mouth" [61% eSim vs. 32% textbook, $p=0.004$], and P stands for "direct pressure" [54% eSim vs. 30% textbook, $p=0.012$]), and placing electrocardiogram (ECG) leads before chest compressions (84% eSim vs. 56% textbook, $p=0.001$).[31] However, there was no difference in time to initiate positive-pressure ventilation or correctly order epinephrine (65% eSim vs. 62% textbook, p=0.622).[31] These promising results indicate that digital simulation can better prepare HCPs for in-person training compared to studying with the textbook alone.

1.4.2 Digital Simulation Games and Extended Reality Applications

Some examples of digital simulation and extended reality games which have been reported in the literature include the Scottish Neonatal Resuscitation mobile game, Singaporean Neonatal Resuscitation computer game, NEOGAMES, e-Baby Neonatal Nursing computer game, Life-saving Instructions for Emergencies (LIFE) mobile game, e-Helping Babies Breathe (eHBB) virtual reality game, and the Compromised Neonate Program virtual reality game (Table 1-1).

The Scottish Neonatal Resuscitation Game (National Health Service Education for Scotland, Edinburg, UK) contains six digital-simulation scenarios to teach neonatal resuscitation skills to rural family physicians with infrequent birth attendance.[32] This game incorporates tactical skills practice like coordinating chest compressions with positive pressure ventilation. Moreover, learners' scores are submitted to a leaderboard on the National Health Service Education for Scotland platform.[32]

The Singaporean Neonatal Resuscitation Game (Singapore General Hospital, Bukit Merah, Singapore) is an online neonatal resuscitation simulator presenting scenarios of varying difficulty levels to retrain and assess experienced neonatal resuscitation providers.[33] Learners prepare (e.g., assemble equipment) and independently perform simulated resuscitations, and receive a performance summary after each scenario. A study following 162 HCPs over 6 months reported no difference in multiple-choice test scores or manikin-based skills test scores between participants who did and did not voluntarily train with the online game.[33]

NEOGAMES (Children's Hospital of Fudan University, Shanghai, China) is a computer-based serious game which presents simulation scenarios of neonatal resuscitation within an immersive learning environment.[34] A study following 81 undergraduate medical students reported some short- and long-term knowledge improvements on test scores (for students undergoing curriculum plus game) compared to the control group (curriculum only), which were maintained up to 6 months after training with the game.[34]

The e-Baby game for neonatal nursing students (University of São Paulo, São Paulo, Brazil) teaches learners to manage oxygenation problems in simulated preterm infants.[35–37] After reviewing the medical history, learners are presented with a preterm infant with respiratory problems and are prompted to choose clinical assessment tools to answer a series of questions. The e-Baby game was evaluated for its usability and reception by nursing students, who reported the game was easy to use, easy to learn from, and enjoyable.[36]

LIFE (Life-saving Instructions for Emergencies; Nuffield Department of Medicine, Oxford University, Oxford, UK) is a mobile game developed for the ETAT+ (Emergency Triage, Assessment and Treatment Plus) platform which aims to disseminate training about World Health Organization (WHO) guidelines for Africa.[38] One scenario in the LIFE game trains learners in performing neonatal resuscitation in a virtual rural hospital setting. The interactive game asks intermittent multiple-choice questions throughout the scenario to reinforce knowledge of resuscitation guidelines.[38]

The LIFE project also collaborated with the Neonatal Education and Simulation-based Training program to develop an electronic Helping Babies Breathe (eHBB) virtual reality game (University of Washington, Seattle, Washington, USA, and Oxford University, Oxford, UK).[39] The game was developed to facilitate continuous learning for HCPs to supplement in-person Helping Babies Breathe classes which are vulnerable to inconsistencies and ineffectiveness in low-resource settings.[39] There are three simulation scenarios for learners to practice their knowledge and skills in neonatal resuscitation. In a usability study, HCPs from the National Hospital in Nigeria reported the game as easy to use and facilitates a low-stress educational environment.[39]

Another virtual reality program for neonatal resuscitation SBE is the Compromised Neonate Program (University of Newcastle, Callaghan, Australia) to train midwifery students.[40] Learners take the lead of a team of virtual HCPs to deliver and resuscitate newborn infants in distress. Some of the scenarios are played with a virtual helper, while others expect the learner to perform the correct steps of neonatal resuscitation independently and correctly to help the simulated infant. A randomized trial is currently underway with midwifery students from the University of Newcastle to compare the learning progress between students who complete the standard curriculum and those who complete the standard curriculum plus the virtual reality game.[40]

1.4.3 Tabletop Games

Tabletop or board games (simulation-based and strategy-based) represent a low-technology alternative to the digital and extended reality media presented above. These serious tabletop games include the Neonatology Game, Neonatal Emergency Trivia Game, and Neonopoly (Table 1-2).

The Neonatology Game (University of Glasgow, Glasgow, UK) is a trivia game which aims to teach neonatal curriculum to undergraduate medical students. Learners are split into teams of four, and dealt cards which summarize various neonatal conditions to help them answer general questions about neonatology, including questions about neonatal resuscitation. In a randomized trial, medical students who completed the curriculum plus board game had improved test scores compared to the students who only completed the curriculum.[41] The game was also rated positively by the medical students, who described it as interesting, useful, and fun.[41]

Similarly, the Neonatal Emergency Trivia Game (Neonatal Education Specialties, Greensboro, North Carolina, USA) is also a trivia-based game, but, more specifically, it aims to prepare neonatal HCPs for emergent events.[42] Learners roll dice to determine from which trivia category to answer a question. The game contains over 100 validated and peer-reviewed questions spanning three categories, including one category on neonatal resuscitation (alongside pathophysiology and medication). The questions were tested with experienced neonatal nurses to evaluate their reliability, and the nurses evaluated the game positively for its clarity and clinical relevance.[42]

Neonopoly (South Africa) was presented in the literature by Swingler (1994) who conducted a study in which midwives evaluated the game for its usability, relevance, and enjoyment.[43] The game was rated as enjoyable and participants reported that the game filled a perceived need, while the insufficient number of question cards was identified as a limitation.[43]

Apart from this data, neither the learning objectives, instructions, nor availability of the game were reported.

1.5 The RETAIN Training Simulators

While each game identified in the literature review is situated within its specific framework of learning objectives, clinical environments, and target users, they all aim to improve the current approach towards training neonatal resuscitation. The simulation-based games in particular, offer a potential solution to improve opportunities for HCPs to access more frequent SBE.[11] However, the literature review revealed a lack of robust research evaluating many of these simulation games. New approaches towards simulation training must be evidence-based to justify their appropriate application in clinical education settings. Testing through research is also an essential step of design thinking, as it provides critical information to guide the iterative and intensive process of developing these games.

The RETAIN (REsuscitation TrAINing for healthcare professionals; Retain Labs Medical, Edmonton, Canada) simulators were developed to help overcome barriers preventing frequent uptake of neonatal resuscitation simulation by HCPs (Table 1-3). RETAIN currently exists as a tabletop simulator, digital simulator, and role-playing video game (Figure 1-3)—each with the aim of improving training for HCPs from a range of locations and resource backgrounds.[44]

In RETAIN, learners select a simulation scenario based on resuscitations recorded at a tertiary perinatal center in North America. The tabletop simulator contains over 50 unique resuscitation scenarios of varying difficulty, while the digital simulator currently presents several different scenarios based on examples from the NRP textbook.[5] While the digital simulator and video game are played individually, the tabletop simulator is played by taking turns within a cooperative team, with one individual as the facilitator. The facilitator reads information about the scenario from a detailed manual of cases and shares this information with the team as appropriate throughout the resuscitation. Using the appropriate equipment pieces, monitors, and action cards, learners practice stabilizing a simulated newborn infant in distress, within the safety of a simulated setting. Feedback (e.g., heart rate, oxygen saturation, breathing, color, and tone) from either the facilitator or computer software provides information about the infant's clinical status to guide learners' decision-making. Correct adherence to NRP guidelines results in the infant's health eventually stabilizing, while inappropriate tasks or tasks in the incorrect order cause the infant's health to decline.

Alternative approaches to traditional in-person simulation training, such as the RETAIN simulators, offer a scalable platform for learners to readily access educational content and achieve many of the same learning objectives as traditional SBE. Games and other immersive media for simulation training may offer a convenient approach to improve HCPs' preparedness to provide neonatal resuscitation care—indicated by the wide range of tabletop, digital, and virtual reality simulators which have already been developed.

A major priority for both high and low-resource healthcare settings is to ensure skilled care at birth. This improves the survival and health of newborn infants and targets the United Nations Sustainable Development Goal 3 for good health and wellbeing.[3] Immersive media like RETAIN offer a potentially engaging, effective, and resource-efficient supplement to traditional neonatal resuscitation SBE. By improving neonatal resuscitation providers' knowledge and skills, the RETAIN simulators may ultimately help improve health outcomes for newborn infants worldwide.

1.6 Thesis Contribution and Structure

This thesis presents an evaluation of the RETAIN digital and tabletop simulators for their effectiveness across different research questions. The main goal of these studies is to evaluate the RETAIN digital and tabletop training simulator to train and to summatively assess knowledge and decision-making skills about the neonatal resuscitation algorithm in experienced HCPs from a tertiary perinatal center, measured by HCPs' performance on different test instruments. The current work is a continuation of an overarching research project to assess the utility of the RETAIN training simulators to improve HCPs' performance during clinical neonatal resuscitations. In the first part of the project to assess the RETAIN role-playing video game, Bulitko *et al.* (2015) described the development and preliminary testing of the game[45], and Cutumisu *et al.* (2018) analyzed the effect of HCP participants' mindset in moderating their performance within the game.[46] The second part of the RETAIN research project aims to evaluate the RETAIN board game. Cutumisu *et al.* (2019) compared HCP participants' performance using a pre-post-test to measure short-term knowledge retention after training with the tabletop simulator.[18] The third part of the RETAIN research project focuses on the RETAIN digital simulator, for which no previous research has been conducted.

The current studies address the RETAIN tabletop and digital simulator. The first study examines whether the RETAIN tabletop simulator can be used as a summative assessment of HCPs' neonatal resuscitation knowledge and decision-making, as an alternative to a traditional written test. The second study evaluates whether training with the RETAIN digital simulator improves HCPs' short- and long-term knowledge retention of the neonatal resuscitation algorithm and facilitates transfer of their knowledge to a novel learning environment. A number of questions informed the direction of this research project, including:

- Can the tabletop simulator be used for summative assessment of HCPs' knowledge, despite having been designed with the initial intention only to train knowledge?
- Will training with the RETAIN digital simulator improve HCPs' short-term knowledge of the neonatal resuscitation algorithm?
- What long-term effects on knowledge will HCPs experience after training with the digital simulator?
- Will training with the digital simulator facilitate HCPs' knowledge transfer, indicating their ability to apply what was learned to a novel environment?
- How are the simulators received by neonatal HCPs? What are HCPs' attitudes towards alternative educational resources, like RETAIN and other technologies?

This thesis consists of five chapters. Chapter one provides background information about the research project, including an overview of simulation-based education for neonatal resuscitation education, and a review of the current landscape of serious games and similar technologies. Chapter two describes the methodological approach and framework used to address the core research questions which constitute this thesis work. Chapter three explains the study evaluating the application of the RETAIN tabletop simulator as a summative assessment of neonatal resuscitation knowledge. Chapter four summarizes the study investigating whether the RETAIN digital simulator facilitates knowledge improvement, retention, maintenance, and transfer over time. Chapter five is a discussion of the results and presents the conclusions and future directions for this research project.

Table 1-1 Summary of the current landscape of serious digital and extended reality games for neonatal resuscitation education

Game	Learning Objectives	How to Play	Availability	Feedback	Assessment of Game	
					Learners' Attitudes	Educational Outcomes
NRP eSim	Prepare learners for in-class NRP provider course	Learners perform assessments and interventions to stabilize patient	4 scenarios available after enrolling in NRP provider course	Percent score determined by adherence to algorithm.	Not reported	eSim+NRP group correct performed actions more frequently than NRP-only HCPs
Scottish Game	Prepare rural HCPs with infrequent birth attendance	Practice simulation cases of different difficulty and clinical settings	6 scenarios available for NHS Scotland course	Final score submitted to NHS leaderboard	Not reported	Not reported
Singapore Game	Train and assess experienced HCPs' knowledge and skills	Lead a virtual team to assemble equipment and perform resuscitations	Scenarios of 3 difficulty levels based on gestational age	Assessment based on knowledge, skills, and leadership	Not reported	No difference between MCQ or simulation scores by HCPs after self-directed play
NEOGAMES	Immersive and accessible simulation education for trainees	Practice simulation cases guided by live feedback of infant's health	Several scenarios offered across different difficulty levels and factors	Not reported	Not reported	Medical students had higher test scores over time in game group vs. control group

Abbreviations: HCP (Healthcare Provider), MCQ (Multiple-Choice Questionnaire), NHS (National Health Service), NICU (Neonatal Intensive Care Unit), NRP (Neonatal Resuscitation Program)

Game	Learning Objectives	How to Play	Availability	Feedback	Assessment of Game	
					Learners' Attitudes	**Educational Outcomes**
eBaby	Prepare nursing students to care for preterm infants	Answer questions and perform assessments on simulated infants	Cases presenting mild to severe respiratory problems	Score based on correct responses to MCQs	Easy to learn from, enjoyable, autonomous, and accountable	Not reported
eHBB	VR simulator to train HBB in low-resource settings	Administer interventions to manage deliveries	3 scenarios to supplement in-person HBB training	Performance based on adherence to guidelines	HCPs reported it was interesting, educational, and less stressful	Ongoing trial in Nigeria and Kenya to measure outcomes
LIFE	VR simulator to train HCPs in low-resource settings	Answer questions and manage deliveries in a rural setting	Developed to supplement in-person ETAT+ training	Score based on correct answers and adherence	Not reported	Not reported
Compromised Neonate Program	VR simulator to teach midwifery students neonatal skills	Undergo time sensitive and immersive scenarios	Developed to supplement midwifery course curriculum	Correct adherence to resuscitation algorithm	Not reported	Ongoing trial comparing curriculum to game+curriculum
RETAIN digital game	Train HCPs' knowledge and decision-making skills	Independently perform realistic simulation scenarios	>20 cases based on deliveries recorded at a level-3 NICU	Correctly follow NRP algorithm to stabilize infant	HCPs reported it was engaging and elicited stress	Not reported

Abbreviations: HBB (Helping Babies Breathe), HCP (Healthcare Provider), MCQ (Multiple-Choice Questionnaire), NICU (Neonatal Intensive Care Unit), NRP (Neonatal Resuscitation Program), VR (Virtual Reality)

Table 1-2 Summary of the current landscape of serious tabletop and board games for neonatal resuscitation education

Game	Learning Objectives	How to play	Availability	Feedback	Assessment of Game	
					Learners' Attitudes	**Educational Outcomes**
RETAIN board game	Improve knowledge, communication, and teamwork skills	Undergo team-based simulation scenarios guided by a facilitator	50 cases based on deliveries recorded at a level-3 NICU	Facilitator booklet contains NRP-based feedback for each scenario	Experienced HCPs enjoyed playing the game	Improved knowledge retention of NRP on an open-answer scenario
The Neonatology Game	Teach undergraduate neonatal curriculum	Team-based trivia game where players race to answer questions	Used during neonatal unit of University of Glasgow medical curriculum	Performance scored based on number of correctly answered questions	Medical students said the game and resources were useful, fun, and interesting way to learn	Compared to curriculum alone, game+curriculum group scored higher on the final exam
Neonatal Emergency Trivia Game	Prepare HCPs for clinically emergent neonatal cases	Team-based trivia game where players answer questions about neonatal pathophysiology, resuscitation, or medication	101 peer-reviewed validated short-answer questions and answers	Performance scored based on number of correctly answered questions	Nurses said the game was easy to play, clinically applicable, helpful, and recommend it to their peers	Not reported
Neonopoly	Not reported	Not reported	Not reported	Not reported	Midwives said the game was enjoyable and easy to learn, but needs more questions	Not reported

Table 1-3 Summary of the existing literature describing the RETAIN simulators

Reference	Media	Objectives	Outcomes
		Original Research	
Bulitko et al. 2015[45]	Video Game	Development and pilot testing for usability and relevance (n=11)	Game developers, academics, and HCPs rated game as stressful, engaging, clinically relevant, and useful for basic neonatal resuscitation training
Cutumisu et al. 2018[46]	Video Game	Effect of fixed vs. growth mindset in moderating performance on the video game (n=50)	Mindset moderated relationship between time since NRP training and performance; HCPs with higher growth mindset made fewer mistakes
Cutumisu et al. 2019[18]	Tabletop Simulator	Improve short term knowledge retention after training (n=30)	HCPs improved performance by 12% after training, especially in temperature management
Lu et al. 2020[47]	Digital Simulator	Machine learning to examine attitudes and longitudinal digital simulation performance (n=50)	Three attitudinal clusters identified, with each cluster exhibiting a diverse learning path; all clusters improved knowledge after training
Lu et al. 2021[48]	Digital Simulator	Effect of growth mindset to moderate performance (n=50)	HCPs who endorsed higher growth mindset performed better 2-months after training
		Review	
Ghoman et al. 2020[11]	Video Game, Tabletop Simulator, Digital Simulator	Review the landscape of technology-enhanced and game-based neonatal education	The RETAIN digital and tabletop simulators exist as two of nine identified alternative tools for neonatal resuscitation/neonatology education
Ghoman & Schmölzer 2020[44]	Video Game, Tabletop Simulator, Digital Simulator	Review the existing literature describing the educational outcomes of RETAIN simulators	Three original papers and one conference proceeding were identified and summarized
		Case Study	
Ghoman et al. 2020[49]	Tabletop Simulator	Describe the methodology and study design of the tabletop simulation clinical studies (n=50)	Summarized information about how training and assessment studies were conducted, including decision-making and troubleshooting

Figure 1-1 Algorithm delineating the important assessments and actions undertaken during neonatal resuscitation (7th edition *Textbook of Neonatal Resuscitation*, Weiner 2016)

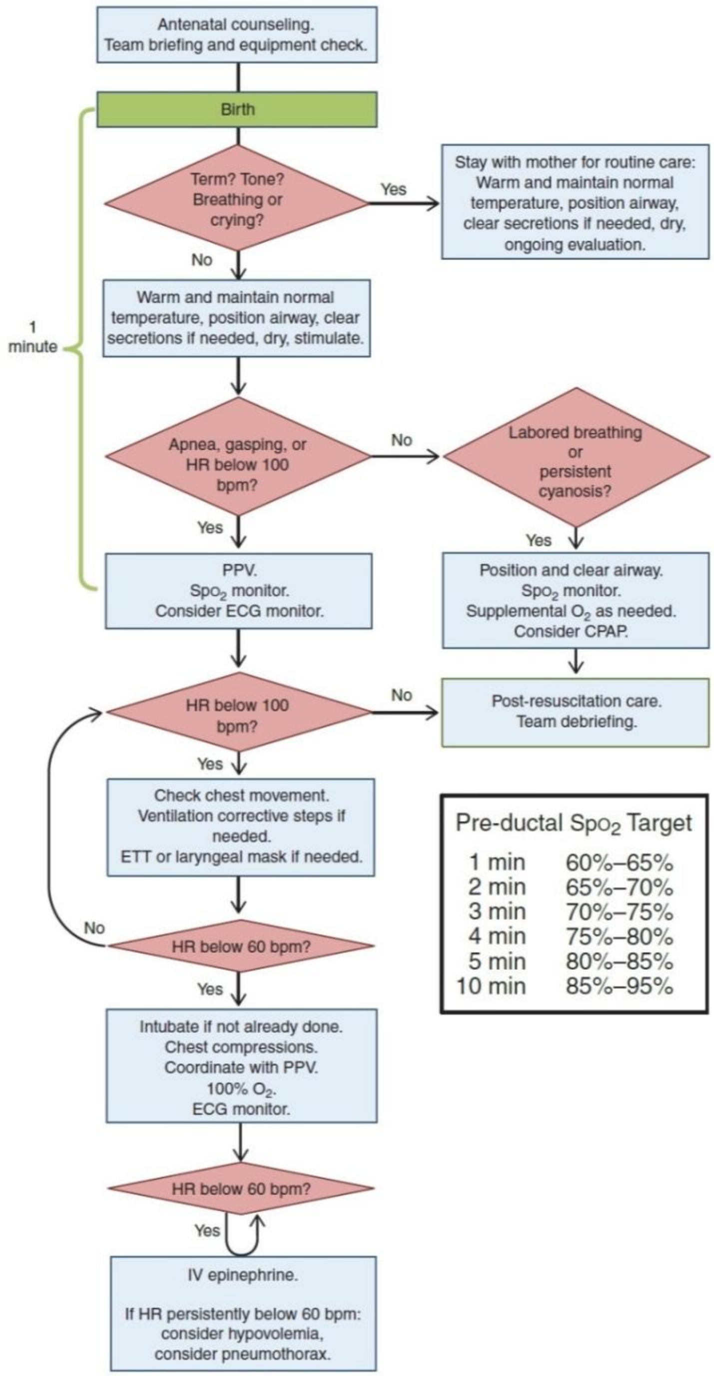
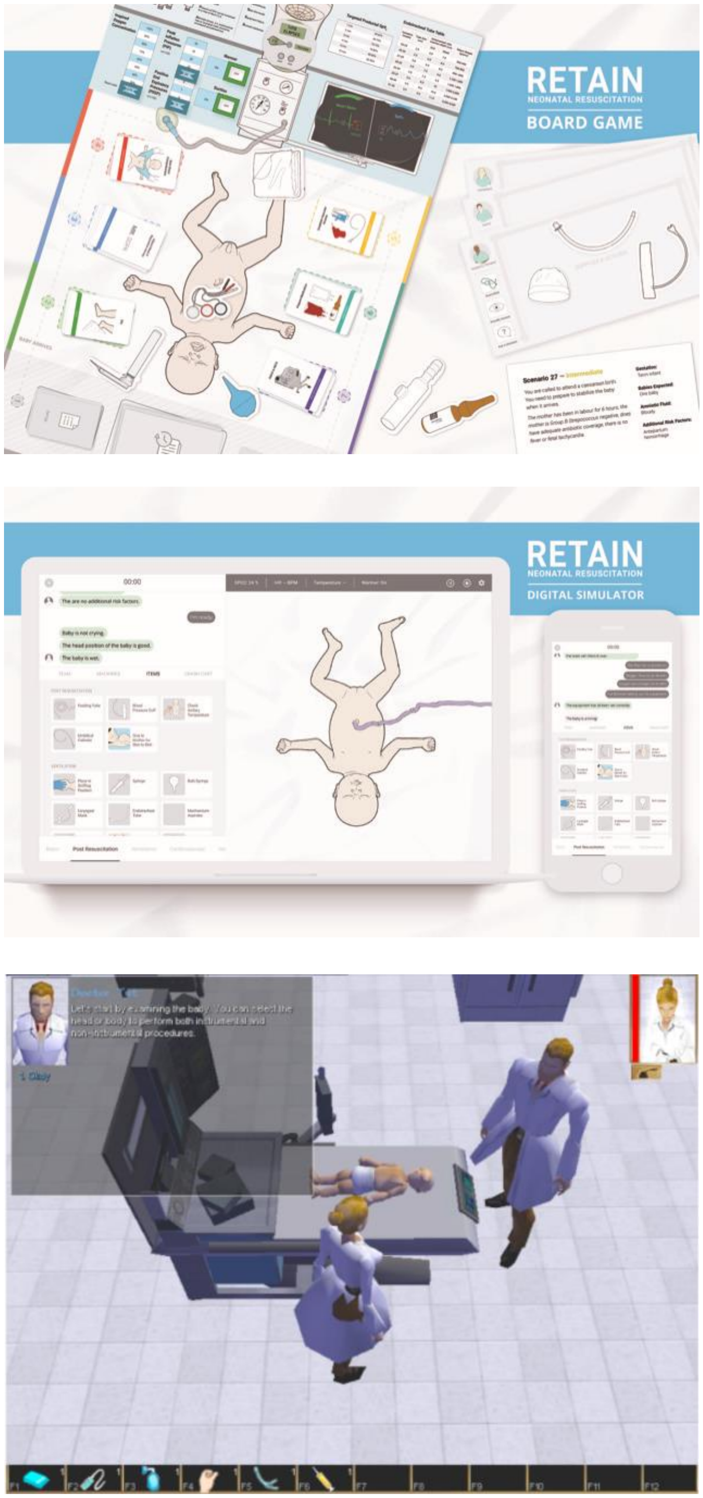


Figure 1-2 Simulation lab with equipment, manikin, and supplies required for a neonatal resuscitation simulation

Figure 1-3 Overview of the RETAIN board game, digital simulator, and role-playing video game (Retain Labs Medical, 2021)



Chapter 2: Methods

2.1 Educational Framework

SBE is the recommended method for HCPs to train and demonstrate their clinical competence while maintaining patient safety.[50] However, traditional SBE requires significant human and financial resource investment which become a barrier against frequent training.[20] Therefore, most HCPs are not able to adequately maintain their clinical knowledge and skills.[17] The previous chapter outlined specific problems that gaps in competence cause during neonatal resuscitation[10], when HCPs must expertly provide cardiorespiratory support to their vulnerable newborn patients.[5]

2.1.1 Adult Learning Theory

Serious games are well-positioned to support healthcare education as many of its elements align with the principles of adult learning.[51,52] As such, serious games have already been developed for most medical disciplines—including surgery[29,53], emergency medicine[54,55], and anesthesiology.[56] Some of the learning principles that serious games offer include collaborating with instructors and peers, taking a problem-centered rather than subject-centered approach, and leveraging internal motivation to foster autonomy.[52,57]

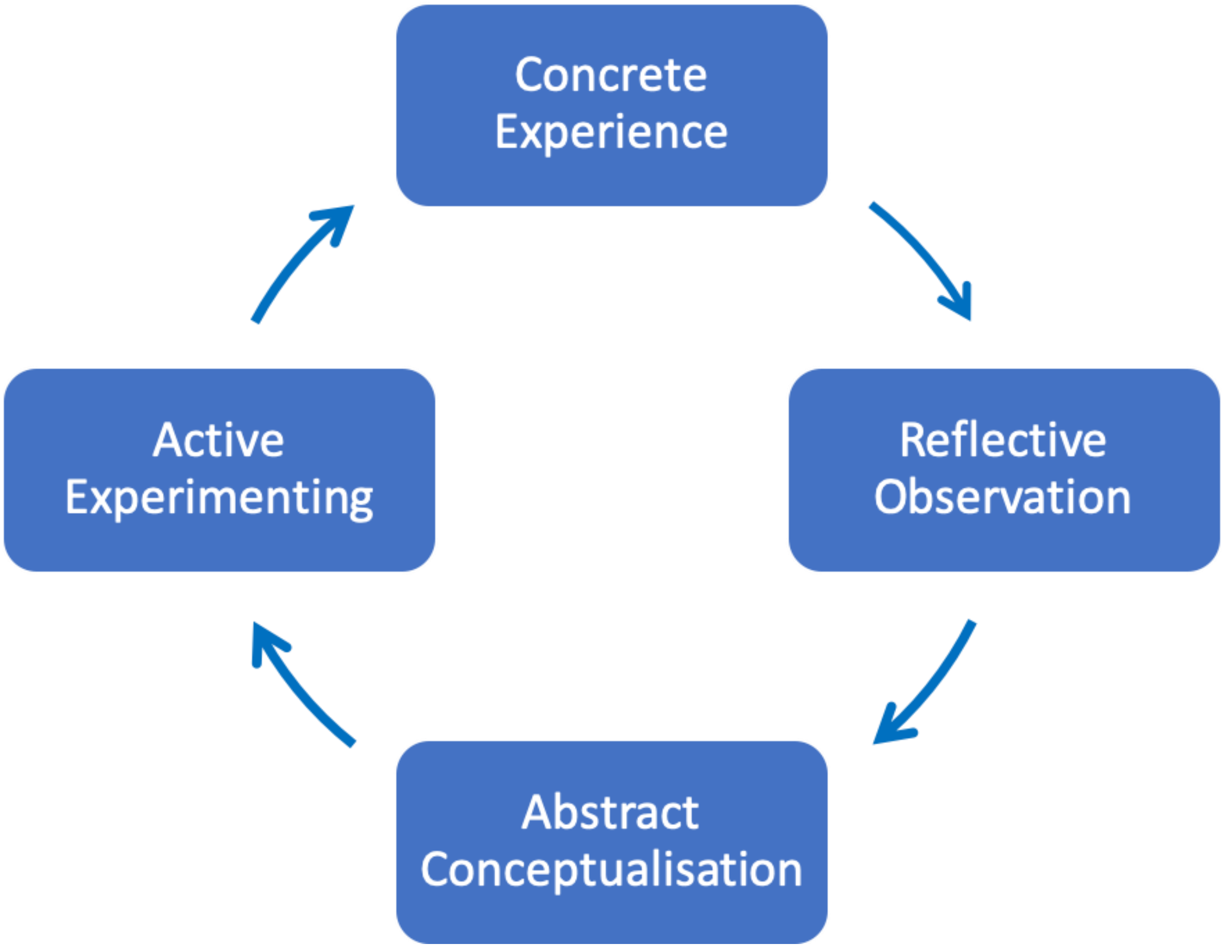
The RETAIN board game and digital game were developed to teach neonatal resuscitation, and thus many of its characteristics overlap nicely with the above principles of adult learning. The RETAIN board game facilitates a collaborative learning environment with learners interacting dynamically with the facilitator and navigating each scenario as a team.[44] Furthermore, the problem-centered format of both the board game and digital game lends itself to autonomous self-directed learning, as learners undertake subsequent scenarios each with its own unique learning objectives.[44]

2.1.2 Experiential Learning

One of the most important adult learning principles is for teaching to be grounded and relevant to the learners' current situations.[52,57] This principle overlaps quite concisely with the central objective of serious games[51], and also informs one of the most significant frameworks in adult learning theory—the experiential learning model.[23,52] In brief, experiential learning occurs when students consolidate their first-hand experiences—rather than theoretical study—into practical knowledge, skills, and strategies.[58] Learners directly interact with the subject matter being studied, rather than just read, hear, talk, or write about it.[59] Importantly, learners engaged in experiential learning report improved understanding[60], performance[61], and enthusiasm.[62] Experiential learning is at the core of many components of continuing medical education, such as residency and continuing clinical practice.[52] Further, experiential learning informs some approaches to undergraduate medical curriculum like the clerkship period.[52]

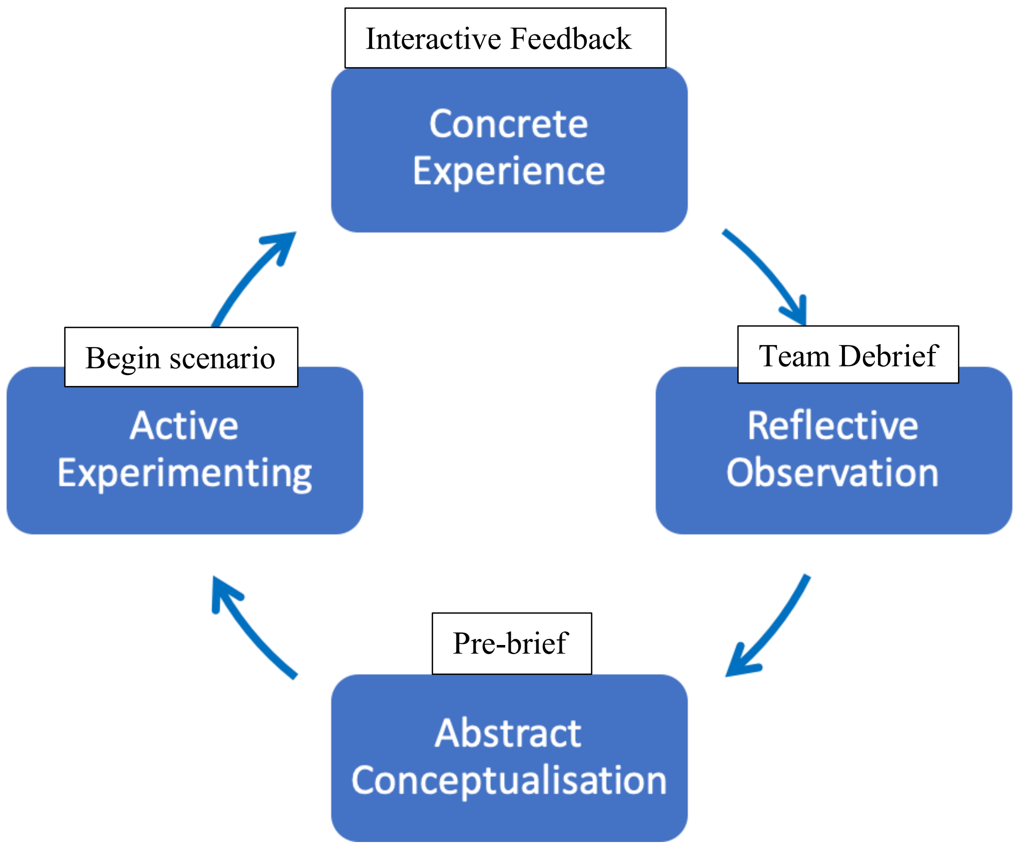
Experiential learning cycles are a four-stage cyclical model to explain adaptive knowledge development, and consist of concrete experiences, reflective observation, abstract conceptualism, and active experimentation (Figure 2-1).[23] SBE which meaningfully utilize Kolb's experiential learning cycles in their design are reported to be the gold standard, by allowing learners to apply their medical knowledge to robust simulated contexts and increase their participation in critical reflection.[63,64]

Figure 2-1 Kolb's learning cycle



Similarly, the simulation-based serious game RETAIN was developed to facilitate experiential learning by providing a structure to scaffold learners into experiential learning cycles.[65] While a thoughtful analysis of educational theory is beyond the scope of this thesis work, the learning objectives of the RETAIN games can be mapped to the stages of the Kolb cycle (Figure 2-2). Understanding that the cycle can start at any point[63,66], in the RETAIN serious games, abstract conceptualization starts with the pre-brief stage. During the pre-brief, learners review information about the patient (e.g., maternal history, perinatal events, etc.) and prepare for delivery by gathering and setting their simulated equipment to the appropriate measurements based on what they expect to encounter during the scenario. In the board game, the pre-brief stage provides an opportunity for learners to communicate as a team, discuss shared expectations, and establish psychological safety.

Figure 2-2 Stages of training with the RETAIN serious games as they correspond to the experiential learning cycle

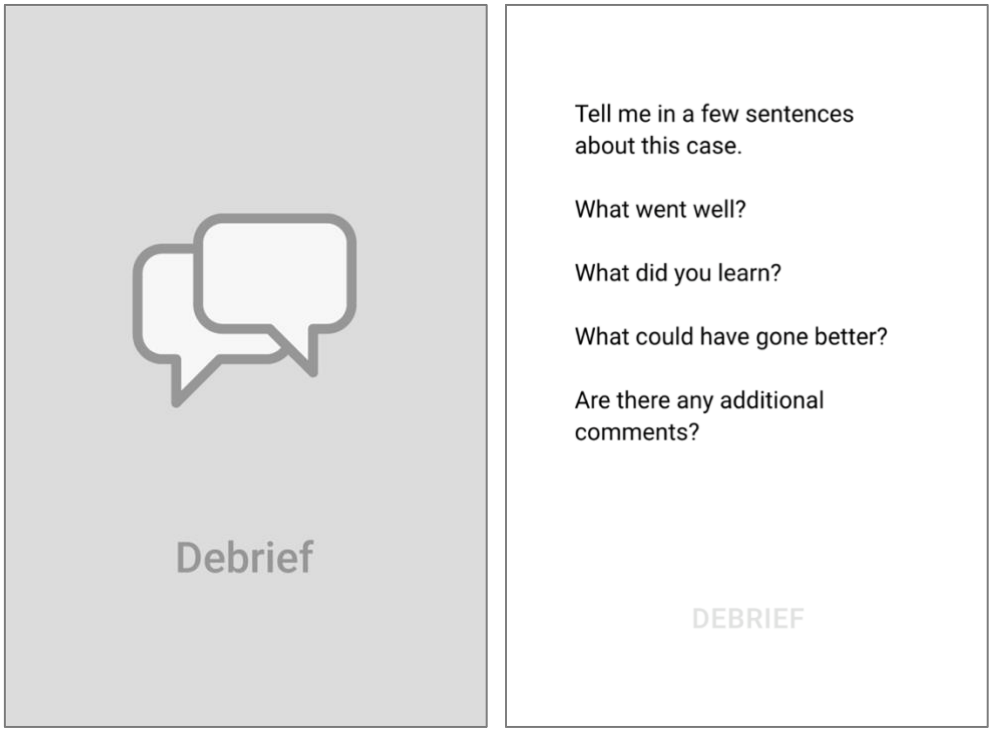


At the start of the scenario when the baby is born, active experimentation is encouraged to begin. Learners, either individually or as a team, apply their knowledge to make decisions within the scenario. Their expectations as to how the case will unfold are either affirmed or challenged, based on the learning objectives of each unique scenario. Simulation-based serious games are an exciting educational approach to encourage active experimentation because within this playful setting, learners can apply their ideas and strategies without consequences for patient safety, nor with the pressures (from peers and supervisors) of traditional SBE.

Feedback about the simulated patient's health (provided by the board game facilitator or within the digital game) creates a shared reference point for learners to understand the validity and implications of their decision-making—providing learners with concrete experience.[63,67] This objective and concrete evaluative feedback (standardized by the facilitator booklet or digital software) allows learners to gauge the success of their experimentation. This explicit feedback about their active experimentation is important to inform the next stage of reflective observation.

During reflective observation, learners review their performance so that they may consider new strategies before beginning the next scenario. In the RETAIN board game in particular, learners review their performance as a group, with the discussion guided by prompting questions on the game cards (Figure 2-3). Dedicated time built into game play allows for learners to synthesize their performance with the support of the facilitator, allowing for meaningful reflective observation rather than rushing straight to the next scenario. In contrast, the digital game has learners reflect on their performance by revieing a post-scenario summary of their time-stamped actions. However, without supervision by an experienced individual, this media may currently lack the support for learners to adequately reflect, which may impact the

Figure 2-3 Example of debrief cards *front* (left) and *back* (right) in the RETAIN board game



educational value of the experience.[23] Moving back to the start of the cycle, as learners generate solutions and strategies to address the problems they faced during the previous scenario, abstract conceptualization begins again. In anticipation of the next scenario, the experiential learning cycle continues.

Despite the limitations of this model[52], experiential learning cycles offer a useful framework to better understand how to support adult HCP learners. This framework can, in turn, be used to inform serious game design and development for healthcare education.

2.2 Research Methods

2.2.1 Objectives

This project aimed to investigate both the RETAIN board game and digital game for neonatal healthcare education. The aim of the first stage of this project was to examine if the RETAIN board game could be used as an objective summative assessment of HCPs' individual neonatal resuscitation competence. The aim of the second stage of this project was to examine if the RETAIN digital game could be used to improve HCPs' short-term and long-term knowledge retention of neonatal resuscitation, and if the knowledge retained could be transferred to a novel learning environment. Overall, throughout these two distinct projects, quantitative and qualitative measurements were collected to ascertain how the RETAIN board game and digital game were perceived by HCP participants (i.e., enjoyment, motivation, and attitudes towards the games).

The current studies were developed and overseen by an interdisciplinary team of clinicians, educational psychologists, designers, computer scientists, and research scientists from the Centre for the Studies of Asphyxia and Resuscitation (Edmonton, Canada).

2.2.2 Research Setting

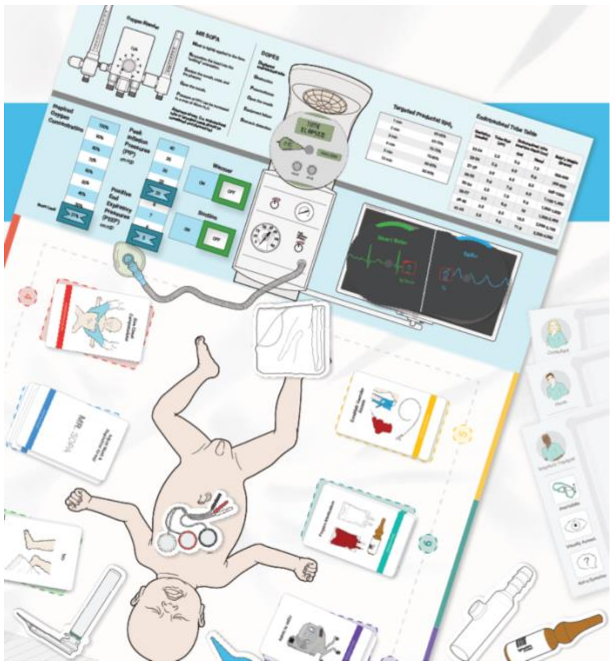
This thesis project was conducted at the Royal Alexandra Hospital (Edmonton, Canada) Neonatal Intensive Care Unit (NICU). This tertiary perinatal center has a robust and highly specialized neonatal program and transport team who provide comprehensive care for critically ill and very premature infants. This site admits more than 350 infants with a birth weight less than 1,500 grams each year, from a total catchment area equivalent to one third of Canada's land mass. Participants were recruited from a population of experienced neonatal HCPs (e.g., registered nurses, respiratory therapists, nurse practitioners, residents, fellows, and consultants) who attend neonatal resuscitations.

2.2.3 Research Design

Neonatal HCPs were eligible to participate in the current studies if they had completed the NRP provider course within 24 months prior to enrolling in the study (as this is the maximum time to maintain provider certification). With the assistance of the on-site research coordinators, a total of 70 on-service HCPs were recruited to participate across the two studies, using convenience sampling dictated by their availability. Throughout recruitment, anonymized information about participants' professional roles was collected and compiled; this information was frequently reviewed to help guide the recruitment process in an aim to ensure the study sample was representative of a typical resuscitation team (both in clinical role and years of experience), and to avoid overrepresentation of any one group (i.e., inadvertently having most participants be very experienced respiratory therapists) to improve validity. To minimize contamination, HCPs were only recruited to participate in one of the two current studies, and were excluded from participating in the other.

Approval for the two simulation studies was obtained by the Human Research Ethics Board at the University of Alberta (Pro00085274, Pro00081221). Written informed consent from HCPs was obtained prior to their participation. Participants were informed that their participation in the studies was voluntary, data collected about their performance would be anonymized immediately using participant ID codes, information about their individual performance would not be shared with their peers or supervisors; and that their refusal to participate would not affect their professional standing.

RETAIN Board Game



2.3 Summative Assessment with the Board Game

2.3.1 Can the Tabletop Simulator be Used for Summative Assessment of HCPs' Knowledge?

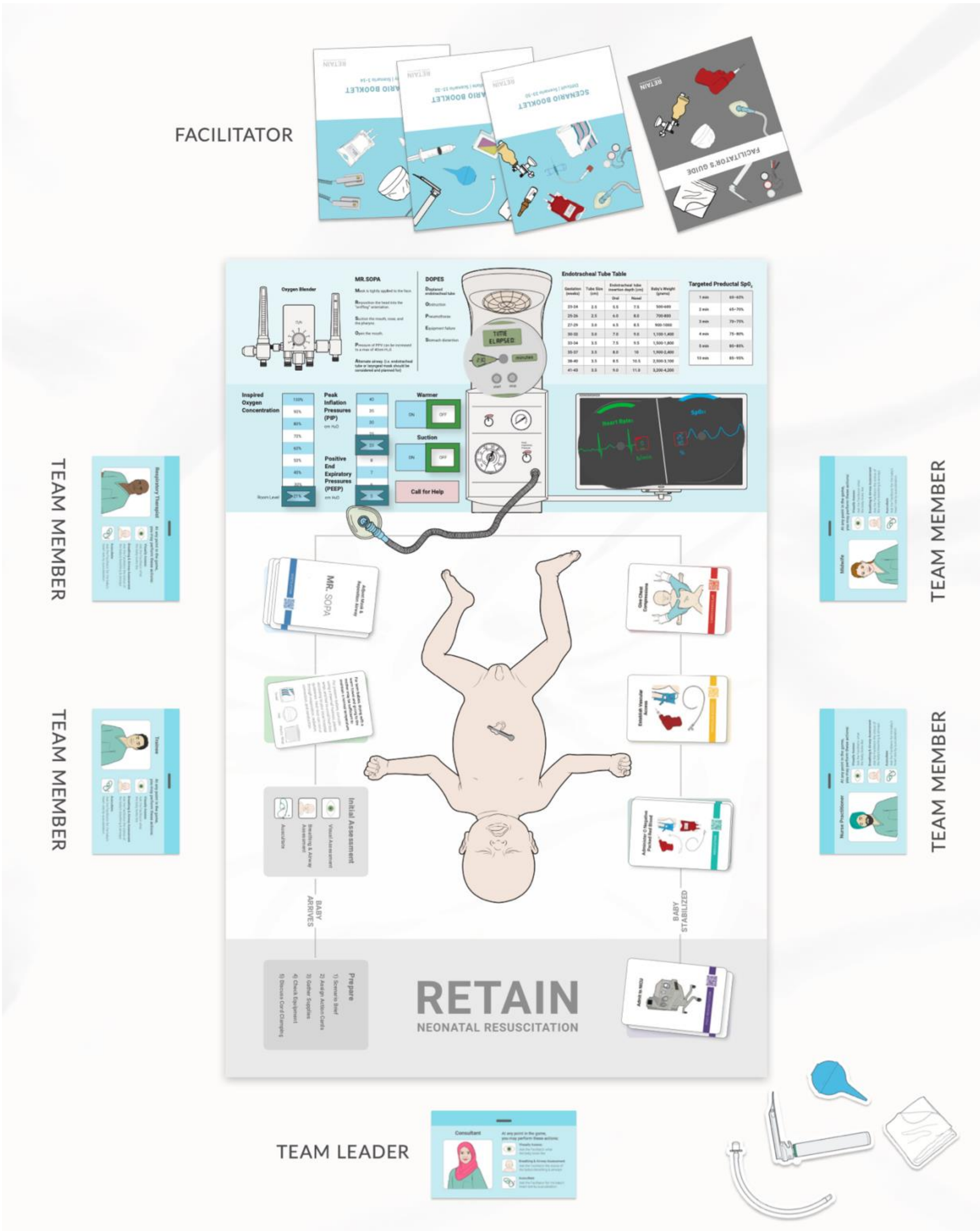
To evaluate if the RETAIN board game could be used as an objective summative assessment of neonatal resuscitation knowledge, intra-participant performance while playing RETAIN was compared to their performance on a traditional written test. The study was conducted over 5 days between October 25 and November 2, 2018, and each session took approximately 30 minutes to complete. The study sessions took place in a private room within the administrative offices of the NICU. Participants completed the sessions alone with the researcher who conducted the observational study. They were not compensated for their participation, apart from receiving a candy bar or baked goods after completing the study, as a token of gratitude for their time. The researcher did not work at the hospital and did not have any interest in or influence over the participants' professional roles. After obtaining informed consent, the study protocol began with participants answering a demographic questionnaire about their clinical role and experience. Next, participants individually completed an open-answer written test, in which they were presented with the following neonatal resuscitation scenario about a newborn 24-week premature infant in fetal distress:

> *26-year-old woman G1P0 with no prenatal care currently at 24 weeks pregnant. The mother received 2 doses of Betamethasone and $MgSO_4$ prior caesarean section due to fetal heart abnormalities. The baby is delivered and receives 60sec of delayed cord clamping. The baby is transferred to the Resuscitation table. What are the next steps?*

Through a series of written prompts providing clinical information about the infant (e.g., heart rate, breathing, etc.), participants were expected to warm (e.g., place hat and plastic wrap), stimulate, perform initial assessment, attach monitoring equipment (e.g., oxygen saturation, heart rate, temperature), initiate positive pressure ventilation, complete ventilation corrective steps, transition to continuous positive airway pressure, and admit the newborn to the NICU (Table 2-1). Participants received no feedback about their performance on the written test.

Immediately after the written test, participants independently completed one scenario with the RETAIN board game (Figure 2-4). The board game was set up on the desk, with equipment pieces and role cards laid out in a single layer to the left of the board, and action cards (grouped in their categories) to the right. The action cards were laid out, so every potential action was always visible to participants as they played the game. Participants underwent a standardized tutorial led by the researcher, to learn how to play the game and become familiar with the action cards and equipment pieces. They were asked to identify each piece of equipment and read through each action card, as well as instructed on how to use the cards and equipment pieces appropriately. At the end of the tutorial, participants were reminded to say all of their thoughts and actions out loud as they played the game, to ensure that their performance was comprehensively measured.

Figure 2-4 The RETAIN board game



After the tutorial, the researcher facilitated the same game scenario for all participants in the study, of an apneic infant with fetal bradycardia. The scenario began with, "*You are called to attend a birth due to fetal bradycardia. How would you prepare for the resuscitation of the baby?*" Through a series of prompts, participants were expected to prepare for the birth, assess, perform initial interventions, initiate positive pressure ventilation/ventilation corrective steps, intubate, perform chest compressions, and admit to the NICU (Table 2-2). The researcher followed the same script for each participant, which included frequent updates of the infant's heart rate, oxygen saturation, and visual appearance. If participants performed the correct interventions, the infant's vitals would improve over time. If participants performed the incorrect interventions, the researcher responded with the same vitals as before (i.e., no improvement nor deterioration of the infant's health). Participants performed all actions independently, so that their individual neonatal resuscitation competence could be assessed objectively. No feedback or assistance was provided, and any questions were addressed by repeating only what was written in the script, or with "I do not have that information". At the end of the scenario, participants were directed to answer four debrief questions (Figure 2-3), followed by a post-game survey. The survey included items about their experience using the RETAIN game, game board habits, growth mindset, and statistical reasoning.

Audiovisual performance while playing the game was captured using a GoPro camera (GoPro, Inc. San Mateo, California). Participants were informed and consented to have the game scenario audio- and video-recorded, so that their simulated neonatal resuscitation performance could be adequately reviewed, coded, assessed, and compared with their pre-test performance. In best efforts to maintain anonymity, the camera was positioned to only capture the board game and participants' hands as they moved through the frame to limit the amount of personal identifying information collected (Figure 2-5).

In the 2 weeks following data collection, the video recordings were transcribed, the survey data was digitized, and participants' performance on both the written pre-test and game scenario was coded and scored. The data analyst was not employed by or associated with the hospital and, therefore, was unlikely to be able to identify any of the HCP participants based on their handwriting, hands, or voices. The answer key for both scenarios was informed by the 7th edition Neonatal Resuscitation Program guidelines[5], and scoring was overseen by an experienced neonatologist and educational psychologist. Actions were scored based on their correct application in the appropriate sequence. To maintain clinical relevance rather than be irrationally punitive, resuscitation actions, which are typically performed simultaneously or in a flexible sequence, were grouped together, and those groups were then ordered to create the answer keys (Table 2-1, 2-3).

Figure 2-5 Example of videorecording to record gameplay while minimizing capture of personal identifying information

Table 2-1 Pre-test simulation scenario of a 24-week infant (written assessment)

Scenario: Your task is to identify the steps needed to react in the following situation: a newborn baby with fetal distress is brought to you.

Medical History: 26-year-old woman G1P0 with no prenatal care currently at 24 weeks pregnant. The mother received 2 doses of Betamethasone and $MgSO_4$ prior caesarean section due to fetal heart abnormalities. The baby is delivered and receives 60 seconds of delayed cord clamping. The baby is transferred to the Resuscitation table.

	Actions	Points
What are the next steps?	1. Hat 2. Wrap 3. Stimulate 4. Visually assess 5. Assess breathing 6. Assess heart rate	+1 +1 +1 +1 +1 +1
The clinical team performs initial assessment: Heart rate (HR) 70/min, blue skin color, and apnea		
What are the next steps?	1. Attach SpO_2 2. Attach ECG 3. Attach temp probe 4. Suction 5. Reposition head	+1 +1 +1 +1 +1
After reassessment: Heart rate (HR) 50/min, blue skin color, and apnea		
What are the next steps?	1. PPV for 60 seconds	+1
After reassessment: HR>100/min, apnea		
What are the next steps?	1. MR SOPA 2. PPV for 60 seconds	+1 +1
After reassessment: HR>120/min, spontaneous breathing with increased work of breathing and grunting		
What are the next steps?	1. Start CPAP 2. Admit to NICU	+1 +1
No further actions are required thereafter		

Table 2-2 Game simulation scenario of an infant with fetal bradycardia (game assessment)

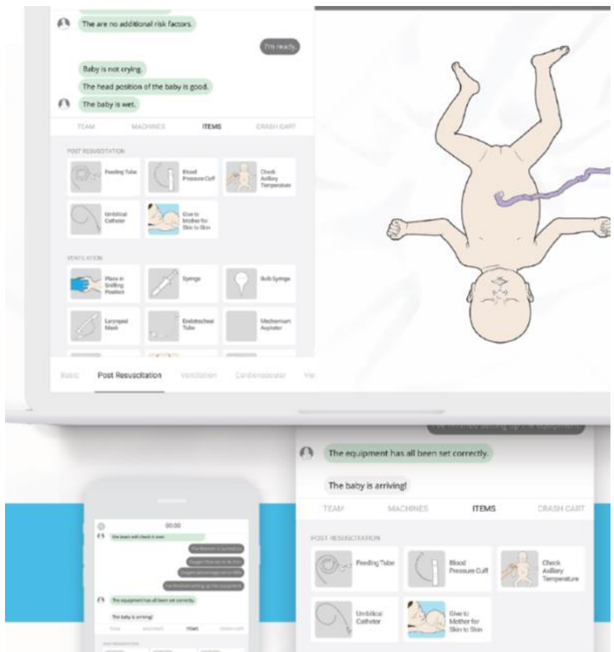
Scenario: You are called to attend a birth due to fetal bradycardia. How would you prepare for the resuscitation of the baby? As you work, say your thoughts and actions aloud so I will know what you are thinking and doing.

Medical History: You are called to attend a birth due to fetal bradycardia for the last 3 minutes. One baby is expected. The fluid is clear.

	Actions	Points
	1. Pre-brief	+1
	1. Assign roles	±1
	2. Call for assistance	+1
What are the next steps?	1. Put on protective equipment	+1
	2. Gather supplies	±1
	3. Check equipment	±1
	4. Set ventilation device	±1
	The baby has been born	
What are the next steps?	1. Visually assess	±1
	The baby appears term, has no tone, and is not breathing	
	1. Tactile stimulation	±1
	2. Dry	±1
What are the next steps?	3. Visually assess	+1
	4. Cord management	±1
	5. Maintain temperature	±1
	6. Suction	+1
	The baby has no tone and is not breathing	
	1. Assess breathing	±1
	2. Measure heart rate	±1
What are the next steps?	3. Initiate PPV	±1
	4. Attach oxygen saturation	+1
	5. Attach temperature probe	+1
	After reassessment: HR 40/min, baby is apneic	
	1. Reassess	±1
	2. MR SOPA	±1
	3. Continue PPV	±1
	4. Reassess	±1
What are the next steps?	5. MR SOPA	±1
	6. Continue PPV	±1
	7. Reassess	±1
	8. MR SOPA	±1

	9. Continue PPV 10. Reassess	±1 ±1
After reassessment: HR 40/min and not increasing, baby is apneic and no chest movement is observed		
What are the next steps?	1. MR SOPA 2. Intubation preparation 1. Confirm tube placement 2. Reintubate	±1 +1 ±1 ±1
After reassessment: Color did change on CO_2 detector on second intubation attempt, HR 40/min and not increasing		
What are the next steps?	1. Call for assistance 2. Oxygen blender to 100% 3. Give chest compressions	±1 ±1 ±1
After reassessment: After 60 seconds of chest compressions, HR increases to 70/min but no spontaneous respirations		
What are the next steps?	1. Stop chest compressions 1. Continue PPV	+1 +1
After reassessment: 5 minutes after birth HR>100/min, oxygen saturation 90%, beginning to have some spontaneous respirations		
What are the next steps?	1. Admit to NICU 2. Update parents	
No further actions are required thereafter		

RETAIN Digital Simulator



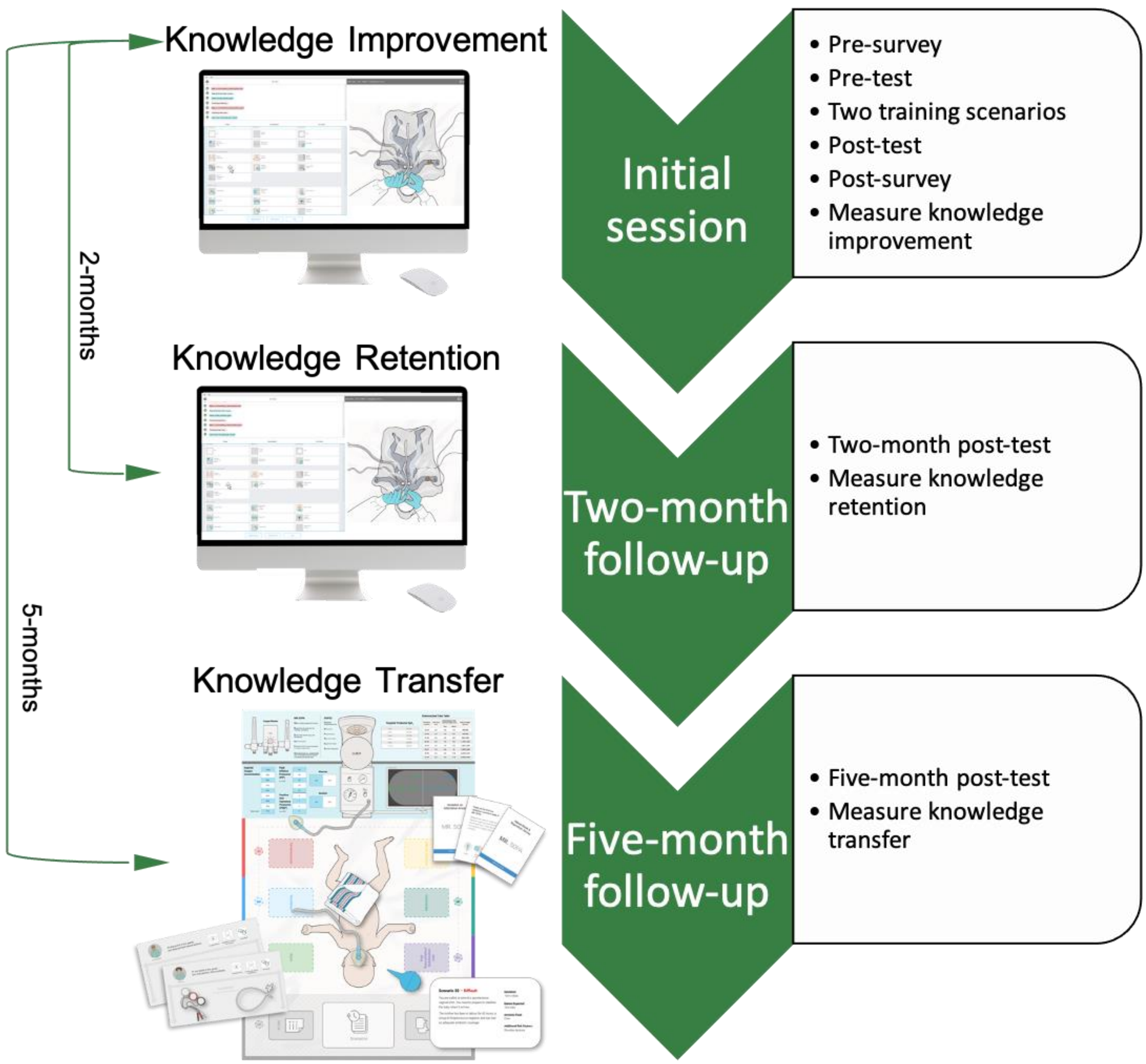
2.4 Training Knowledge with the Digital Simulator

The educational outcomes of training with the RETAIN digital simulator were evaluated in a three-part study to measure 1) immediate knowledge improvement, 2) long-term knowledge retention, and 3) knowledge transfer into a novel learning environment.

2.4.1 Will Training Improve HCPs' Short-term Knowledge?

To evaluate if the RETAIN digital game improves HCPs' short-term neonatal resuscitation knowledge, a pre-post-test study design was used to measure intra-participant performance immediately before and after training (Figure 2-6). The study was conducted over 17 days between May 27-August 7, 2019, with each session taking approximately 30-40 minutes to complete. The study sessions took place in either a private room within the administrative offices of the NICU, in the communal office spaces on the unit (e.g., fellow office, respiratory therapist office, nurse practitioner office, lactation consultant office, etc.), or at the bedside.

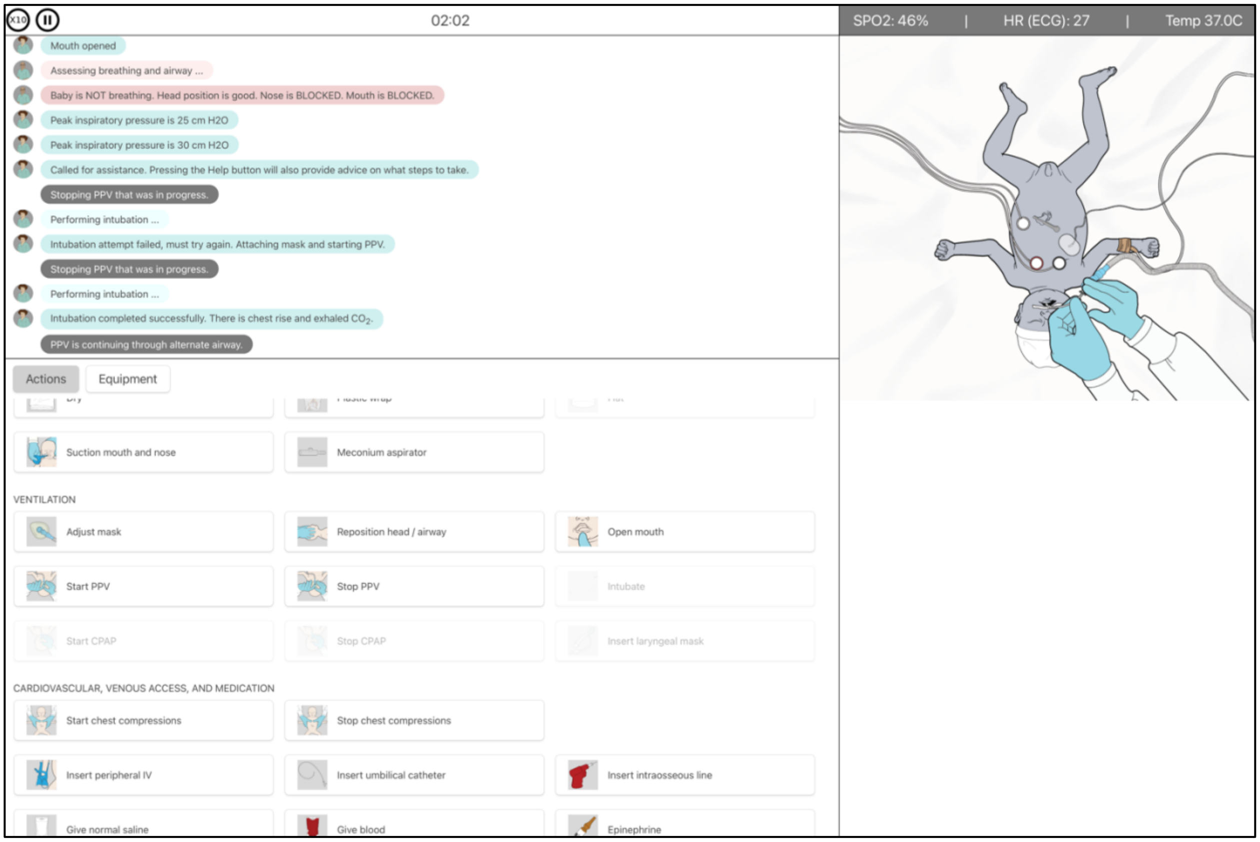
Figure 2-6 Diagram of study design to evaluate the RETAIN digital game



Best effort was made by researchers to ensure that participants were undisturbed and able to complete the study sessions relatively uninterrupted (i.e., covering clinical responsibilities for the participant by delegating their pager to another HCP for the duration of the session). However, in the instances where participants (particularly those undertaking the study at the bedside) were interrupted, a note was made in their data file, and participants were given an opportunity to reacclimate to the digital game before resuming the session.

After obtaining informed consent, the study protocol began with participants answering a demographic questionnaire about their clinical role and experience. The researcher then presented the digital game to participants on a research laptop with an external wired optical mouse (Figure 2-7). Participants underwent a guided tutorial to learn how to use the game, which consisted of an example simulation scenario about a newborn 24-week premature infant in fetal distress. The tutorial required participants to review the case history (e.g., 26-year-old woman G1P0 with no prenatal care currently at 24 weeks pregnant. The mother received 2 doses of Betamethasone and $MgSO_4$ prior caesarean section due to fetal heart abnormalities.), gather their team (e.g., respiratory therapist, neonatal nurse, nurse practitioner, and/or neonatologist), set their equipment appropriately (e.g., turn on radiant warmer, set peak inspiratory pressure to 20 cmH_2O, etc.), and prepare for the birth (don personal protective equipment, assign roles, gather supplies, and check equipment). Once the baby was born, participants browsed the available actions within the game, and practiced choosing different assessments and interventions (e.g., visually assess, apply plastic wrap, attach pulse oximeter, start positive pressure ventilation (PPV), etc.). Throughout the tutorial, participants were encouraged to ask the researcher any questions they had about how to operate the game, prior to beginning the assessment scenarios. Total time to complete the tutorial ranged from between approximately 2-5 minutes.

Figure 2-7 The RETAIN digital game



Once participants confirmed they were ready to begin, they were presented with the digital pre-test assessment simulation scenario (*You are called to attend a birth due to fetal bradycardia. Please prepare for the birth of the baby.*). The scenario was a difficult case example from the NRP textbook, requiring participants to follow the NRP algorithm through PPV to chest compressions (Table 2-3). This scenario was implemented with the aim to assess participants' baseline or incoming knowledge of the neonatal resuscitation algorithm, prior to training with the RETAIN digital simulator. Participants completed the scenario individually with no help, other than for potential technical assistance (e.g., if the computer keyboard or mouse was not working correctly, only then would the researcher help to troubleshoot those issues). The scenario ended if the participants completed the steps of the NRP algorithm correctly so that the health of the simulated infant stabilized, and they could admit the patient to the NICU. If participants completed the steps of the NRP algorithm incorrectly, or in the incorrect order, the health of the simulated infant continued to deteriorate. In this case, the scenario ended once the participant decided to give up and exit (i.e., they did not know what to do next, or had clicked on all of the actions they thought may help but had now exhausted all of the options in the game). To note, in this situation, the game never incorporated death as a punitive outcome in the simulation, as it was not a predefined learning objective of the assessment.[68]

Participants received no feedback after the pre-test scenario, apart from witnessing the binary outcome of successfully admitting to the NICU, or unsuccessfully exiting the scenario (i.e., they did not debrief their performance, review the NRP algorithm, nor receive any instruction).

Immediately after the pre-test scenario, participants independently undertook two training scenarios with the RETAIN digital game. The training scenarios aimed to allow an opportunity for participants to practice their knowledge and decision-making about neonatal resuscitation. While the time taken to complete the two scenarios varied between participants, overall training took approximately 10 minutes to complete. These scenarios ranged from easy (Table 2-4) to intermediate (Table 2-5) and were taken from examples presented in the NRP textbook.[5] The easy case example consisted of a vigorous term newborn, in which participants were informed that they have been "*called to attend a vaginal birth. The mother is in active labor with ruptured membranes. Please prepare for the birth of this baby*." Participants were expected to prepare for the birth, perform initial assessments, take basic steps (e.g., dry, stimulate, warm), and end the scenario by leaving the baby with the mom. The intermediate case example consisted of a "*vaginal birth, with labor progressing rapidly*." To successfully complete this scenario, participants were required to prepare for the resuscitation, perform initial assessments, complete basic steps, provide PPV, and move through ventilation corrective steps (e.g., mask adjustment, reposition head, suction mouth and nose; open mouth, and increase pressure).

After training with the digital game via the two practice simulation scenarios, participants completed a post-test, which consisted of repeating the pre-test scenario (Table 2-3). The post-test scenario aimed to assess changes in participants' knowledge of neonatal resuscitation after training with the digital game. Choosing a difficult scenario for the pre- and post-test allowed for participants to demonstrate their knowledge on a range of learning objectives within neonatal resuscitation simulation education. Repeating the scenario for both the pre- and post-test allowed for more straightforward comparison of participants' performance before and after training. Using two different scenarios for the pre- and post-test may have introduced confound, where any differences measured between performance pre- and post-training may have actually been caused by differences in the assessment scenarios. As was the case with the pre-test, participants completed the scenario independently with no help or assistance, so that their individual performance could be measured objectively.

After completing the post-test, participants filled out a post-session survey, which included items (closed- and open-ended) to collect their feedback about the RETAIN game, growth mindset, digital game usage, experience with educational games, attitudes towards technology, and typical personal technology habits.

Performance data was collected for all participants during all scenarios with the game, including the tutorial, pre-test, 2 practice scenarios, and post-test. The data file generated by this and all simulation scenarios within the RETAIN digital game was a timestamped (by milliseconds) .txt file that listed the actions that users performed, simultaneously with the patient's current heart rate, oxygen saturation, temperature, and other assessment measures and outcomes at that time. The files also listed the binary outcome of whether participants passed or failed each scenario. Participants passed the scenario if their actions were 100% adherent to the answer key (which was based on the NRP algorithm), and participants failed the scenario if their actions were <100% adherent to the answer key.

Participant data was collected and analyzed anonymously as participant ID codes. The only potentially identifying information linked throughout the study was the initial demographic questionnaire (i.e., clinical role, number of years of experience, etc.) which was also marked with participants' ID code. Due to the longitudinal nature of the study investigating the RETAIN digital game, a master list was necessary to keep track of participation over time. The master list was organized by only one researcher who was not associated with the hospital in any way. The master list contained minimal information about the date of each study session, participants' ID code, and participants' first name and last name initial (e.g., Sarah G.).

2.4.2 Will HCPs experience Long-term Knowledge Changes After Training?

To evaluate whether the RETAIN digital game improves HCPs' long-term retention of neonatal resuscitation knowledge, a 2-month follow-up session was conducted to measure participants' performance after initial training (Figure 2-6). The study was conducted over 18 days between July 29 and November 25, 2019, with each session taking approximately 10-15 minutes to complete. Once again, the sessions took place either in a private room (NICU administrative office), semi-private room (communal professional office on the unit), or at the bedside (to accommodate HCPs' responsibilities), and support was provided where possible to ensure that participants were able to complete the session relatively uninterrupted and privately.

The researcher arranged a time to meet each participant in a comfortable location to complete the follow-up session. This arrangement was done with the help of a research nurse, research respiratory therapist, or research clinician, who worked at the site. The research HCP reviewed the names of the participants who were due for their follow-up, who then did a walk-through of the NICU to see if any of those participants were on-service, and approached them to organize a time. The research HCPs also consulted the NICU schedule to see when those participants were expected to be working in the upcoming days, in order to make a tentative plan for scheduling sessions for the upcoming week. Best effort was made to ensure that participants underwent their follow-up session exactly 2 months after the initial session, however due to scheduling and clinical demands, this was not always possible. Researchers allowed for moderate flexibility in scheduling follow-up sessions by a few weeks. However, if the follow-up session could not be reasonably arranged within this time period, those participants were dropped from the study.

At the start of the follow-up session, the researcher reviewed the aims of the study with participants, and talked them through the expectations of the current session. The researcher presented the digital game to each HCP, and allowed them to informally reacclimate themselves to the digital game. The researcher reviewed how to navigate the game, and reminded participants about the available actions and information provided within the scenario. When participants confirmed that they were comfortable with proceeding, then the assessment scenario would begin. For the 2-month follow-up post-test, participants independently repeated the pre- and post-test from the initial session (Table 2-3), however they were not explicitly informed that it was the same assessment scenario from the initial session. The same protocol as the pre- and post-test was applied, and data was collected in the same way. No feedback was provided during or after the scenario, nor was there a post-assessment survey administered. To note, participants had no access to the digital game in between the initial and follow-up sessions. The game was downloaded only on the research laptop used in the study, which was kept locked in a cabinet in a private office in the NICU administrative wing. The only neonatal resuscitation training that participants undertook as part of the study were the 2 digital simulation practice scenarios from the initial session.

2.4.3 Will Training Facilitate HCPs' Knowledge Transfer to a Novel Environment?

The third and final phase of the current study examined whether training with the digital simulator allowed for HCPs to ultimately transfer their knowledge to a novel simulation environment. To measure knowledge transfer, the table-top simulation-based RETAIN board game was used, as the game had been investigated (in the first study presented in this thesis) as a summative assessment tool.

To understand if the RETAIN digital game facilitated knowledge transfer, a 5-month follow-up session (i.e., 5-months after the initial session) was conducted to measure participants' performance using the RETAIN board game (Figure 2-6). The study was conducted over 15 days between November 12, 2019 and January 9, 2020, with each session taking approximately 15-20 minutes to complete. As in the previous two sessions within this study, these sessions mostly took place in a private office (e.g., the NICU research office, communal professional office) or sometimes at the bedside (as the board game was much more cumbersome than the laptop to set up at the small bedside stations). Similar arrangements were made to schedule the 5-month follow-up session as was described above for the 2-month follow-up session.

To begin the 5-month follow-up session, the researcher presented participants with the board game, and led a brief tutorial to review the instructions, role cards, equipment pieces, action cards, and other elements important to gameplay. Participants were allowed a few minutes to familiarize themselves with the game format, and practice using the action and equipment pieces. Once participants indicated they were ready to proceed, the study protocol began, and participants were presented with the 5-month knowledge transfer assessment. This assessment simulation scenario consisted of a difficult case based on a delivery recorded at the Royal Alexandra Hospital. The case was presented verbally by the researcher as:

> *Please prepare for the birth of the baby by completing set-up, assigning roles, checking equipment, and reviewing the medical history. Once the baby is born, you and your hypothetical team must stabilize the baby. Throughout the scenario, please say your thoughts and actions aloud to demonstrate what you are thinking and doing. The pre-brief checklist consists of 1) term gestation, 2) one baby expected, 3) meconium-stained fluid, and 4) no additional risk factors that your team is aware of.*

The scenario required participants to follow the NRP algorithm through chest compressions, including establishing vascular access and administering medication (Table 2-6). As this scenario was administered with the aim to assess participants' knowledge transfer from their training with the digital game to the novel board game environment, it was the most difficult and advanced scenario, and was presented in a different format than the previous digital scenarios.

Participants completed the scenario individually, with no formative feedback from the facilitator nor help from any teammates. The facilitator (researcher) guided each participant through the scenario by providing information about changes in the simulated patient's oxygen saturation and heart rate, as well as other information obtained from participant-initiated assessments (e.g., the patient's visual appearance). The scenario ended if participants successfully completed each step of the NRP algorithm correctly to admit the infant to the NICU, or if the resuscitation attempt failed due to incorrect actions taken. Performance data was collected by the researcher using a written checklist based on the NRP guidelines (Table 2-6).[5]

The data from the digital game assessment scenarios and board game assessment scenario was analyzed, coded, and scored using a binary pass or fail grade, where pass indicated 100% adherence to the NRP algorithm and fail indicated <100% adherence to the NRP algorithm. A binary score system was chosen as the digital game allowed for users to incorrectly deviate from the algorithm, which would cause the infant's health to deteriorate. In this case, participants would react by potentially deviating further from the answer key set out for the scenario. For example, if the learning objective of a digital scenario was to successfully administer continuous positive airway pressure, but a participant was to pre-emptively provide chest compressions, the simulated infant in the digital game would potentially respond negatively (i.e., poor heart rate and oxygen saturation). In response, this participant may escalate by establishing vascular access and providing medication—thereby deviating further from the intended learning objectives (and thus, answer key) for this scenario. Therefore, to avoid these complicated situations, the binary pass/fail was determined to be an appropriate outcome measure. To make comparisons between the digital assessment scenarios and the board game assessment, a pass/fail score was also assigned to the 5-month knowledge-transfer board game assessment as well.

As was with the previous study examining the board game as a summative assessment, the individual performing the data analysis for this study was not employed by the hospital from which the study participants were recruited, and thus did not have any influence or interest in their performance from a professional standpoint. To reiterate, the answer key used for all of the assessment scenarios in this three-phase study was developed by an experienced neonatologist and educational psychologist, and informed by the NRP textbook and neonatal resuscitation algorithm.[5]

Table 2-3 Difficult pre-post-2-month-test digital simulation scenario

Scenario: *"You are called to attend a birth due to fetal bradycardia. How would you prepare for the resuscitation of the baby?"*	
NRP	**RETAIN**
Preparation for Resuscitation	*Set it Up*
Assessment of Perinatal risk: Gestation? **Term** Fluid clear? **Fluid is clear** Number of babies? **One baby is expected** Additional risk factors? **Fetal bradycardia for the last 3 minutes**	Assign Roles Gather Supplies Pre-Brief Check Equipment Put on protective equipment Set ventilation device Call for assistance
The baby has been born	
Rapid Evaluation and Initial Steps	*Basic Steps*
Term? **Appears term** Tone? **No tone** Breathing or Crying? **No breathing** Positions, suctions, dries, stimulates… Vital Signs: Checks breathing – **Baby is apneic**	Dry Tactile Stimulation Maintain Temperature Measure Oxygen Saturation Measure Temperature Measure Blood Pressure Measure Heart Rate Cord Management
Positive Pressure Ventilation	*Ventilation*
Begins PPV Within 15 seconds requests to check HR rising **HR is about 40 bpm, not increasing** Assess chest movement: PPV 15 seconds, **no chest movement observed**, proceed through MR. SOPA, PPV 30 seconds, **still no chest movement** – indicate need for alternative airway (intubation or laryngeal mask placement) Checks heart rate **HR about 40 BPM, still not increasing**	Initiate PPV MR Adjust Mask and Reposition Airway SO Suction Airway and Open Mouth P Adjust Ventilation P (max 40 cm H_2O)
Reassessment: HR is 40 bpm and not increasing, pulse oximetry is not detecting a signal	

Scenario (continued)**:** *"You are called to attend a birth due to fetal bradycardia. How would you prepare for the resuscitation of the baby?"*

NRP	RETAIN
Alternative Airway	*Ventilation*
Intubates (endotracheal tube, 3.5 mm) Checks CO_2 detector color change/HR/mvmt Checks tip to lip insertion depth Secures endotracheal tube/laryngeal mask **Color is not changing on the CO_2 detector and HR not increasing** Remove device, resume PPV, repeat insertion **Color is changing on the CO2 detector, pulse oximetry is not detecting a signal** Continue PPV 30 seconds, check/secure tube	A Establish Alternative Airway Intubation preparation Confirm correct tube placement
Reassessment: HR is 40 bpm and not increasing, pulse oximetry is not detecting a signal	
Chest Compressions	*Cardiovascular*
Calls for additional help if necessary Increase oxygen concentration to 100% Compress Sternum 1/3 AP diameter of chest PPV administered during pause	Give chest compressions
Reassessment: The HR is 70 bpm and rising, pulse oximetry is starting to detect a signal, no spontaneous respirations	
PPV without compressions	*Ventilation*
Discontinue chest compressions PPV continuer, higher ventilation rate 40-60 Adjust oxygen concentration per oximetry	Stop chest compressions
Reassessment: The heart rate is >100 bpm. Oxygen saturation is 78%. No spontaneous respirations	
Vital Signs	*Post Resuscitation*
Continues PPV and adjusts oxygen **HR is >100 bpm. Oxygen sat is 90%, tone is improving, beginning to have some spontaneous respirations** Prepares for transport to nursery Updates parents	Admit to NICU Transfer to mother

Abbreviations: AP (anteroposterior), HR (heart rate), NICU (Neonatal Intensive Care Unit), NRP (Neonatal Resuscitation Program), PPV (positive pressure ventilation).

Table 2-4 Easy practice digital simulation scenario

Scenario: *"You are called to attend a vaginal birth. The mother is in active labor with ruptured membranes. How would you prepare for the birth of this baby?"*

NRP	**RETAIN**
Preparation for Resuscitation	*Set it Up*
Assessment of Perinatal risk:	Assign Roles
Gestation? **39 weeks gestation**	Gather Supplies
Fluid clear? **Fluid is clear**	Pre-Brief
Number of babies? **One baby is expected**	Check Equipment
Additional risk factors?	Put on protective equipment
There are no additional risk factors	Set ventilation device
	Call for assistance
The baby has been born	
Rapid Evaluation and Initial Steps	*Basic Steps*
Term? **Yes**	Dry
Tone? **Yes**	Tactile Stimulation
Breathing or Crying? **Crying**	Maintain Temperature
	Measure Oxygen Saturation
Newborn stays with mother for initial steps	Measure Temperature
Dries, skin-to-skin, cover with blanket	Measure Heart Rate
Evaluate breathing, HR, tone, color, temp	Cord Management
Vital Signs	*Post Resuscitation*
Newborn stays with mother	Transfer to mother

Abbreviations: HR (heart rate), NRP (Neonatal Resuscitation Program).

Table 2-5 Intermediate practice digital simulation scenario

Scenario: *"You are called to attend a vaginal birth. Labor is progressing rapidly. Demonstrate how you would prepare for the birth of this baby."*

NRP	RETAIN
Preparation for Resuscitation	*Set it Up*
Assessment of Perinatal risk:	Assign Roles
Gestation? **38 weeks gestation**	Gather Supplies
Fluid clear? **Fluid is clear**	Pre-Brief
Number of babies? **One baby is expected**	Check Equipment
Additional risk factors?	Put on protective equipment
Mom has pregnancy-induced hypertension and labor has been induced at 38 weeks' gestation. Several fetal heart rate decelerations have been noted.	Set ventilation device Call for assistance
The baby has been born	
Rapid Evaluation and Initial Steps	*Basic Steps*
Term? **Appears term**	Dry
Tone? **No tone**	Tactile Stimulation
Breathing or Crying? **No breathing**	Maintain Temperature
	Measure Oxygen Saturation
Positions, suctions, dries, stimulates…	Measure Temperature
Vital Signs:	Measure Blood Pressure
Checks breathing – **Baby is apneic**	Measure Heart Rate
Indicates need for PPV	Cord Management
Positive Pressure Ventilation	*Ventilation*
Begins PPV	Initiate PPV
Within 15 seconds requests to check HR rising	MR Adjust Mask and Reposition Airway
HR is about 40 bpm, not increasing	
Assess chest movement:	SO Suction Airway and Open Mouth
PPV 15 seconds, **no chest movement observed**	P Adjust Ventilation P (max 40 cm H_2O)
Proceed through MR. SOPA, PPV 30 seconds	

Reassessment: Chest is moving with PPV, HR 120/min, oxygen saturation 64%, occasional respiratory effort

Scenario (continued)**:** *"You are called to attend a vaginal birth. Labor is progressing rapidly. Demonstrate how you would prepare for the birth of this baby."*

NRP	RETAIN
Positive Pressure Ventilation	*Ventilation*
Continues PPV, Directs FiO_2 per oximetry	Continue PPV
Reassessment: HR 140/min, oxygen saturation is 74%, increasing spontaneous respiratory effort, muscle tone improving	
Positive Pressure Ventilation	*Ventilation*
Gradually discontinues PPV	Give chest compressions
Reassessment: HR 140/min, strong and consistent spontaneous respiratory effort	
Vital Signs	*Post Resuscitation*
Monitor HR, breathing, oxygen saturation, temperature Plans post-resuscitation care Updates parents Prepares for transport to nursery	Transfer to mother

Abbreviations: bpm (beats per minute), FiO_2 (fraction of inspired oxygen), HR (heart rate), NRP (Neonatal Resuscitation Program), PPV (positive pressure ventilation)

Table 2-6 Difficult knowledge transfer simulation scenario

Scenario: The case history is presented on Scenario 41 card. Please prepare for the birth of the baby by completing each set-up step (including assigning roles, checking the equipment, and reviewing the medical history). Once the baby is born, you and your team must stabilize the baby. Throughout the scenario (including set-up and stabilization/resuscitation of the baby), say your thoughts and actions aloud to demonstrate what you are thinking and doing. The scenario is complete when the baby is stabilized, or the attempt has failed.

	Actions	
What are the next steps?	1. Pre-brief 2. Assign roles 3. Call for assistance 4. Put on protective equipment 5. Gather supplies 6. Check equipment 7. Set ventilation device	Gestation? Term Number of babies? One baby expected Fluid clear? Meconium stained Additional risk factors? No information that the team is aware of The plan for the cord will be immediate cord clamping
	The baby has been born	
What are the next steps?	1. Visually assess	
	The baby is apneic, airways are blocked with meconium, and the baby has no muscle tone	
What are the next steps?	1. Tactile stimulation 2. Dry 3. Visually assess 4. Cord management 5. Maintain temperature 6. Suction	
	The baby has no tone and is not breathing	
What are the next steps?	1. Assess breathing 2. Measure heart rate 3. Initiate PPV 4. Attach oxygen saturation 5. Attach temperature probe	
	After reassessment: HR 37/min, baby is apneic	
What are the next steps?	1. Reassess 2. MR SOPA 3. Continue PPV 4. Reassess	

	5. MR SOPA 6. Continue PPV 7. Reassess 8. MR SOPA 9. Continue PPV 10. Reassess
After reassessment: HR 33/min and no chest movement is observed	
What are the next steps?	1. MR SOPA 2. Intubation preparation 3. Confirm correct tube placement
After reassessment: Chest rise, misting, and color change on CO_2 detector, HR 42/min	
What are the next steps?	1. Call for assistance 2. Oxygen blender to 100% 3. Give chest compressions
After reassessment: After 60 seconds of chest compressions, HR is 43/min but no spontaneous respirations	
What are the next steps?	1. Establish vascular access 2. Continue chest compressions 3. Administer medication (1st dose of epinephrine)
After reassessment: HR is 89/min	
What are the next steps?	3. Admit to NICU 4. Update parents
No further actions are required thereafter	

Changes in oxygen saturation and heart rate over first 10 minutes after birth

Time (mins)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SpO_2	*31*	*30*	*33*	*34*	*43*	*46*	*52*	*66*	*70*	*97*
HR	*37*	*38*	*42*	*42*	*49*	*89*	*125*	*132*	*137*	*141*

Abbreviations: HR (heart rate), NICU (Neonatal Intensive Care Unit), PPV (positive pressure ventilation), SpO_2 (oxygen saturation)

2.5 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics (IBM, Armonk, NY) and RStudio (RStudio Inc., Boston, MA). Participants' survey, questionnaire, and performance data were recorded, coded, analyzed, and compared within studies. Scenario performance was scored using the 7th edition NRP textbook.[5]

In the summative assessment study, the *written assessment* measure represents a participant's cumulative score across all actions, interventions, or tasks described by the participant in the open-answer written simulation scenario assessment. The maximum score for each participant was 16 points, when all actions, assessments, interventions, and tasks were answered correctly (range from 0 to 16). For each correct action indicated on the written assessment, participants were assigned one point (no points were deducted for an incorrect answer) as shown in Table 2-1. The *game assessment* measure represents a participants' cumulative score across all actions, interventions, or tasks indicated or described by the participant within the game session with the RETAIN board game. The maximum score for each participant was 40 points, when all actions, assessments, interventions, and tasks were answered correctly (range from 0 to 40). For each correct action performed, participants were assigned one point. For each incorrect action, participants were either deducted zero points or one point, depending on the severity of the action, as indicated in the answer key (Table 2-2).

In the digital study, the *pre-test* measure represents participants' outcome on the difficult digital simulation scenario administered prior to training. The *post-test* measure represents participants' outcome on the same difficult simulation scenario, administered at the timepoint immediately after undergoing the practice scenarios within the RETAIN digital game. The *2-*

month post-test measure represents participants' outcome on the same difficult simulation scenario, administered at the timepoint 2 months after completing the initial study session. The *5-month post-test* measure represents participants' outcome on the knowledge transfer task (simulation scenario presented with the RETAIN board game) administered at the timepoint 5 months after completing the initial study session. All 4 measures used a binary outcome to measure performance.

Descriptive analyses were conducted of the demographic and survey questionnaire data, and performance measures to determine whether performance outcomes were correlated or changed over time were carried out. Outcome parameters were compared using the appropriate tests for parametric, continuous, and/or categorical variables. *P*-values were 2-sided and $p<0.05$ was considered significant. Data for continuous variables are presented as median(interquartile range [IQR]) or mean(standard deviation [SD]).

Chapter 3: Results

3.1 Tabletop Simulator for Summative Assessment of HCPs

3.1.1 Demographic Information

Participants were n = 20 HCPs (19 female and 1 male; 8 neonatal nurses, 4 neonatal nurse practitioners, 4 neonatal respiratory therapists, and 4 neonatal fellows), as shown in Table 3-1. All HCPs recruited for the study did participate and completed informed consent. As per recruitment guidelines, all participants had completed NRP-recertification within the last 24 months, with the median(IQR) number of months elapsed since recertification being 6(1-10.5) months (range of 1-24 months elapsed). HCPs had different levels of experience providing neonatal care, ranging between 6 months to 30 years of experience, and median(IQR) of 10.5(3-17) years.

Three participants reported their highest level of education completed as a diploma program, 6 completed a bachelor's degree, 2 completed an after-degree (e.g., after-degree nursing program), 4 completed a master's degree, 4 completed an undergraduate medical degree, and 1 participant reported "Other".

Table 3-1 Demographic information of HCP participants for board game study

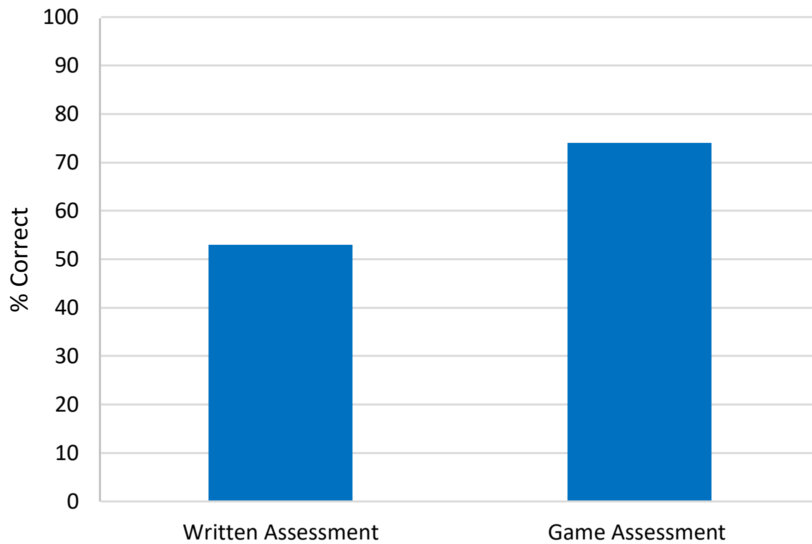
Item		Participants (n%)	Median(IQR)
Gender	*Male*	1 (5%)	
	Female	19 (95%)	
Time since last NRP course	*Less than 6 months*	10 (50%)	6(1-10.5) months
	Between 6-18 months	8 (40%)	
	Between 19-24 months	2 (10%)	
Education completed	*Diploma*	3 (15%)	
	Bachelor's	6 (30%)	
	After-degree	2 (10%)	
	Master's	4 (20%)	
	Medical degree	4 (20%)	
	Other	1 (5%)	
Clinical role	*Nurse*	8 (40%)	
	Nurse practitioner	4 (20%)	
	Respiratory therapist	4 (20%)	
	Fellow	4 (20%)	
Clinical experience	*Less than 1 year*	1 (5%)	10.5(3-17) years
	2-5 years	5 (25%)	
	6-10 years	3 (15%)	
	11-20 years	8 (40%)	
	More than 20 years	3 (15%)	

3.1.2 Performance Outcomes

Overall, participants' score on the *written assessment* had mean(SD) 8.6(2.1) out of a total possible score of 16 points (53%). In comparison, the overall participants' score on the *game assessment* had mean(SD) 29(3.2) out of a total possible score of 40 points (74%), as shown in Figure 3-1. Non-significant Shapiro-Wilk normality tests revealed that all performance variables were normally distributed.

This difference in the total number of points available in each scenario can be attributed to the unique characteristics of each of the assessment media. Due to the hand-written open-answer nature of the *written assessment*, the total number of points was 16 (i.e., the number of bullet-point actions participants needed to indicate they would perform in order be successful in the simulated scenario). In contrast, due to the nature of gameplay, the *game assessment* necessitated participants to engage in many more individual actions due to the specificity of each action card (e.g., in the *written assessment*, ventilation corrective steps were represented as correctly writing the mnemonic acronym MR SOPA [1 point], whereas in the *game assessment*, ventilation corrective steps were represented by correctly playing 6 action cards [6+ points]). Moreover, the *game assessment* was a more difficult and therefore a lengthier scenario than the *written assessment*.

Figure 3-1 Overall performance on the written assessment and game assessment



Beyond this overall raw measure, there were 10 clinically relevant and specific actions that were shared between the *written assessment* and *game assessment* (Table 3-2). Performance on these shared actions had mean(SD) 7.2(1.3) (72%) on the *written assessment* and 8.8(1.4) (88%) on the *game assessment*. Participants' scores on the *game assessment* were significantly higher than on the *written assessment* for the 10 shared actions, when analyzed using a non-parametric Wilcoxon paired *t*-test ($V=17$, $p<0.01$) (Figure 3-2). Performance scores on these shared actions were only weakly correlated across both assessment media ($r=0.14$).

To understand these results in a third context, beyond the overall raw measure and 10 shared actions, scores can also be compared using a pass-fail outcome. When comparing performance on the *game assessment* and *written assessment* using a passing score of 65% (where scores ≥65% are assigned a pass outcome, and scores <65% are assigned a failure outcome), significantly more participants passed the *game assessment* (19/20 participants, 95%) compared to the *written assessment* (14/20 participants, 70%) when analyzed using a paired samples *t*-test ($p<0.01$). To note, a cut-off score of 65% was chosen as this standard is used to score the United States Medical Licensing Examination.[69]

Looking more closely, differences between specific actions undertaken in both assessments were considered. On the *written assessment*, all HCPs (20/20) correctly wrote the ventilation corrective acronym MR SOPA, whereas 18 out of 20 HCPs correctly played all six ventilation corrective steps in the *game assessment*. Moreover, the format of the *game assessment* allowed for further probing in comparison to the *written assessment*. When prompted to explain what actions MR SOPA referred to (i.e., Mask adjustment, Reposition airway, Suction mouth and nose, Open mouth, direct Pressure, and establish an Alternate airway), only 15 out of

20 HCPs correctly answered all 6 actions (an example of an incorrect answer would be attributing “provide Oxygen” to “O” rather than “Open mouth”).

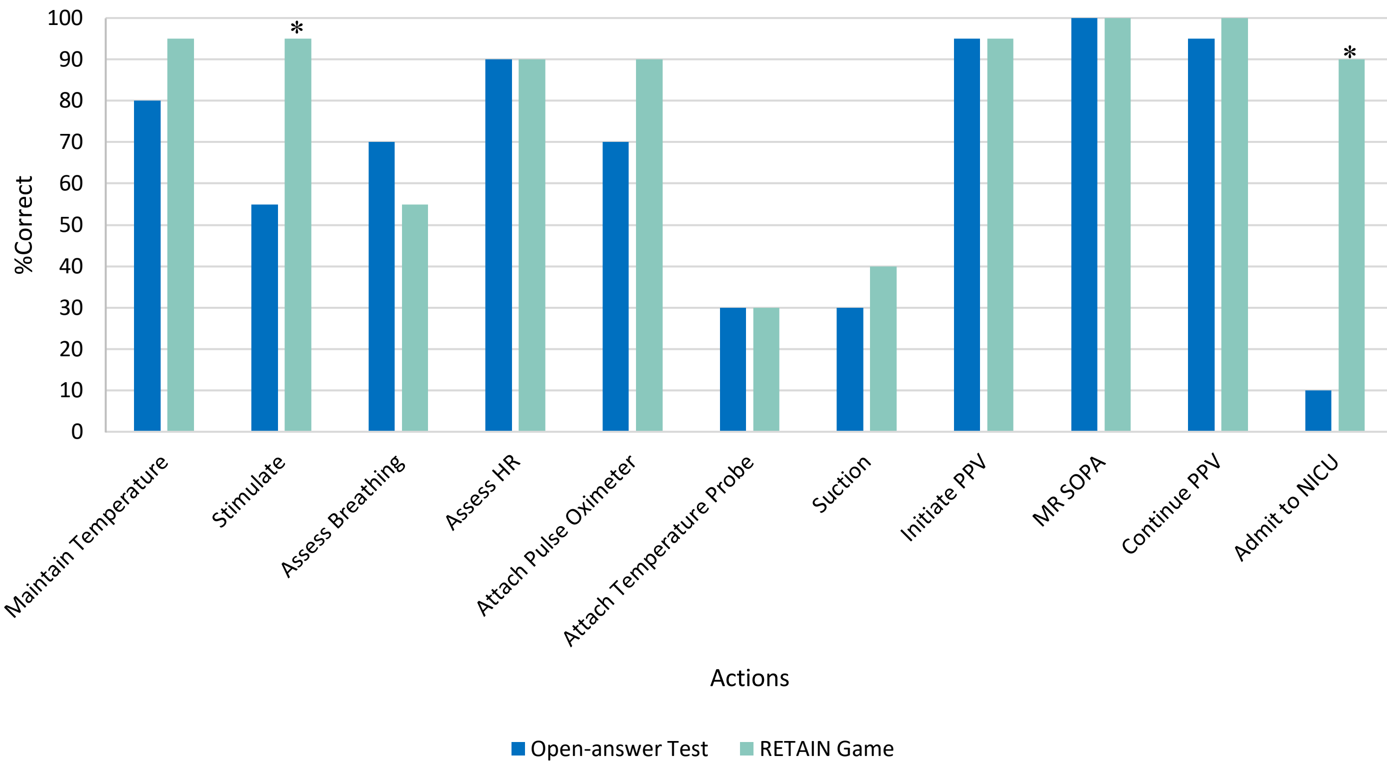
There was no significant difference in participants’ performance on the actions of assessing breathing (p=0.32), maintaining temperature (p=0.08), attaching pulse oximeter (p=0.11), or providing suction (p=0.42); and no difference in assessing heart rate or initiating PPV (Table 3-2) across the assessments. However, the basic resuscitation step of stimulating the patient was performed more frequently in the *game assessment* compared to the *written assessment* (p<0.01). As well, HCPs more frequently indicated they would admit the infant to the NICU in the *game assessment* compared to the *written assessment* (p<0.001). However, this could have been caused by participants’ misunderstanding of the expectations of the *written assessment*, rather than being a clinically relevant difference between the assessment methods.

Table 3-2 Performance on actions shared between the written assessment and game assessment

Action	Written assessment	Game assessment
	n (%) correct	*n (%) correct*
Maintain temperature	16 (80%)	19 (95%)
Stimulate	11 (55%)	19 (95%) *
Assess breathing	14 (70%)	11 (55%)
Assess heart rate	18 (90%)	18 (90%)
Assess oxygen saturation	14 (70%)	18 (90%)
Attach temperature probe	6 (30%)	6 (30%)
Suction	6 (30%)	8 (40%)
Initiate PPV	19 (95%)	19 (95%)
MR SOPA	20 (100%)	20 (100%)
Continue PPV	19 (95%)	20 (100%)
Admit to NICU	2 (10%)	18 (90%) *

**indicates significant difference in performance between assessments (p value <0.05)*

Figure 3-2 Performance on shared actions across the written assessment and game assessment



*Abbreviations: HR (heart rate), PPV (positive pressure ventilation), MR SOPA (mnemonic acronym for ventilation corrective steps), NICU (Neonatal Intensive Care Unit). *indicates significant difference in performance between assessments (p value <0.05)*

3.2 Digital Simulator Improves HCPs' Short-term Knowledge

3.2.1 Demographic Information

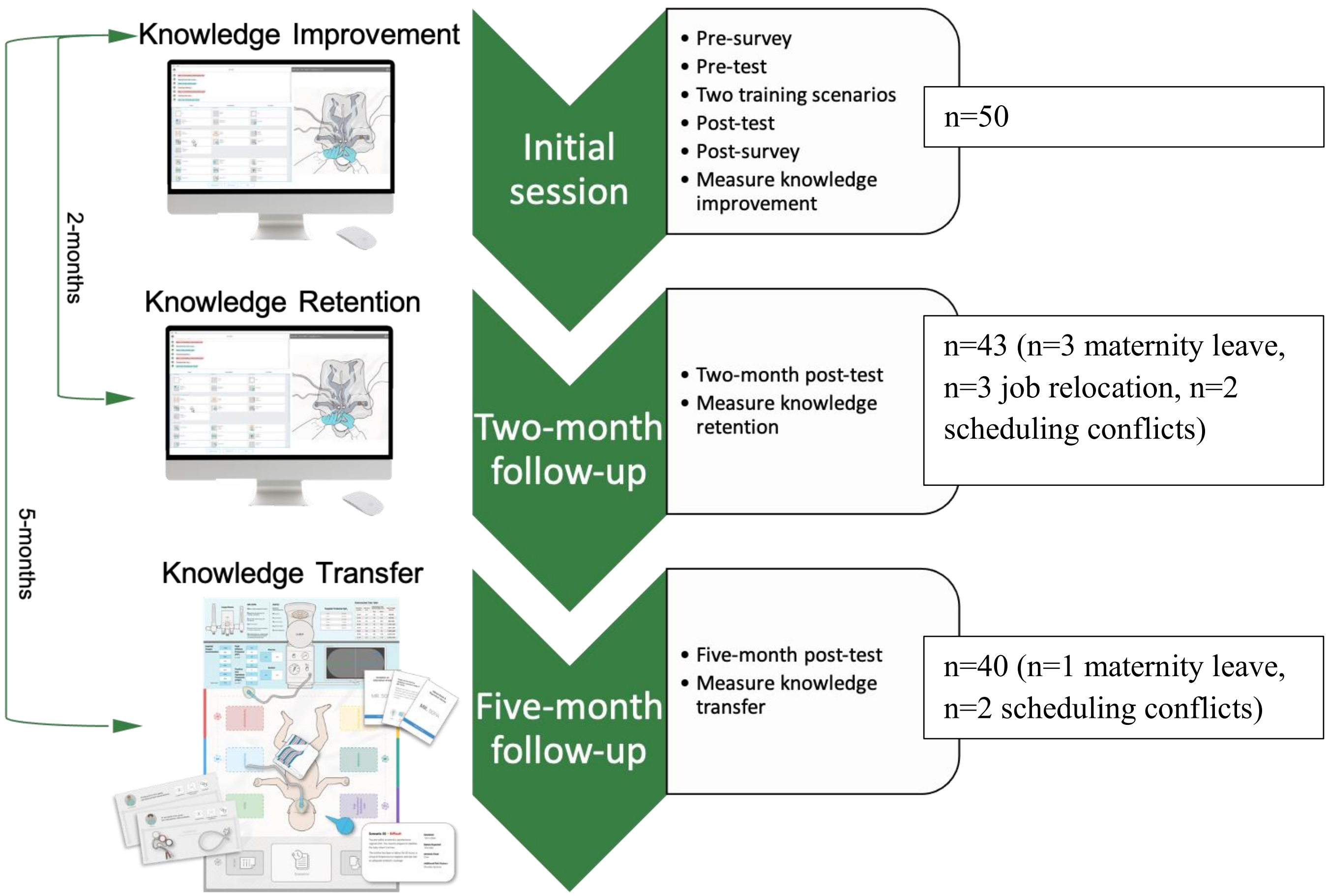
Participants were n=50 neonatal HCPs (44 females and 6 males; 27 registered nurses, 3 nurse practitioners, 14 respiratory therapists, and 6 neonatal fellows), shown in Table 3-3, who completed the first study session (Figure 3-3). As described in the methods section, the first study session consisted of a pre-survey (demographic questionnaire), *pre-test* (baseline assessment), 2 practice scenarios (digital simulation training), *post-test* (to measure immediate knowledge improvement), and post-survey (feedback questionnaire). Fifty-two HCPs were recruited for the study, however 2 HCPs declined to participate (1 due to disinterest, and 1 due to competing clinical responsibilities).

As per the recruitment guidelines, all participants had completed NRP-recertification within the previous 24 months, with a range of 1 to 24 months, and median(IQR) 9(5-12) months elapsed. Number of years of clinical neonatal background varied widely across HCP participants, ranging from 2 months to 30 years, and median(IQR) 9(6.4-15.2) years of experience. HCP reported their highest level of education as a diploma program (n=13), bachelor's degree (n=24), after-degree program (n=4), master's degree (n=4), and undergraduate medical degree (n=6); (responses on this item equal 51 as 1 participant reported having obtained both a master's degree and an undergraduate medical degree).

Table 3-3 Demographic information of HCP participants for digital game study

Item		Participants (n%)	Median(IQR)
Gender	*Male*	6 (12%)	
	Female	44 (88%)	
Time since last NRP course	*Less than 6 months*	14 (28%)	9(5-12) months
	Between 6-17 months	31 (62%)	
	Between 18-24 months	5 (10%)	
Education completed	*Diploma*	13 (26%)	
	Bachelor's	24 (48%)	
	After-degree	4 (8%)	
	Master's	4 (8%)	
	Medical degree	6 (12%)	
Clinical role	*Nurse*	27 (54%)	
	Nurse practitioner	3 (6%)	
	Respiratory therapist	14 (28%)	
	Fellow	6 (12%)	
Clinical experience	*Less than 1 year*	5 (10%)	9(6.4-15.2) years
	2-5 years	8 (16%)	
	6-10 years	17 (34%)	
	11-20 years	16 (32%)	
	More than 20 years	4 (8%)	

Figure 3-3 HCP participation throughout the longitudinal digital game study



3.2.2 Performance Outcomes

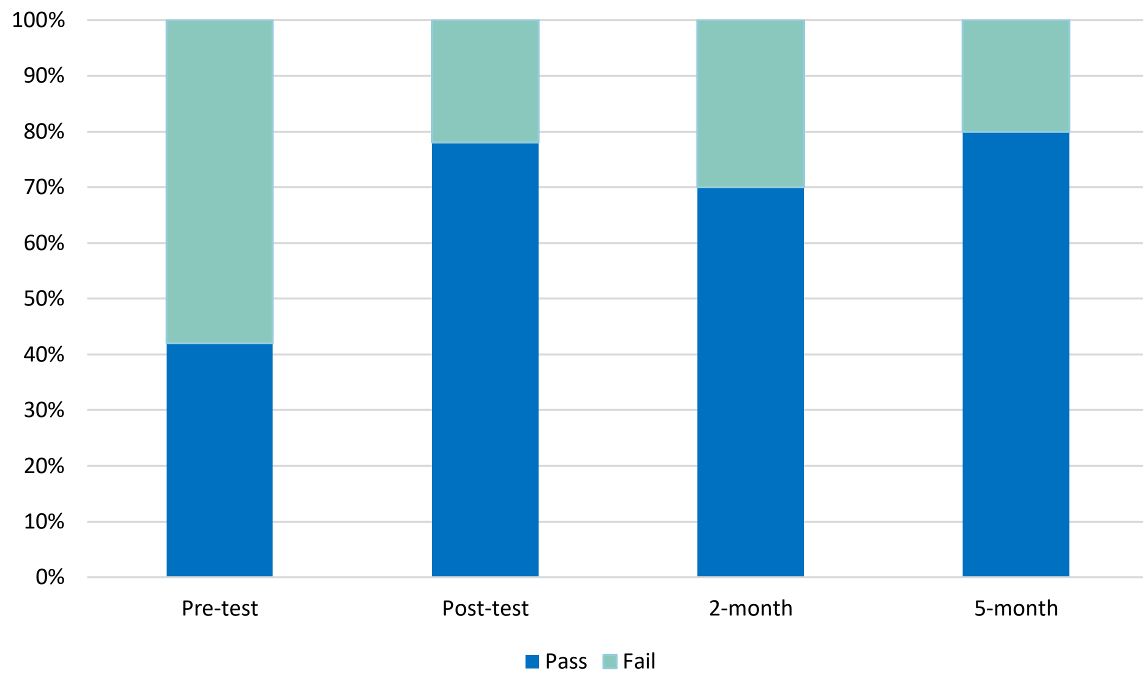
All HCPs completed the *post-test* more quickly than the *pre-test*; the median(IQR) time to complete the *pre-test* was 396(369-454) seconds, and 283(251-322) seconds to complete the *post-test*. Performance on the digital game was scored using either a pass (100% adherence to the NRP guidelines) or fail (<100% adherence to the NRP guidelines) outcome. There was a significant overall increase in the proportion of correct performance by HCP participants across the *pre-test* and *post-test* (Figure 3-4). A Chi-squared test showed that the proportion of participants who passed the pre-test (42%, or 21 out of 50) was significantly smaller (Chi-squared(1)=13.365, p=0.0003, 95% confidence interval [16.8988% to 51.6487%]) than the proportion of the participants who passed the post-test (78%, or 39 out of 50).

3.3 Digital Simulator Improves HCPs' Long-term Knowledge Retention

Two months after the initial study session in which participants trained with the RETAIN digital simulator, they undertook the *2-month post-test* to assess long-term knowledge retention of the neonatal resuscitation guidelines. Forty-three out of the initial 50 HCP participants completed the *2-month post-test*. Reasons for dropout (n=7) included job relocation (n=3), maternity leave (n=2), and being otherwise unavailable to schedule a follow-up session according to study protocol (n=2), as shown in Figure 3-3. These participants were dropped from the study from this timepoint onwards, and there was no significant difference in the pre-test or post-test of participants who dropped out compared to those who completed the full duration of the study.

The proportion of HCPs who correctly passed the *2-month post-test* was 30 out of 43 participants (70%), as illustrated in Figure 3-4. Compared to the initial *post-test*, performance slightly declined at the 2-month timepoint, as was expected due to knowledge typically decreasing over the passage of time. However, there was no significant difference between overall performance on the *2-month post-test* compared to the initial *post-test* (p=0.32), indicating that knowledge was retained over this timeframe.

Figure 3-4 Proportion of correct performance over time in the digital game study



3.4 Digital Simulator Facilitates HCPs' Knowledge Maintenance and Transfer

Five months after the initial study session, participants underwent the *5-month post-test*, which assessed whether they were able to successfully transfer the neonatal resuscitation knowledge gained from training with the digital simulator, to a novel learning environment. Forty participants completed the 5-month post-test (n=3 additional dropouts, with n=1 taking maternity leave and n=2 otherwise unavailable), as shown in Figure 3-3.

Thirty-two out of 40 participants successfully passed the *5-month post-test* (80%), which is the highest proportion reported from any of the 4 assessments performed in this study (Figure 3-4). Mean performance at the 5-month timepoint was nearly double the mean performance on the initial *pre-test*, suggesting that participants' learning was sustained and transferred. *Pre-test* performance was associated with the *5-month post-test* when analyzed using the Pearson correlation test of association (r=0.43, p<0.5). Remember that the *5-month post-test* was a more difficult scenario than the *pre-test*, *post-test*, and *2-month post-test*, as it required escalation of the NRP algorithm through 2 rounds of chest compressions, establishing vascular access, and administering medication.

3.5 HCPs' Attitudes and Habits towards RETAIN and Other Media

Self-reported habits and attitudes were measured with a post-study questionnaire (open- and closed-answer items). As described above, the questionnaire was administered immediately after gameplay in both the summative assessment board game study, and the longitudinal digital game study.

3.5.1 Board Game Study

Overall, 85% of participants (17 out of 20 HCPs) enjoyed playing the RETAIN board game (n=5 strongly agreed, n=12 agreed, n=3 were neutral), with a median(IQR) score of 4(4-4.25) on a 5-point Likert-scale (Table 3-4). Most participants reported playing board games infrequently, anywhere from not at all (n=11) to 1 hour per month (n=4). However, some reported more frequent usage, at 1 hour per week (n=4) and 3 hours per week (n=1). When asked about their number of years of overall game board experience, participants reported median(IQR) 22.5(11-30) years (Table 3-4). However, some participants reported confusion about understanding how to answer this item, so the results should be interpreted cautiously. That being said, performance on the *game assessment* was moderately associated with the number of years of board game experience (r=0.45, p=0.06, n=20), but not with the *written assessment*. However, this correlation did not reach significance (possible due to the relatively small dataset).

Table 3-4 HCPs' self-reported habits and attitudes towards the RETAIN board game, growth mindset, and board games overall

Item		Participants (n%)	Median(IQR) or Mean(SD)
Did you enjoy playing the RETAIN game?	*Strongly Agree*	5 (25%)	4.1(0.6)
	Agree	12 (60%)	
	Neutral	3 (15%)	
	Disagree	0	
	Strongly Disagree	0	
Board game habits in a typical week	*None*	11 (55%)	
	1 hour or less	8 (40%)	
	More than 1 hour	1 (5%)	
Overall board game experience	*Less than 5 years*	3 (15%)	22.5(11-30) years
	5-10 years	4 (20%)	
	10-30 years	8 (40%)	
	More than 30 years	5 (25%)	
You can't really do much to change how good you are at your job	*Strongly Agree*	0	1.4(0.5)
	Agree	0	
	Neutral	0	
	Disagree	8 (40%)	
	Strongly Disagree	12 (60%)	
You can learn new things, but you cannot really change how good you are at your job	*Strongly Agree*	0	1.6(0.5)
	Agree	0	
	Neutral	0	
	Disagree	12 (60%)	
	Strongly Disagree	8 (40%)	
You can always change how good you are at your job	*Strongly Agree*	14 (70%)	4.7(0.5)
	Agree	6 (30%)	
	Neutral	0	
	Disagree	0	
	Strongly Disagree	0	
You can get better at your job with practice	*Strongly Agree*	17 (85%)	4.8(0.4)
	Agree	3 (15%)	
	Neutral	0	
	Disagree	0	
	Strongly Disagree	0	

5-point Likert scale (1- strongly disagree, 2- disagree, 3- neutral, 2- agree, 1- strongly agree)

3.5.2 Digital Game Study

Participants responded to a series of closed-answer items soliciting their feedback on the usability of the digital game (Table 3-5). Forty-eight out of 50 (96%) participants agreed that the length of time and pacing of the game was appropriate to retain information of the basic resuscitation steps. Regarding the terminology used in the game, 37 participants (74%) reported that the terminology used did not impede their ability to complete the required actions (n=13 found it to be a barrier). When asked if they could make decisions quickly, 8 participants disagreed, citing that it was cumbersome to have to scroll and locate their desired actions (n=42 agreed that they could make decisions quickly). This sentiment was echoed in another item asking whether the actions participants wished to perform were available and could be quickly and easily found and selected while playing (n=20 agreed, while n=30 disagreed). The size of the actions screen was consistently flagged as an issue (caused by a display ratio issue with the game software on the research laptop), as it required users to continuously scroll up and down to apply different actions (e.g., if participants "initiated PPV" halfway through the scenario, they would have to scroll back to the top of the actions screen to then "assess breathing" again).

The next series of questionnaire items aimed to assess HCPs' attitudes towards the RETAIN digital simulator. Overall, HCPs reported that the scenario was realistic (n=42 agreed or strongly agreed), simulated the stressful nature of neonatal resuscitation (n=35 agreed or strongly agreed), and enjoyed playing the game (n=41 agreed or strongly agreed). Most HCPs reported that the game could be beneficial for NRP training (n=47 agreed or strongly agreed). Participants also reported being fairly motivated to use RETAIN, as they liked this way of learning, and felt encouraged to play the game again (mean(SD) 3.7(0.8) and 3.6(0.6), respectively, on a 5-point Likert scale).

Table 3-5 HCPs' self-reported attitudes towards the RETAIN digital simulator

Item		**Participants (n%)**	**Mean(SD)**
Pacing of game was appropriate	*Yes*	48 (96%)	
	No	2 (4%)	
Terminology used was appropriate	*Yes*	37 (74%)	
	No	13 (26%)	
Could make decisions quickly	*Yes*	42 (84%)	
	No	8 (16%)	
Could quickly and easily find actions	*Yes*	20 (40%)	
	No	30 (60%)	
Scenario was realistic	*Strongly agree*	7 (14%)	3.9(0.8)
	Agree	35 (70%)	
	Neutral	4 (8%)	
	Disagree	3 (6%)	
	Strongly disagree	1 (2%)	
Scenario simulated stress	*Strongly agree*	3 (6%)	3.7(0.7)
	Agree	32 (64%)	
	Neutral	11 (22%)	
	Disagree	3 (6%)	
	Strongly disagree	1 (2%)	
Enjoyed playing the game?	*Strongly agree*	7 (14%)	3.8(0.8)
	Agree	34 (68%)	
	Neutral	4 (8%)	
	Disagree	4 (8%)	
	Strongly disagree	1 (2%)	
Game could be beneficial for NRP training	*Strongly agree*	12 (24%)	4.1(0.6)
	Agree	35 (70%)	
	Neutral	1 (2%)	
	Disagree	2 (4%)	
	Strongly disagree	0	

5-point Likert scale (1- strongly disagree, 2- disagree, 3- neutral, 2- agree, 1- strongly agree)

The positive themes that emerged from the open-answer responses included that the game was fun, interactive, provided realistic feedback, facilitated an accessible opportunity to practice neonatal resuscitation, encouraged critical thinking, and was less embarrassing or stressful than in-person team-based instructor-supervised simulation (Figure 3-5). The negative themes were the usability issues (i.e., difficult to find actions quickly, layout of screen meant having to look away from the patient, preference for using drag-and-drop rather than clicking action buttons), lack of team-based training (and subsequent lack of being able to apply some interventions simultaneously), lack of some desired actions, actions already undertaken in the scenario were not prominently indicated, time that actions were initiated (e.g., time that a dose of epinephrine was administered) was not displayed to users during gameplay, lack of auditory feedback (e.g., hearing ventilations, voiceover with important information), image of the simulated patient was not very interactive (e.g., color of baby did not change from blue to pink as oxygen saturation improved), and that some people did not enjoy this way of learning (Figure 3-5).

Lastly, the questionnaire presented several closed-answer items to assess participants' habits and attitudes towards technology (Table 3-6). Most HCPs did not report spending any time playing mobile or video games (n=32), however the time for those who did ranged widely from 1 to 60 hours per month (overall mean(SD) of 6.3(14.4) hours). Less than half of participants (n=20) reported having any previous experience with educational video games (n=30 said no). Overall, participants had favorable attitudes towards technology in education (holistic mean(SD) of 3.9(0.7) on a 5-point Likert scale). When asked about their use of personal electronics, n=30 participants self-reported spending at least 2 or more hours on their smartphones, computers, laptops, and/or tablets at home each day (n=16 reported 1-2 hours, and n=4 reported less than 1 hour).

Figure 3-5 Summary of themes from HCPs' feedback about the digital simulator

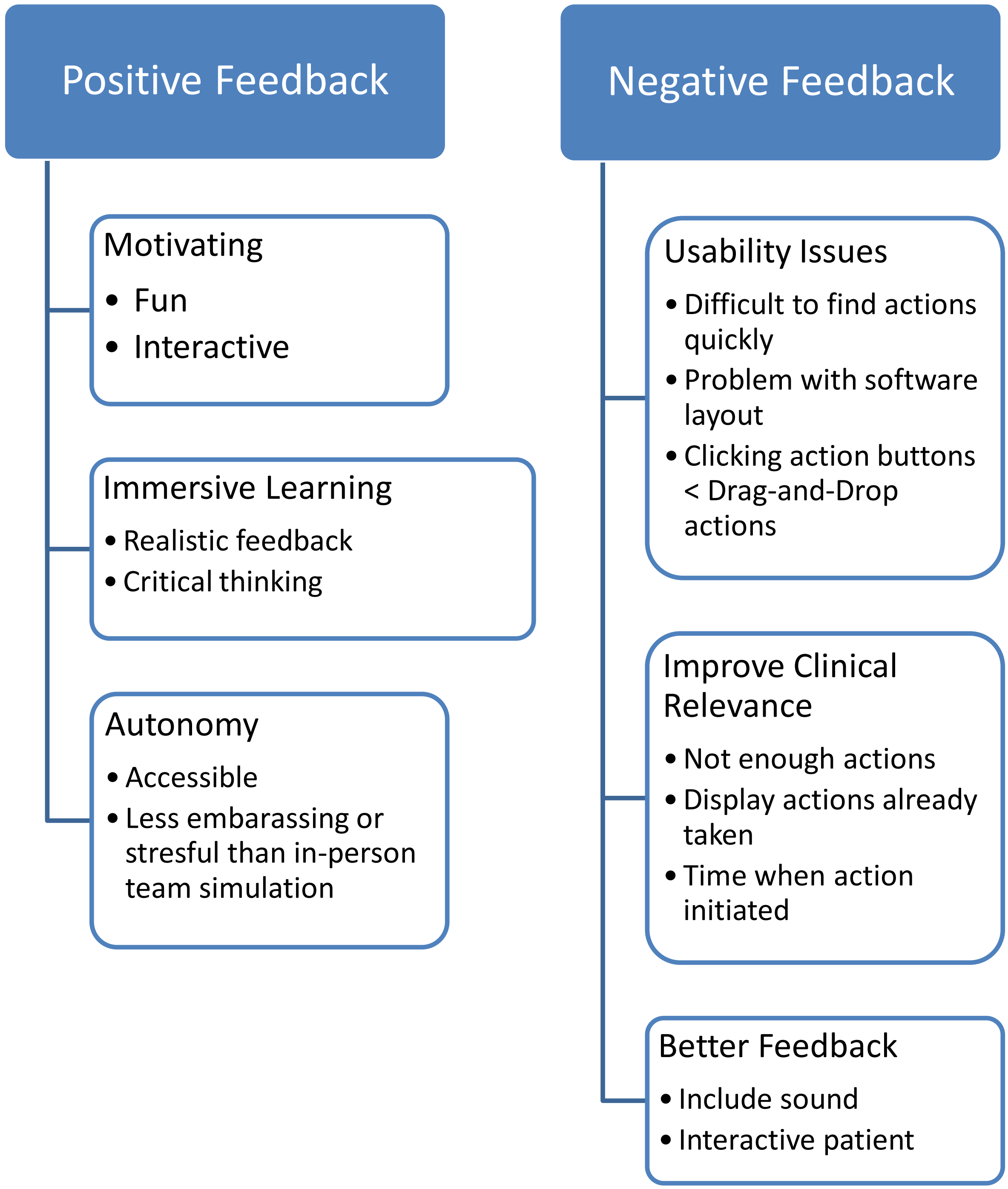


Table 3-6 HCPs' self-reported habits and attitudes towards technology

Item		Participants (n%)	Mean(SD)
Experience with educational games	*Yes*	20 (40%)	
	No	30 (60%)	
Enjoy reading about technology	*Strongly agree*	3 (6%)	3.1(1.1)
	Agree	20 (40%)	
	Neutral	12 (24%)	
	Disagree	10 (20%)	
	Strongly disagree	5 (10%)	
Enjoy using technology	*Strongly agree*	8 (16%)	4.0(0.7)
	Agree	34 (68%)	
	Neutral	6 (12%)	
	Disagree	2 (4%)	
	Strongly disagree	0	
Learning technology useful for career	*Strongly agree*	14 (28%)	4.2(0.5)
	Agree	34 (68%)	
	Neutral	2 (4%)	
	Disagree	0	
	Strongly disagree	0	
Look forward to learning new technology	*Strongly agree*	9 (18%)	4.1(0.5)
	Agree	35 (70%)	
	Neutral	6 (12%)	
	Disagree	0	
	Strongly disagree	0	
Interested in learning new technology	*Strongly agree*	6 (12)	3.9(0.6)
	Agree	32 (64%)	
	Neutral	11 (22%)	
	Disagree	1 (2%)	
	Strongly disagree	0	
Technology improves learning	*Strongly agree*	10 (20%)	4(0.6)
	Agree	31 (62%)	
	Neutral	9 (18%)	
	Disagree	0	
	Strongly disagree	0	
Enjoy using technology to learn	*Strongly agree*	10 (20%)	4.1(0.6)
	Agree	33 (66%)	
	Neutral	7 (14%)	
	Disagree	0	
	Strongly disagree	0	
Personal technology use per day	Less than 1 hour	4 (8%)	
	1-2 hours	16 (32%)	
	2-3 hours	13 (26%)	
	5 or more hours	17 (34%)	

5-point Likert-scale (1- strongly disagree, 2- disagree, 3- neutral, 4- agree, 5- strongly agree)

Chapter 4: Discussion, Future Directions, and Conclusions

4.1 Discussion

Lifelong learning is one of the central components of the professional responsibilities taken up by HCPs.[70] Continuing healthcare education to support lifelong learning is vital to adequately equip and empower HCPs to provide high-quality care for their patients. Both training and assessment are central to the objectives of continuing healthcare education. In most cases, the ideal environment for training and assessment is one that is as similar to the real-life parameters that HCPs will encounter in the clinic—particularly for advanced trainees and experienced professionals. Simulation education is therefore considered the gold standard for healthcare education, for both training and assessment of HCPs.

Simulation education facilitates an immersive learning environment for HCPs to practice their knowledge, skills, and teamwork in a controlled setting which prioritizes both patient and learner safety. Due to this value, many institutions invest significant resources to build out simulation centers outfitted with specialized manikins and equipment; hire simulation operation technicians to repair and maintain equipment to run smoothly; and train instructors to develop, facilitate, and expertly debrief simulation scenarios across a wide range of medical specialties and learning objectives. However, this initial investment in and of itself is a significant barrier to incorporating SBE[71], in addition to the ongoing investments needed to keep these centers operational.[72] Beyond the financial, human, and physical resources required to establish a comprehensive simulation program at a healthcare institution, busy HCPs need to devote significant and coordinated time above and beyond their clinical duties to undergo simulation sessions as frequently as is required to stave off knowledge decrease that occurs over time, and effectively maintain their skills.[17] Therefore, the traditional approach to in-person simulation training—while an essential component of a robust healthcare education program—presents significant challenges intrinsic to the nature of its format.

To help overcome these challenges, alternative approaches to supplement traditional SBE are a burgeoning area of interest for clinical education researchers. Simulation-based serious games are one such approach that has been identified as a potential alternative. Serious games aim to create an immersive environment to motivate learners to develop professionally-relevant knowledge and skills through active, experiential, or problem-based learning.[73] By purposefully utilizing elements like emotional design (e.g., high-stakes scenarios, immersive graphics, realistic auditory feedback) and competition (e.g., point-system, badges, or leaderboards), serious games stimulate pressure and stress in players, which may help improve their motivation[74,75] and learning.[76,77] Serious games can also help facilitate self-directed learning (in regard to topics and timing) to foster learners' autonomy.[11] In addition to these characteristics, serious games can be widely disseminated at relatively low initial and ongoing costs for the end-user, and are usually quite flexible, accessible, and familiar to HCPs.

Simulation-based serious games have been implemented across a wide range of contexts, including across medical specialties like surgery[78] and trauma[79], as well as disaster preparedness training for in-hospital HCPs.[80] In this thesis, the RETAIN simulation-based serious game for neonatal resuscitation was presented, and some of the educational outcomes of the board game and digital game were investigated.

4.1.1 Board Game Study

Lifelong training and assessment of HCPs are both necessary to improve health outcomes and uphold the standards of care expected by the public. Since the RETAIN board game had previously been reported to successfully train HCPs' neonatal resuscitation knowledge[18], it was prudent to next investigate if the board game could also be used as a summative assessment of HCPs' neonatal resuscitation knowledge. Leveraging serious games like RETAIN for individual assessment of neonatal resuscitation providers is an attractive possibility, as more frequent audits of HCPs' competence would aim to ultimately improve healthcare delivery in the clinic.

Summative assessment is used to evaluate learners after they complete an instructional unit, and typically involves measuring learners' relative position in comparison to their peers or to an expected standard.[81,82] Simulation-based summative assessment in healthcare education is ideal, as this format is more congruent with the material being tested (in comparison to other assessment approaches like a multiple-choice exam). When the assessment format is incongruent with the content, there is a risk for instructors to educate and for HCPs to study for the exam rather than for clinical preparedness.[81,83] Furthermore, good feedback is essential to the success of any meaningful assessment and must be purposefully deployed to best support learners. Interactive and clinically grounded simulation-based assessment is often better positioned to provide good feedback than a written exam.

While there are many benefits of simulation-based assessment to demonstrate and measure HCPs' learning, it remains a stubbornly underutilized approach to assess HCPs' ongoing competence.[84,85] This is most likely due to the significant barriers against its implementation, including intense resource requirements and logistical challenges. Therefore, a balance must be struck between clinically relevant versus feasible assessments.

Serious games like the RETAIN board game could help improve this balance and flip the scales towards a relatively low-resource yet clinically relevant simulation-based assessment. This thesis presented a study conducted to investigate the RETAIN board game as an objective summative assessment of neonatal resuscitation knowledge. The study explored the relationship between HCPs' individual performance on an open-answer test (*written assessment*) compared to their performance on the board game (*game assessment*).

The results from this study revealed that HCPs performed better on the *game assessment* than on the *written assessment*, despite the game scenario having been more difficult than the open-answer scenario. Despite performance on the *game assessment* and *written assessment* being only weakly correlated with one another, there were not many differences identified across the assessment methods (i.e., NICU admission and stimulation was provided significantly more frequently in the *game assessment*). A strength of the *game assessment* was to probe HCPs' specific actions in real-time (i.e., more deeply assess HCPs' understanding of the specific ventilation corrective steps beyond stating the mnemonic acronym MR SOPA).

Moreover, since HCPs' performance on the *game assessment* was moderately associated with their reported previous board game experience (albeit, not significantly), assessing those participants with the board game could help better elicit their knowledge within this familiar environment, compared to a potentially stressful or less inviting written test. Importantly, both assessment methods worked equally well for participants who did not report previous board game experience. On this note, it was also promising to observe that most HCPs enjoyed using

RETAIN, which is important information to support the proposition that serious games indeed have the potential to make assessments more attractive and engaging for learners.

One limitation of using the board game as an assessment is that it requires a person to facilitate the scenario. In contrast, a traditional pen-and-paper test requires only the learners and the proctor (but with a larger personnel ratio than one-on-one). However, note that the traditional simulation-based approach would require at least the same or a greater number of people than the board game to run the assessment effectively.

Considering the limitations specific to this study, in hindsight, it would have been better to use scenarios of equal difficulty level for both the *game assessment* and *written assessment*, which escalate up to the same point in the neonatal resuscitation algorithm. This would have likely resulted in answer keys that better overlapped with one another, and perhaps not quite as big of a difference in the total number of points each scenario was calculated out of (16 versus 40 total possible points for the written and game scenarios, respectively).

To speculate why participants performed better on the *game assessment* despite it being a harder scenario than the *written assessment*, it is important to consider whether the board game may have simultaneously helped teach or cue HCPs as they interfaced with the game during the assessment. This is especially important to consider as Cutumisu *et al.* previously reported that HCPs improved their knowledge of the neonatal resuscitation algorithm by 12% after training with the board game.[18] However, in contrast to the protocol used in that study, no help or formative feedback was provided to participants during the assessment in the current study.

An overall limitation of this pilot study was the small sample size (n=20), which unfortunately precluded deeper analysis. With more data points, potentially more variables would have reached significant association, and sub-group analysis could have been appropriately performed (i.e., comparing performance on the different assessment media between clinical roles, or along years of clinical experience).

The results from this pilot study indicate that the RETAIN board game can function as an assessment tool for neonatal resuscitation knowledge and may offer additional benefits above and beyond a traditional assessment (i.e., one-on-one assessment, more attractive for learners, opportunities for instructors to probe for more details). The outcome of this study is significant as the board game was previously only developed and designed as a training tool. These results ultimately contribute to a larger effort to validate the board game more comprehensively, and to inform its continued iterative development.

4.1.2 Digital Game Study

As described above, the twin pillars of lifelong learning in healthcare education are training and assessment. Having just explored the RETAIN board game in the context of assessment, the second part of this thesis investigated the RETAIN digital game in the context of training. The potential application of a simulation-based digital game for training neonatal resuscitation providers could help supplement traditional SBE with more frequent, personalized, and self-directed refresher sessions. This may present a valuable strategy to help curb the decline in learners' mastery after simulation training observed over time.[17]

In the present study, experienced HCPs who trained with the digital game were followed longitudinally over time to assess their potential knowledge improvement, retention, maintenance, and transfer. Compared to their baseline scores on the *pre-test* scenario, participants improved their performance significantly after training with the RETAIN simulator. Performance trends improved over time, even though HCPs only underwent a single session with the digital game. While overall performance on the *pre-test* was slightly poor, the results indicate that some participants performed very well on the pre-test (as the median was smaller than the mean). This may have meant that some participants experienced less dramatic changes in their performance post-training. Participants' performance on the *pre-test* and *5-month post-test* were moderately correlated, which is promising to consider especially as the 5-month session presented the most difficult simulation scenario throughout the study. All in all, training with the digital simulation game appeared to result in long-term knowledge retention by HCPs, at least over the 5-month period examined.

Knowledge transfer at the 5-month timepoint was measured using the board game as the assessment method. Knowledge transfer represents analogical thinking, whereby knowledge learned in one situation is transferred to another, but rarely happens spontaneously, as its successful demonstration requires learners to possess a deep understanding of a concept before being able to recognize and apply its general form across different instances.[86] Medical education and simulation training that help learners apply their knowledge to unfamiliar learning contexts facilitates the development of good problem-solving and decision-making skills. These skills are essential once learners progress to the clinical environment, where they must ultimately make difficult decisions on their own.[87] The proportion of participants who passed the knowledge transfer task was on par with all other post-training assessments, indicating that training with the RETAIN digital game not only improves and maintains but also transfers HCPs' neonatal resuscitation knowledge.

As presented in the introduction of this thesis, RETAIN is situated within a wider landscape of simulation games—particularly digital and virtual reality games—for neonatal resuscitation training and assessment. However, the most consistent shortcoming of these media is the lack of evidence-based educational outcomes reported as a result of their use. Outcomes can be reported at different levels ranging from measuring changes in performance on a test, performance on a game-based simulation, performance on a traditional simulation scenario, performance in the delivery room, and ultimately improvement of health outcomes for patients at institutions that implement these educational media.

A potentially important factor which may likely determine the success and viability of alternative educational media like serious games is their uptake by learners and instructors. The survey results from the digital study indicate that the HCPs at this site were experienced in and had generally positive attitudes towards technology and were interested in its use to support their education and professional development. Their attitudes towards RETAIN were generally positive, including that they thought it could be helpful for NRP training. The negative open-answer feedback was overall constructive towards actionable changes to improve the user experience. However, there are some HCPs who reported not enjoying playing the game, and even with the future usability improvements, may never be inclined to engage with this way of learning. Therefore, it would be important for any site which is thinking of adopting a novel education technology to ideally accommodate all HCPs' different learning approaches to avoid anyone feeling excluded or ignored, and thus deter their motivation to train.

Overall limitations of the RETAIN digital simulator is that this medium is not designed with the goal to help train HCPs' psychomotor or physical skills (e.g., provide chest compressions), and must therefore be used in conjunction with traditional SBE to reinforce knowledge and decision-making skills. This study was only able to assess HCPs' knowledge demonstrated within the game, and not whether improved performance within the digital simulation translates to actual competence to provide neonatal resuscitation care. However, participants were able to transfer their knowledge from one medium (digital game) to another (tabletop game), which indicates some deeper level understanding and potential for transfer to the delivery room setting.

In consideration of the reported outcomes from the first summative assessment study, it may have been more likely for participants to perform well on the board game during the knowledge transfer task. However, the study reported this relatively "better performance" on the board game in comparison to an open-answer written test, whereas the second study compared participants' performance on the board game to its digital game analog. Therefore, this potential limitation of the knowledge transfer assessment was likely not relevant in this longitudinal study. However, future studies to measure knowledge transfer may choose to use a different assessment method.

Other limitations are the lack of control condition (e.g., studying with a textbook, watching a video of a simulation scenario, etc.) and random assignment. Additional studies are needed to compare the digital simulation game to other educational approaches. The use of convenience sampling and participant attrition across the three studies (20% between the first and last timepoint) were also limitations, but reasonable for the study as participants were HCPs on-service in a busy intensive care unit, which made follow-up for retesting challenging. Fortunately, there were no observed differences between the pre-test scores or survey-attitudes for HCPs who dropped out of the study, compared to those who remained.

4.2 Future Directions

Future directions for research on the RETAIN simulators for neonatal resuscitation education will need to implement a randomized controlled trial to measure changes in HCPs' performance (e.g., improved adherence, closed-loop communication) after training with RETAIN—first in a traditional simulation setting, then in the delivery room.

To build on the current research examining RETAIN for assessment, a next step would include conducting a larger study to explore these potential relationships between performance, clinical roles, and experience levels, as well as implementing the board game assessment across a variety of simulation scenarios and situations (e.g., low-stakes versus high-stakes cases). In consideration of the specific challenges faced by learners in remote or rural locations[88,89], and in response to current public health guidelines encouraging distanced learning, it would also be interesting to investigate using the board game (facilitated by videoconferencing) for tele-education and remote training and assessment of learners.

Speaking further to these potential applications and implementation, digital simulation can help facilitate more frequent and convenient training at high-resource urban sites (like the level-three perinatal center where this research was conducted) but may also play an important role in improving access to SBE for HCPs from low-resource or rural healthcare sites. Most recently, digital simulation may also help respond to the current need for distanced healthcare education strategies in response to the ongoing coronavirus disease 2019 (COVID-19) pandemic.[90]

Due to COVID-19, educators across all settings have had to rely overall on more passive methods like video lectures and online assessments. While SBE would be preferred to maintain clinical relevance, simulation programs have faced tremendous challenges to remain operational (e.g., maintaining physical distancing, rationing personal protective equipment, depleting personnel due to self-isolation or reassignment to clinical duties; and the threat of converting simulation space to increase hospital capacity).[90] After the current public health crisis has subsided, pandemic preparedness will likely be more thoughtfully incorporated into risk management and disaster preparedness protocol for healthcare institutions, including strategies to mitigate interruptions for both professional training programs (e.g., medical, nursing, diploma programs) and continuing healthcare education for experienced HCPs alike. Digital simulators like RETAIN offer scenarios of varying difficulty and patient risk factors, with limited equipment or personnel requirements; and are accessible by HCPs anywhere and anytime. These three important characteristics make these simulators an attractive resource to support healthcare education during the current and potentially similar future crises, so that HCPs may continue to be equipped to provide safe and effective healthcare for their patients.

4.3 Conclusions

This thesis explored some educational outcomes and attitudes towards the RETAIN board game and digital game, in a population of experienced HCPs from a level-3 NICU. The board game was observed to function as an enjoyable, clinically relevant, and low-cost summative assessment of HCPs' neonatal resuscitation knowledge. Training with the digital game was observed to improve HCPs' knowledge of the neonatal resuscitation algorithm, with improved performance sustained over 2 and 5 months after the initial training session, even when performance was measured with different instruments (digital game and tabletop game, respectively). HCPs were also able to successfully transfer their gained knowledge to a novel learning environment of the board game. HCPs expressed positive attitudes towards the RETAIN simulation-based games, indicating their potential receptiveness towards incorporating these media to support their continuing healthcare education.

The potential for effective incorporation and long-term viability of these games will likely depend on their efficacy and uptake—two factors which were supported by the outcomes of this research project. Overall, there seems to be a role for simulation-based serious games to support HCPs' mastery of their neonatal resuscitation knowledge and skills, and is well-positioned to address specific challenges persistent to traditional SBE, like improving access to training for rural, remote, or distanced HCP learners during the COVID-19 pandemic and beyond.

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